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Preoperative Three-Dimensional Assessment of Secondary Naso-Palato-Alveolar Clefts Using Computed Tomography: A Retrospective Observational Study

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Abstract

Introduction: Secondary naso-palato-alveolar clefts exhibit considerable three-dimensional anatomical variations, which may complicate preoperative assessment and surgical planning. This study evaluated the morphological characteristics of these clefts using three-dimensional computed tomography (3DCT).

Materials and methods: This retrospective observational study included patients with secondary naso-palato-alveolar clefts who underwent preoperative 3DCT between January 2019 and December 2024. Demographic and clinical records were reviewed, and cleft volume, anteroposterior length, transverse width, and vertical height were assessed. Adjacent tooth/root involvement and nasal floor discontinuity were recorded. Comparisons between unilateral and bilateral clefts accounted for within-patient clustering by using mixed-effects models. Measurement reproducibility was assessed using intraclass correlation coefficients (ICCs) and Cohen's kappa.

Results: Ninety-five patients (mean age, 11.8 ± 3.4 years) contributed 112 cleft observations, comprising 78 unilateral and 34 bilateral clefts. The overall mean cleft volume was 1.82 ± 0.71 cm^3. Bilateral clefts demonstrated a greater mean volume than unilateral clefts (2.30 ± 0.82 vs. 1.61 ± 0.56 cm^3; mean difference, 0.69 cm^3; $p < 0.001$; Cohen's $d = 0.91$). Bilateral clefts also exhibited greater anteroposterior length (18.90 ± 5.40 vs. 15.30 ± 4.10 mm; mean difference, 3.60 mm; $p = 0.001$; $d = 0.76$), transverse width (8.50 ± 2.60 vs. 6.50 ± 1.90 mm; mean difference, 2.00 mm; $p < 0.001$; $d = 0.86$), and vertical height (15.00 ± 4.30 vs. 13.00 ± 3.60 mm; mean difference, 2.00 mm; $p = 0.023$; $d = 0.51$). Adjacent tooth/root involvement and nasal-floor discontinuity were more frequent in bilateral clefts, with odds ratios of 3.46 (95% CI, 1.40-8.55; $p = 0.007$) and 6.42 (95% CI, 2.52-16.36; $p < 0.001$), respectively. Cleft volume was positively associated with anteroposterior length ($\rho = 0.72$), transverse width ($\rho = 0.65$), and vertical height ($\rho = 0.56$; all $p < 0.001$). Measurement reproducibility was excellent, with an ICC of 0.94 (95% CI, 0.88-0.97) for cleft volume.

Conclusion: 3DCT demonstrated substantial variation in secondary naso-palato-alveolar cleft morphology. Bilateral clefts showed greater anatomical involvement, whereas cleft volume was consistently related to the linear dimensions. Standardized three-dimensional assessment may provide useful anatomical information for individualized preoperative evaluation and surgical planning.

Categories: Dentistry
Keywords: cleft lip, cleft palate, complications, computed tomography, surgical planning

Introduction

The cleft lip and palate are among the most common congenital craniofacial anomalies and may result in persistent defects involving the alveolar process, nasal floor, and palatal structures, even after primary cleft repair [1]. Mathew et al. [2] proposed a three-dimensional computed tomography (3DCT)-based classification system specifically for cleft alveolar defects, using preoperative 3DCT assessment to characterize the extent and morphology of the defect. The proposed system classifies alveolar clefts according to the extent of alveolar involvement and further recognizes defects in communication with the nasal floor and those occurring concomitantly with cleft lip and/or palate. This approach emphasized three-dimensional visualization of the defect and its relevance to preoperative surgical planning.

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Accurate characterization of anatomical features is important before performing secondary reconstructive procedures because the extent and configuration of the defect may influence surgical access, graft placement, and the amount of graft material required. Conventional two-dimensional radiographic techniques provide limited information regarding the complex spatial anatomy of cleft defects [3]. In contrast, 3DCT permits multiplanar and volumetric assessment and facilitates the visualization of the alveolar segments, nasal floor, adjacent tooth roots, and palatal structures [4]. Volumetric assessments may also provide a more comprehensive representation of defects than linear measurements alone [5]. However, the morphology of secondary clefts may differ according to unilateral or bilateral involvement and may demonstrate substantial interindividual variation [6]. Establishing reproducible three-dimensional measurements may therefore improve anatomical characterization and provide clinically relevant information for preoperative planning.

Although previous studies have demonstrated the utility of 3DCT for volumetric assessment of alveolar cleft defects and evaluation of secondary alveolar bone grafting, important aspects of preoperative cleft morphology remain insufficiently characterized [4,5]. In particular, the extent to which cleft volume and individual linear dimensions differ between unilateral and bilateral secondary naso-palato-alveolar clefts has not been comprehensively evaluated within a single analytical framework accounting for the correlation between bilateral cleft observations from the same patient. Furthermore, the relationship between cleft volume and individual anatomical dimensions, the potential influence of laterality among unilateral defects, and the distribution of associated anatomical findings, including adjacent tooth/root involvement and nasal-floor discontinuity, warrant further investigation. A comprehensive assessment of these characteristics may provide a more detailed understanding of cleft morphology and its variability according to cleft configuration.

Therefore, the present study aimed to characterize the preoperative morphology of secondary naso-palato-alveolar clefts using 3DCT imaging. The specific objectives were to quantify cleft volume and three-dimensional dimensions, compare morphological characteristics between unilateral and bilateral clefts while accounting for within-patient clustering, evaluate differences between right- and left-sided unilateral defects, examine associations between cleft volume and linear dimensions, assess the relationship of cleft morphology with adjacent dental structures and nasal-floor continuity, and determine the reproducibility of selected 3DCT measurements. By integrating volumetric, linear, and categorical anatomical assessments, this study sought to provide a more comprehensive characterization of cleft morphology relevant to individualized preoperative evaluation and surgical planning.

Materials And Methods

Study design and setting

This retrospective study was conducted in the Department of Oral and Maxillofacial Surgery of the RKDF Dental College and Research Centre, Bhopal, India. The records and imaging examinations performed between January 2019 and December 2024 were reviewed. Because the study involved only previously acquired clinical records and imaging examinations, no additional imaging or radiation exposure was performed for research purposes.

Study population and case identification

Because this was a retrospective exploratory study, all eligible records available during the predefined study period were included; therefore, no a priori sample-size calculation was performed. The study population comprised patients with a documented clinical and radiological diagnosis of secondary naso-palato-alveolar clefts [2] who underwent preoperative 3DCT imaging as part of their routine clinical evaluation. Eligible cases were identified from hospital electronic medical records, radiology databases, cleft clinic records, and surgical registers. All records available during the study period were consecutively screened. The final study population comprised 95 patients, contributing to 112 cleft observations. Seventeen patients had bilateral clefts and therefore contributed to two cleft observations, whereas patients with unilateral clefts contributed to one observation each (Figure *1*).

