Comparison of 2- and 3-dimensional radiologic evaluation of secondary alveolar bone grafting of clefts: a systematic review

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Objective. Secondary alveolar bone grafting (SABG) has become the principal means of treating alveolar cleft defects. We reviewed the literature on 2-dimensional (2-D) and 3-dimensional (3-D) radiographic evaluation of SABG in patients with cleft lip and alveolus (CLA) and those with cleft lip and palate (CLP), with a focus on outcomes.

Study Design. We searched several electronic databases to the end of 2018. The inclusion criteria were nonsyndromic CLA or CLP treated with SABG at an optimal age and evaluation performed no earlier than 3 months postoperatively. Study quality was evaluated by using the Methodological Index for Non-Randomized Studies and the Cochrane Collaboration tool.

Results. We identified 282 articles from 3 databases. Full texts of 102 articles were analyzed, and finally 11 articles were included for qualitative analysis. 2-D and 3-D radiographic evaluations were performed in each study. Traditional 2-D radiographic imaging tended to overestimate success; bone resorption in the labiopalatal direction was inaccurate in 2-D views. Most articles were observational in nature and of moderate methodologic quality.

Conclusions. 2-D evaluation tended to overestimate SABG outcomes; 3-D evaluation was more precise and reliable than 2-D radiography. A gold standard 3-D evaluation protocol is required for quantitative comparisons in the future. (Oral Surg Oral Med Oral Pathol Oral Radiol 2020;130:455−463)

Alveolar bone grafting (ABG) is commonly employed to treat alveolar cleft defects in patients with cleft lip and alveolus (CLA) and those with cleft lip and palate (CLP).[1] ABG stabilizes and improves continuity of the upper arch, affords bony support for the teeth adjacent to the cleft, restores facial symmetry, eliminates oronasal fistulae, and facilitates further repair.[2-10] All orthodontic clefts that restrict spatial closure, even minute incomplete clefts, require ABG.[11] The optimal timing of ABG has been controversial since the 1970s. Primary ABG was usually performed at the same time as cleft lip repair.[12] Secondary ABG (SABG) was first described in 1972 by Boyne and Sands, who suggested that it should be performed on children age 8 to 12 years when the canine roots are one-half to two-thirds formed.[13] Currently, SABG is generally defined as a bone grafting procedure performed after reconstruction of cleft lip and palate. SABG has largely replaced primary ABG.

Satisfactory SABG treatment should provide adequate bony support for the teeth adjacent to the cleft, allowing for subsequent orthodontic tooth movement or prosthetic repair. As bone resorption is inevitable in all patients, successful stability of the grafted bone is required to achieve the continuity of the upper arch by forming an adequate bony bridge.[14] The outcome of SABG is evaluated both clinically and radiographically. Normal canine eruption through the grafted bone on the cleft side is the most promising outcome for clinical success.[3,15]

Evaluation may be performed by using 2-dimensional (2-D) or 3-dimensional (3-D) radiography. Panoramic, periapical, and occlusal radiographs have been the most commonly used images for 2-D evaluation. Generally, 2-D radiographs have been used for evaluation, and various methods have been developed over the years for determination of the outcome of bone grafting.[15] The 2-D gold standard is the Bergland grading system, which has been widely used for decades. However, the credibility of 2-D radiography is acknowledged to be problematic in the assessment of alveolar clefts because of the 3-D nature of the cleft defect.[16] For evaluation of SABG, the main drawback of the methods based on 2-D images is the inability to visualize the irregular shape of the cleft and to measure bone formation along the labiopalatal thickness.[17]

In recent years, different 3-D imaging methods have been used to evaluate treatment outcomes. ABG has

Statement of Clinical Relevance

For evaluation of secondary alveolar bone grafting outcomes, analysis of the published evidence suggests that 3-dimensional radiographic methods are more precise and reliable than 2-dimensional radiographic methods, especially when assessment of labiopalatal bone status is required.

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been best quantified in terms of volume or area with computed tomography (CT) if the clinician can justify its benefit.[18] However, no standardized protocol has yet emerged. Although 2-D images of the cleft defect become superfluous when a 3-D image is available, additional 2-D radiographs have been acquired in some studies. Despite the fact that redundant x-ray exposure is not justified, it is understandable that 2-D images are made to serve as a comparison for 3-D evaluations.[19-21]

No systematic review has yet compared the 2-D and 3-D results; the authenticity and reliability of both data sets remain controversial. No optimal 3-D evaluation method has been identified. This systematic review was conducted to evaluate the evidence of the benefits of 2-D and 3-D radiographic evaluations in effectively determining the success of SABG in patients with CLA/CLP, with the aim of offering clinical guidance on the best practices for imaging analysis.

MATERIALS AND METHODS

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines.[22]

Inclusion/exclusion criteria

Studies. Randomized controlled trials (RCTs), controlled clinical trials (CCTs), and observational studies (retrospective and prospective) were included. Cross-sectional studies were excluded because they lacked long-term patient evaluation. Commentaries, systematic reviews, and meta-analyses were also excluded.

Participants. We included studies evaluating patients with unilateral or bilateral nonsyndromic CLA or nonsyndromic CLP. Patients with syndromic conditions were excluded. Young patients who underwent primary ABG were excluded. Adult patients were included and regarded as delayed SABG.

Interventions. We included studies that harvested bone from the iliac crest, mandibular symphysis, tibia, rib, or calvarium. We imposed no restriction on the surgical method used or orthodontic treatment status before surgery. Cases involving a second ABG after previous failure were excluded.

Outcome measures. The evaluation methods were not restricted. The 2-D outcome was the postoperative change in the cleft defect evaluated from periapical, occlusal, and panoramic radiographs or 2-D radiographs reconstructed from CT. The 3-D outcome was the postoperative 3-D change in the alveolar cleft defect evident on CT, whether or not it was compared with the preoperative value. We placed no restriction on the instrument or the software used. We excluded evaluations made before 3 months postoperatively, as several authors have reported that there was little difference between the bone bridge after 3 months and the bone bridge after 6 months or 1 year.[23,24]

The search

We searched the electronic databases of the Cochrane Library, PubMed, and Embase for articles published from January 1986 to December 2018, with no language restriction. We searched the gray literature by using SIGLE (System for Information on Grey Literature in Europe). The keywords were unique to each database. The PubMed search strategy is shown in Table I. The other databases were searched with the aid of a librarian. We searched both *Cleft Palate−Craniofacial Journal* and *Oral Surgery Oral Medicine Oral Pathology Oral Radiology* manually for the same period and also reviewed the reference lists of selected articles.

Selection of studies

Two researchers (X.Y. and R.G.) independently selected the studies. Titles and abstracts were examined, and duplicate studies were eliminated. If the abstracts lacked sufficient information, the full texts were obtained and carefully inspected. Any interexaminer disagreement was resolved through discussion with the third author (W.L.).

Data extraction

Two of the authors (X.Y. and R.G.) independently extracted the study design, participants, sample size, surgical details, type of radiography, follow-up time, assessment method, outcomes, and conclusions by using standard electronic checklists. We contacted the authors of the articles for further information if data were absent or ambiguous. Any interexaminer disagreement was resolved through discussion with the third author (W.L.).

Quality assessment

Two of the authors (X.Y. and R.G.) independently assessed the methodologic quality of all studies. The Methodological Index for Non-randomized Studies (MINORS) scale was used for nonrandomized studies.[25] Noncomparative and comparative studies were scored separately. All nonrandomized studies were assessed by using the first 8 items of the scale, and 4 additional items were added when evaluating comparative studies. Each item was scored as 0 (not reported); 1 (reported but inadequate); or 2 (reported and adequate) (Table II). The risk of bias in the RCTs was assessed by using the Cochrane Collaboration tool.[26] Seven criteria were used to grade the risk of bias

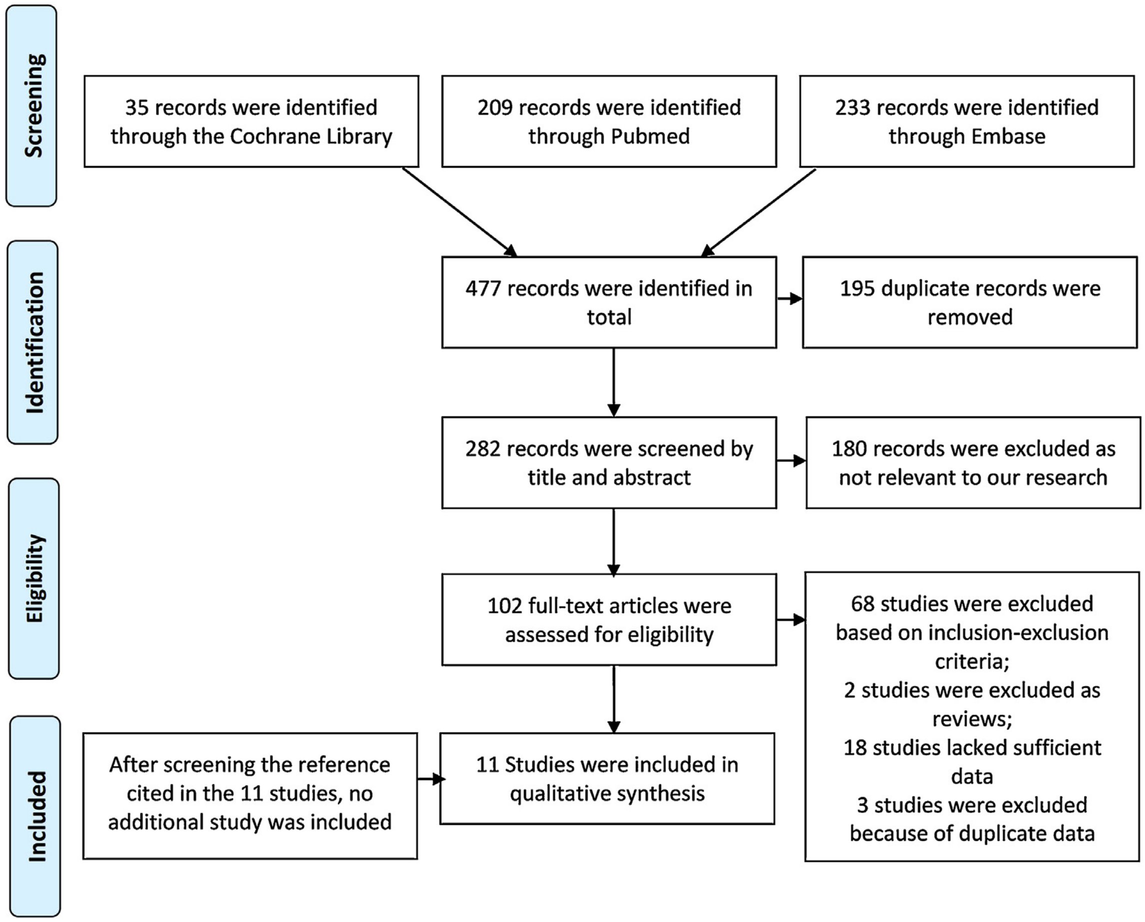

Fig. 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram.

inherent in CCTs: random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessors, completeness of outcome data, nonselective outcome reporting, and other potential sources of bias (Table III). Any disagreement was resolved through discussion with the third author (W.L.).

Table I. Search strategy for PubMed

# 1	"cleft lip" [Mesh] OR "cleft lip*" [Tiab] OR "cleft palate" [Mesh] OR "cleft palate*" [Tiab] OR "alveolar cleft*" OR "alveolar defect*" OR "alveolar bone defect*"	27732 *
# 2	(bone* [Tiab] OR osseous*[Tiab]) AND (transplant*[Tiab] OR graft*[Tiab])	102017
# 3	"bone transplantation" [Mesh:NoExp]	29502
# 4	"alveolar bone grafting" [Mesh]	206
# 5	"Imaging, Three-dimensional" [Mesh] OR "three dimensional" [Tiab] OR 3 d [Tiab] OR CT [Tiab] OR "computed tomography" [Tiab]	680979
# 6	#2 OR #3	114080
# 7	#1 AND #6	1584
# 8	#4 OR #7	1629
# 9	#5 AND #8	209

*Number of articles that resulted from the respective keywords.The search period was January 1986 to December 2018.

RESULTS

Search results

The PRISMA flow diagram of study selection is shown in Figure 1. After reviewing the titles and abstracts, 102 articles were subjected to full-text evaluation; 91 were subsequently excluded, as shown in Figure 1. Finally, 11 studies met the eligibility criteria. We manually screened the references cited in these 11 studies, none of which met the inclusion criteria.

Assessment of methodological quality

The MINORS scores of comparative studies were 17 through 19 of a possible 24. For noncomparative studies, the scores ranged from 8 to 11 of a possible 16 (see Table II). The scientific evidence was, thus, of moderate quality. For the RCTs, the risks of interpretation bias were moderate (see Table III).

Table II. Methodologic Index for Non-randomized Studies (MINORS) scores of the 9 non-randomized studies

MINORS score														
Author	*Year*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*Total*
Du et al.	2017	2	0	2	2	0	2	2	0	2	2	1	2	17
Han et al.	2017	2	1	1	2	0	2	0	0					8
Kawakami et al.	2003	2	2	2	2	0	2	2	0	1	2	1	2	18
Mikoya et al.	2010	2	1	2	2	1	1	2	0					11
Oh et al.	2016	2	1	1	2	0	2	0	0					8
Seike et al.	2012	2	2	1	2	0	1	2	0					10
Calvo et al.	2014	2	1	2	2	0	2	1	0					10
Trindade-Suedam et al.	2012	2	1	1	2	0	2	1	0					9
Liang et al.	2017	2	2	2	2	1	1	2	0	2	2	1	2	19

Items 1−12: 1. Clearly stated aim; 2. Inclusion of consecutive patients; 3. Prospective collection of data; 4. Endpoints appropriate to the aim of the study; 5. Unbiased assessment of the study endpoint; 6. Follow-up period appropriate to the aim of the study; 7. Loss to follow-up less than 5%; 8. Prospective calculation of the study size; 9. An adequate control group; 10. Contemporary groups; 11. Baseline equivalence of groups; and 12. Adequate statistical analysis. A score of 0 indicates not mentioned, 1 indicates reported but inadequate, and 2 indicates reported and adequate. The maximum total scores are 24 for cohort studies and controlled clinical trials (CCTs), and 16 for self-controlled studies.

Study characteristics

An overview of study characteristics is shown in Table IV. The 11 studies[19-21,27-42] included 2 RCTs, 1 CCT, 6 prospective studies, and 2 retrospective studies. Most studies were observational in nature and could be regarded as self-controlled. The RCT and CCT control groups met our eligibility criteria.

CT was obtained in all included studies, and 6 studies acquired additional 2-D radiographs, such as occlusal, periapical, or panoramic radiographs, postoperatively. Specifically, 2-D radiographs of 5 included studies were reconstructed from CT images; 3 studies[27,29,30] reported that 2-D reconstructed images were evaluated separately from the 3-D reconstructions, with the examiners blinded to the 3-D reconstructions, whereas the other 2 studies[31,32] did not make a clear statement. In 9 of the 11 studies, harvested bone was taken from the iliac crest, whereas the other 2 selected calvarial bone and monocortical mandibular bone, respectively. Six studies reported preoperative orthodontic treatment for all patients or those who requested it. The other 5 studies did not mention this treatment.

2-D outcome was evaluated on the basis of commonly used 2-D classification methods, including the Bergland scale, the modified Bergland scale, the Chelsea scale, and the Enemark grading system. The identical characteristic was the focus on the height of the interalveolar septum at follow-up time compared with the normal height. Satisfactory outcomes were reported among studies as significant changes that were found in the cleft defect area.

Linear measurements at different levels and volumetric measurements were the most commonly used parameters evaluated with the use of appropriate software. Most studies included both pre- and postoperative CT scans and calculated bone formation rate (BFR) at certain follow-up times. The BFR measurement data were continuous and were presented as means ± standard deviations. The remaining studies did not utilize preoperative CT scans; therefore, the 3-D evaluations were described only on the basis of postoperative CT scans, thus lacking pre- and postoperative comparisons.

Although some studies did not carry out a direct comparison of the 2-D and 3-D evaluation methods, statistics revealed that alveolar heights evaluated with use of 2-D radiographic methods were consistent with 3-D radiographic evaluation, but alveolar thickness measured with the use of 2-D radiographs showed better results compared with 3-D evaluation. In 3 of the 11 studies, 2-D and 3-D radiographic evaluations were compared statistically. Han et al.[33] evaluated SABG outcomes measured on planar radiographs by using the Enemark grading system. In total, 21 patients reached grade I, 5 reached grade II, 3 reached grade III, and 4 reached grade IV. In 3-D evaluation, alveolar thickness and alveolar height were assessed with postoperative CT. As a result, alveolar height was strongly correlated with the Enemark scale results ($r = 0.878$; $P < .001$), whereas alveolar thickness was not significantly correlated with the Enemark results ($r = 0.4575$; $P = .08$). Kawakami et al.[19] carried out a prospective study that included 17 patients with alveolar clefts. Preoperative CT, postoperative dental radiography, and CT at 1-year follow-up time were performed for all patients in the study. The Enemark grading system revealed 6 in grade I, 6 in grade II, 7 in grade III, and 0 in grade IV of the alveolar height. Residual bone ratio (density) was evaluated and classified according to the 2-D outcomes (grade I: 17.60% ± 9.54%; grade II: 34.28% ± 25.68%; grade III: 65.07% ± 30.03%); 2-D and 3-D outcomes were correlated with each other. Oh et al.[31] evaluated 40 patients preoperatively and 1-year postoperatively with cone beam computed tomography (CBCT) images. The average graft survival rate was 67.5% (range 27.67%−86.41%). Assessment with the Bergland scale was performed at the same time. In

Table III. The Cochrane Collaboration tool assessing the risk of bias in the 2 randomized clinical trials

Author, year	Domains							Interpretative risk of bias
	Random sequence generation	Allocation concealment	Blinding of participants and personnel	Blinding of outcome assessors	Incomplete outcome data	Selective outcome reporting	Other potential source of bias	
Dickinson et al., 2008	Unclear risk	Low risk	Unclear risk	Low risk	Low risk	Low risk	Low risk	Unclear risk
Marukawa et al., 2011	Unclear risk	Low risk	Unclear risk	Low risk	Low risk	Low risk	Low risk	Unclear risk

total, 34 patients (85%) showed satisfactory bony integration (I or II), and 6 patients (15%) exhibited poor outcome (III or IV). Canine eruption was found to be correlated with success. A moderate negative correlation ($r = -0.474$; $P = .002$) was found between the 2 outcome evaluations.

DISCUSSION

On 2-D evaluation, the success rates varied but were mostly above 80%, similar to the earlier reports of success. On 3-D evaluation, although volume was determined in different ways in the included studies by using several available volume-rendering software programs, the techniques were quite comparable.[35] Segmentation and integration were performed semiautomatically, and calculations were performed by the computer software according to a particular formula.[3,15,34-38] The accuracy of volumetric analysis in 3-D software has been confirmed by many studies.[39] Although quantitative comparison of 2-D and 3-D data is difficult because of study heterogeneity, 2-D evaluation seemed to indicate better outcomes than 3-D evaluation. However, because the alveolar cleft is 3-dimensional, 2-D overestimation of BFRs must be considered. Dado and Rosenstein[40] compared the 2-D and 3-D calculations by using standard dental radiographs and found that the 2-D data were inaccurate because 2-D imaging (compared with CT) was associated with overestimates of up to 21.4% and underestimates of up to 17.7%. Enemark et al.[41] found that although ABG patients seemed to enjoy 90% success rates, as observed on short-term radiographic examination, the later clinical results were poor; cleft closure succeeded in fewer than half the patients. Iino et al.[42] compared intraoral radiography and CT in the evaluation of bone formation after SABG in patients with CLP. In all, 24 cases had adequate interdental bone height as assessed by using intraoral radiographs. However, 10 of these 24 cases showed insufficient labiopalatal width on CT. Two of the remaining 5 cases were also overestimated by using intraoral radiographs. Approximately 40% of surgical outcomes may have been overestimated with the use of intraoral images, and CT revealed that the labiopalatal thickness was less than the root widths of the teeth adjacent to the cleft. Other reports also found more labiopalatal bone resorption than vertical bone resorption, indicating that bone filling is overestimated when only the interalveolar septal height is assessed. Bahr and Coulon[43] noted that the labiopalatal width of the bony bridge needed to be 9 mm to accommodate the permanent canine because the erupting canine would have bone plates around the largest vestibular−palatinal diameter (8 mm), which indicated the importance of the labiopalatal width condition at follow-up time. In summary,

Table IV. Included studies assessing the outcome of SABG and extracted data

Author, Year	Study design	Number of patients	Number and type of clefts	Age during surgery	Follow-up period	Bone source	Orthodontic treatment preoperative	Radiology	Outcome (2-D)	Outcome (3-D)	Comparison
Dickinson et al. 2008	RCT	12(CG)	UCLP	15.9 ± 1.9 y	6 m	IC	Yes	CT	Four-point grading system: 2.0 ± 0.8 (panoramic from CT） 2.8 ± 0.4 (periapical from CT)	BFR = 63% Four-point grading system: 2.0 ± 0.8	
Du, 2017	CCT	10	UCLA	8−15 y	6/12 m	IC	Not mentioned	CT	Eight-point Chelsea Scale: 6.7 ± 0.61	BFR = 58.3 ± 6.7%.	
Han, 2017	Retrospective study	27	UCLP: 22 BCLP: 5	6−12 y	≥ 2 y	CB	Performed when necessary	Planar radiography; CT	Enemark's grading system: I: 21; II: 5; III: 3; IV: 4	Alveolar thickness: I: 3; II: 6; III: 5; IV: 1 Alveolar height: I: 8; II: 4; III: 1; IV: 2	Alveolar height was strongly correlated with the Enemark scale results (r = 0.878; $P < .001$); Alveolar thickness was not significantly correlated with the Enemark results (r = 0.4575, $P = .08$) Planar radiographs tended to overestimate graft survival and cannot be used to determine alveolar thickness
Kawakami, 2003	Prospective study	17	UCLA: 4 UCLP: 11 BCLA: 4	8 y 10 m−12 y 8 m	1 y	IC	Yes, expansion and alignment	Dental radiography; CT	Alveolar side—Enemark: I:6; II:6; III:7; IV:0 Nasal side—Kawakami et al., 2002 Group A14; Group B: 5	RCB ratio (density): I: 17.60% ± 9.54%, II: 34.28% ± 25.68% III: 65.07% ± 30.03% A: 25.40% ± 30.16%； B: 60.02% ± 19.00%	2-D and 3-D outcomes correlated with each other
Marukawa, 2011	RCT	6	UCLA: 5 UCLP: 1	20 ± 4.7 y	1 y	IC	Not mentioned	Panoramic; Occl; CT	Mean bone loss in height: 2.09 ± 0.36% Density: 2.02 ± 0.3 3 mm Al equivalent	Mean bone loss in width: 35.5 ± 2.12%	
Mikoya, 2010	Prospective study	42	UCLA: 9 UCLP: 27 BCLP: 6	5 y 1 m−10 y 1 m	≥ 1 y 6 m	MMB	Performed when necessary：11	PA; CT	Chelsea scale: A + C: 83.3% B: 8.3% D + E + F: 4.2%	Labiopalatal width of bony bridge: Mean: 9.6 mm (range, 6.2−14.4 mm) 85.4%	
Oh 2016	Retrospective study	40	UCL	6.7−12.8 y	1 y	IC	Not mentioned	CBCT	Bergland: I&II: 85% III: 10%; IV: 5%	BFR = 67.5% (27.67%−86.41%)	Moderate negative correlation (r = −0.474; > .002
Seike, 2012	Prospective study	41	UCLA: 14 UCLP: 15 BCLA: 2 BCLP: 10	6−15 y	3 m	IC	Not mentioned	Dental radiography; CT	Enemark classification: IV:16; III:14; II:8; I:0; 0:11 Shortest vertical length:	Anteroposterior bone width: Mean: 5.4 mm	
Calvo, 2014	Prospective study	25	BCLP	10−13 y 15−23 y	6−12 m	IC	Yes	CBCT	Modified Bergland scale: Excellent/good: 96% / 65%	Bone septum height: Buccal: 1.08 ± 0.16 Intermediate: 1.08 ± 0.16 Palatal: 1.08 ± 0.16 Buccal: 2.11 ± 1.70 Intermediate: 2.00 ± 1.62 Palatal: 2.15 ± 1.71	
Trindade-Suedam, 2012	Prospective study	31(16/15)	UCLP	10−13 y 15−28 y	6−12 m	IC	When required	CBCT	Modified Bergland scale: Excellent/good: 75% / 53% Regular: 4% / 8%	Bone septum height: Buccal: 1.38 ± 0.50 Intermediate: 1.75 ± 1.18 Palatal: 1.63 ± 1.09 Buccal: 2.93 ± 1.49 Intermediate: 2.93 ± 1.44 Palatal: 2.80±1.52	

(*continued on next page*)

Table IV. Continued

Author, Year	Study design	Number of patients	Number and type of clefts	Age during surgery	Follow-up period	Bone source	Orthodontic treatment preoperative	Radiology	Outcome (2-D)	Outcome (3-D)	Comparison
Liang, 2017	Prospective cohort study	13(CG)	14 Unilateral: 12 Bilateral: 1	8−12 y	3 m 6−9 m	IC	Not mentioned	Occl; CBCT	Bergland scale: I: 56% (complete bone fill)	Bone filling rate: 32.5% (mean) Range:22.1%–42.9%	

BCLA, bilateral cleft lip and alveolus; *BCLP*, bilateral cleft lip and palate; *BFR*, bone formation ratio; *CB*, cranial bone; *CBCT*, cone beam computed tomography; *CCT*, controlled clinical trial; *CG*, control group; *CT*, computed tomography; *IC*, iliac crest; m, month; *MMB*, mandibular monocortical bone; *Occl*, occlusal radiograph; *PA*, periapical radiograph; *RCT*, randomized clinical trial; *UCLA*, unilateral cleft lip and alveolus; *UCLP*, unilateral cleft lip and palate; *y*, year.

although traditional radiographic evaluation has multiple advantages, including easy application, low cost, and the relatively low radiation doses involved, studies have limited accuracy because of structural overlap, distortion, and magnification.[33,44] Moreover, alveolar thickness varies in CT analyses despite the apparent evidence of successful results obtained with traditional radiography. CT scans are required to determine the suitability of bone for dental implants and the potential movement of orthodontically manipulated teeth.[45] Thus, it was recommended that SABG outcomes be evaluated with CT, especially in cases where further orthodontic management is needed because of variations in alveolar thickness. More unsuccessful cases were expected in studies that used CT because conventional radiography might overestimate successful cases.[29] 3-D scans depicted the amount of bone in the labiopalatal direction and accurately portrayed the location of the bone graft and the positions of adjacent teeth.[5,6,46] Lee et al.[47] suggested that CT should be used for this purpose, particularly in comparative studies. CT is associated with relatively high radiation doses, but CBCT can provide similar information with 15-fold less radiation than CT[48] and 4 to 15 times the dose of a standard panoramic image.[49,50] Thus, CBCT is recommended for this task.

As there were differences among the included studies, we could not compare the outcomes of 2-D and 3-D evaluations of SABG quantitatively and come up with scientific and rigorous conclusions. Some degree of bone graft resorption is compatible with a successful outcome so long as the graft will still provide sufficient bone for tooth movement in orthodontic treatment or prosthetic repair later.[51] Thus, the gold standard of 3-D evaluation should be defined with criteria similar to those for 2-D evaluation to enhance comparability between studies.

Most studies indicated that SABG outcomes were better when surgery was performed before the eruption of canines, but a few concluded that canine status (and, thus, age at surgery) was irrelevant. The question as to whether SABG can be performed on older patients remains controversial, but canine development stage has more reference value compared with physiologic age.[35] In addition, it was difficult to determine whether orthodontic treatment before SABG affected the success rate of the grafts. Surgeons evaluate the alveolar cleft condition and the SABG surgical difficulty on an individual basis and schedule orthodontic therapy before SABG if that would be helpful.[52] We included studies in which bone was harvested from the iliac crest, mandible, or cranium. Most studies used iliac crest bone, perhaps because the volume available is greater than that from the mandible or the cranium.[53] This may have affected the success of bony bridging.

Although a previous study found no statistical differences in outcomes between SABG using iliac crest bone and SABG using mandibular symphysis bone,[54] we could not draw any definitive conclusion.

SABG is expected to optimize opportunities for later orthodontic treatment, especially by establishing bony bridges between alveolar roots. Most studies measured total BFRs or alveolar thickness at optimal follow-up times but did not measure bone formation at the apical level, which is the critical level in terms of the success of later orthodontic therapy. The various cleft regions should be separately evaluated; additionally, a gold standard 3-D evaluation protocol is required. Many studies have sought factors reflecting good SABG outcomes, but the debate continues, and no one factor that is significantly associated with success has yet been identified. Larger 3-D studies exploring various factors are required to help surgeons improve SABG success rates.

CONCLUSIONS

We compared SABG outcomes as revealed by 2-D and 3-D radiography. 3-D evaluation was more precise and reliable than 2-D evaluation. CT examination showed that 2-D evaluation tended to overestimate SABG outcomes. The effectiveness of SABG has been recognized, but efforts should always be made to improve outcomes. A gold standard 3-D evaluation protocol is required for quantitative comparisons in the future. No gold standard for 3-D evaluation of success has been established, which makes quantitative comparisons of 2-D and 3-D evaluations difficult.

REFERENCES

1. Guo J, Li C, Zhang Q, et al. Secondary bone grafting for alveolar cleft in children with cleft lip or cleft lip and palate. *Cochrane Database Syst Rev*. 2011;6:Cd008050.
2. Schuchardt K. Congenital deformities. I. Primary bone graft in clefts of lip, alveolus and palate. *Mod Trends Plast Surg*. 1966;2:214-225.
3. Tai CC, Sutherland IS, McFadden L. Prospective analysis of secondary alveolar bone grafting using computed tomography. *J Oral Maxillofac Surg*. 2000;58:1241-1249. discussion 1250..
4. Witherow H, Cox S, Jones E, Carr R, Waterhouse N. A new scale to assess radiographic success of secondary alveolar bone grafts. *Cleft Palate Craniofac J*. 2002;39:255-260.
5. Feichtinger M, Zemann W, Mossbock R, Karcher H. Three-dimensional evaluation of secondary alveolar bone grafting using a 3 D- navigation system based on computed tomography: a two-year follow-up. *Br J Oral Maxillofac Surg*. 2008;46:278-282.
6. Oberoi S, Chigurupati R, Gill P, Hoffman WY, Vargervik K. Volumetric assessment of secondary alveolar bone grafting using cone beam computed tomography. *Cleft Palate Craniofac J*. 2009;46:503-511.
7. Albuquerque MA, Gaia BF, Cavalcanti MG. Comparison between multislice and cone-beam computerized tomography in the volumetric assessment of cleft palate. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2011;112:249-257.
8. Arctander K, Kolbenstvedt A, Aalokken TM, Abyholm F, Froslie KF. Computed tomography of alveolar bone grafts 20 years after repair of unilateral cleft lip and palate. *Scand J Plast Reconstr Surg Hand Surg*. 2005;39:11-14.
9. Boyarskiy S, Choi HJ, Park K. Evaluation of alveolar bone support of the permanent canine in cleft and noncleft patients. *Cleft Palate Craniofac J*. 2006;43:678-682.
10. Nwoku AL, Al Atel A, Al Shlash S, Oluyadi BA, Ismail S. Retrospective analysis of secondary alveolar cleft grafts using iliac of chin bone. *J Craniofac Surg*. 2005;16:864-868.
11. Bergland O, Semb G, Abyholm FE. Elimination of the residual alveolar cleft by secondary bone grafting and subsequent orthodontic treatment. *Cleft Palate J*. 1986;23:175-205.
12. Witsenburg B. The reconstruction of anterior residual bone defects in patients with cleft lip, alveolus and palate. A review. *J Maxillofac Surg*. 1985;13:197-208.
13. Boyne PJ, Sands NR. Secondary bone grafting of residual alveolar and palatal clefts. *J Oral Surg*. 1972;30:87-92.
14. Datana S, Chattopadhyay PK, Kadu A. Bony bridge resorption after secondary alveolar grafting and correlation with success of orthodontic treatment: a prospective volumetric cone beam computed tomography (CBCT) study. *Med J Armed Forces India*. 2019;75:375-382.
15. Feichtinger M, Mossbock R, Karcher H. Assessment of bone resorption after secondary alveolar bone grafting using three-dimensional computed tomography: a three-year study. *Cleft Palate Craniofac J*. 2007;44:142-148.
16. Craven C, Cole P, Hollier L Jr., Stal S. Ensuring success in alveolar bone grafting: a three-dimensional approach. *J Craniofac Surg*. 2007;18:855-859.
17. Yoshida S, Suga K, Nakano Y, Sakamoto T, Takaki T, Uchiyama T. Postoperative evaluation of grafted bone in alveolar cleft using three-dimensional computed tomography data. *Cleft Palate Craniofac J*. 2013;50:671-677.
18. Awarun B, Blok J, Pauwels R, Politis C, Jacobs R. Three-dimensional imaging methods to quantify soft and hard tissues change after cleft-related treatment during growth in patients with cleft lip and/or cleft palate: a systematic review. *Dentomaxillofac Radiol*. 2019;48:20180084.
19. Kawakami S, Hiura K, Yokozeki M, et al. Longitudinal evaluation of secondary bone grafting into the alveolar cleft. *Cleft Palate Craniofac J*. 2003;40:569-576.
20. Mikoya T, Inoue N, Matsuzawa Y, Totsuka Y, Kajii TS, Hirosawa T. Monocortical mandibular bone grafting for reconstruction of alveolar cleft. *Cleft Palate Craniofac J*. 2010;47:454-468.
21. Seike T, Hashimoto I, Matsumoto K, Tanaka E, Nakanishi H. Early postoperative evaluation of secondary bone grafting into the alveolar cleft and its effects on subsequent orthodontic treatment. *J Med Invest*. 2012;59:152-165.
22. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS medicine*. 2009;6:e1000097.
23. McCollough CH, Kaufmann RB, Cameron BM, Katz DJ, Sheedy PF 2nd, Peyser PA. Electron-beam CT: use of a calibration phantom to reduce variability in calcium quantitation. *Radiology*. 1995;196:159-165.
24. Kim JH, Lee JG, Han DH, Kim HJ. Morphometric analysis of the anterior region of the maxillary bone for immediate implant placement using micro-CT. *Clin Anat*. 2011;24:462-468.
25. Slim K, Nini E, Forestier D, Kwiatkowski F, Panis Y, Chipponi J. Methodological index for non-randomized studies (minors): development and validation of a new instrument. *ANZ J Surg*. 2003;73:712-716.
26. Higgins JP, Altman DG, Gotzsche PC, et al. Cochrane Bias Methods Group, Cochrane Statistical Methods Group. The

Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *BMJ*. 2011;343:d5928.
27. Dickinson BP, Ashley RK, Wasson KL, et al. Reduced morbidity and improved healing with bone morphogenic protein-2 in older patients with alveolar cleft defects. *Plast Reconstr Surg*. 2008;121:209-217.
28. Marukawa E, Oshina H, Iino G, Morita K, Omura K. Reduction of bone resorption by the application of platelet-rich plasma (PRP) in bone grafting of the alveolar cleft. *J Craniomaxillofac Surg*. 2011;39:278-283.
29. Trindade-Suedam IK, Da Silva Filho OG, Carvalho RM, et al. Timing of alveolar bone grafting determines different outcomes in patients with unilateral cleft palate. *J Craniofac Surg*. 2012;23:1283-1286.
30. Calvo AM, Trindade-Suedam IK, da Silva Filho OG, et al. Increase in age is associated with worse outcomes in alveolar bone grafting in patients with bilateral complete cleft palate. *J Craniofac Surg*. 2014;25:380-382.
31. Oh TS, Park JS, Choi JW, Kwon SM, Koh KS. Risk factor analysis of bone resorption following secondary alveolar bone grafting using three-dimensional computed tomography. *J Plast Reconstr Aesthet Surg*. 2016;69:487-492.
32. Du F, Wu H, Li H, et al. Bone marrow mononuclear cells combined with beta-tricalcium phosphate granules for alveolar cleft repair: a 12-month clinical study. *Sci Rep*. 2017;7:13773.
33. Han K, Jeong W, Yeo H, et al. Long-term results of secondary alveolar bone grafting using a technique to harvest pure calvarial cancellous bone: evaluation based on plain radiography and computed tomography. *J Plastic Reconstr Aesthet Surg*. 2017;70:352-359.
34. Liang F, Yen SL, Imahiyerobo T, et al. Three-dimensional cone beam computed tomography volumetric outcomes of rhBMP-2/demineralized bone matrix versus iliac crest bone graft for alveolar cleft reconstruction. *Plast Reconstr Surg*. 2017;140:767-774.
35. De Mulder D, Cadenas de Llano-Perula M, Jacobs R, Verdonck A, Willems G. Three-dimensional radiological evaluation of secondary alveolar bone grafting in cleft lip and palate patients: a systematic review. *Dentomaxillofac Radiol*. 2018;2018:20180047.
36. Reddy MG, Babu VR, Rao VE, Chaitanya JJ, Allareddy S, Reddy CC. Prospective analysis of secondary alveolar bone grafting in cleft lip and palate patients. *J Int Oral Health*. 2015;7:73-77.
37. Feng B, Jiang M, Xu X, Li J. A new method of volumetric assessment of alveolar bone grafting for cleft patients using cone beam computed tomography. *Oral Surg Oral Med Oral Pathol Oral Radiol*. 2017;124:e171-e182.
38. Kuijpers MA, Chiu YT, Nada RM, Carels CE, Fudalej PS. Three-dimensional imaging methods for quantitative analysis of facial soft tissues and skeletal morphology in patients with orofacial clefts: a systematic review. *PLoS One*. 2014;9:e93442.
39. Amirlak B, Tang CJ, Becker D, Palomo JM, Gosain AK. Volumetric analysis of simulated alveolar cleft defects and bone grafts using cone beam computed tomography. *Plast Reconstr Surg*. 2013;131:854-859.
40. Dado DV, Rosenstein SW, Alder ME, Kernahan DA. Long-term assessment of early alveolar bone grafts using three-dimensional computer-assisted tomography: a pilot study. *Plast Reconstr Surg*. 1997;99:1840-1845.
41. Enemark H, Sindet-Pedersen S, Bundgaard M. Long-term results after secondary bone grafting of alveolar clefts. *J Oral Maxillofac Surg*. 1987;45:913-919.
42. Iino M, Ishii H, Matsushima R, et al. Comparison of intraoral radiography and computed tomography in evaluation of formation of bone after grafting for repair of residual alveolar defects in patients with cleft lip and palate. *Scand J Plast Reconstr Surg Hand Surg*. 2005;39:15-21.
43. Bahr W, Coulon JP. Limits of the mandibular symphysis as a donor site for bone grafts in early secondary cleft palate osteoplasty. *Int J Oral Maxillofac Surg*. 1996;25:389-393.
44. Waitzman AA, Posnick JC, Armstrong DC, Pron GE. Craniofacial skeletal measurements based on computed tomography: Part II. Normal values and growth trends. *Cleft Palate Craniofac J*. 1992;29:118-128.
45. Liu L, Ma L, Lin J, Zhang C, Jia Y. Assessing the interdental septal thickness in alveolar bone grafting using cone beam computed tomography. *Cleft Palate Craniofac J*. 2016;53:683-689.
46. Suomalainen A, Åberg T, Rautio J, Hurmerinta K. Cone beam computed tomography in the assessment of alveolar bone grafting in children with unilateral cleft lip and palate. *Eur J Orthod*. 2014;36(5):603-611.
47. Lee C, Crepeau RJ, Williams HB, Schwartz S. Alveolar cleft bone grafts: results and imprecisions of the dental radiograph. *Plast Reconstr Surg*. 1995;96:1534-1538.
48. Kitagawa H, Scheetz JP, Farman AG. Comparison of complementary metal oxide semiconductor and charge-coupled device intraoral X-ray detectors using subjective image quality. *Dentomaxillofac Radiol*. 2003;32:408-411.
49. Young SJ, Chaibi MS, Graves DT, et al. Quantitative analysis of periodontal defects in a skull model by subtraction radiography using a digital imaging device. *J Periodontol*. 1996;67:763-769.
50. Van der Meij AJ, Baart JA, Prahl-Andersen B, Valk J, Kostense PJ, Tuinzing DB. Bone volume after secondary bone grafting in unilateral and bilateral clefts determined by computed tomography scans. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2001;92:136-141.
51. De Ruiter A, Janssen N, Van Es R, et al. Micro-structured beta-tricalcium phosphate for repair of the alveolar cleft in cleft lip and palate patients: a pilot study. *Cleft Palate Craniofac J*. 2015;52:336-340.
52. Kindelan J, Roberts-Harry D. A 5-year post-operative review of secondary alveolar bone grafting in the Yorkshire region. *Br J Orthod*. 1999;26:211-217.
53. Bajaj AK, Wongworawat AA, Punjabi A. Management of alveolar clefts. *J Craniofac Surg*. 2003;14:840-846.
54. Trujillo RL, Kadioglu O, Currier GF, Smith KS, Yetkiner E. Volumetric cleft changes in treatment with bone morphogenic protein/β-tricalcium phosphate versus grafts from the iliac crest or symphysis. *J Oral Maxillofac Surg*. 2018;76:1991-1997.

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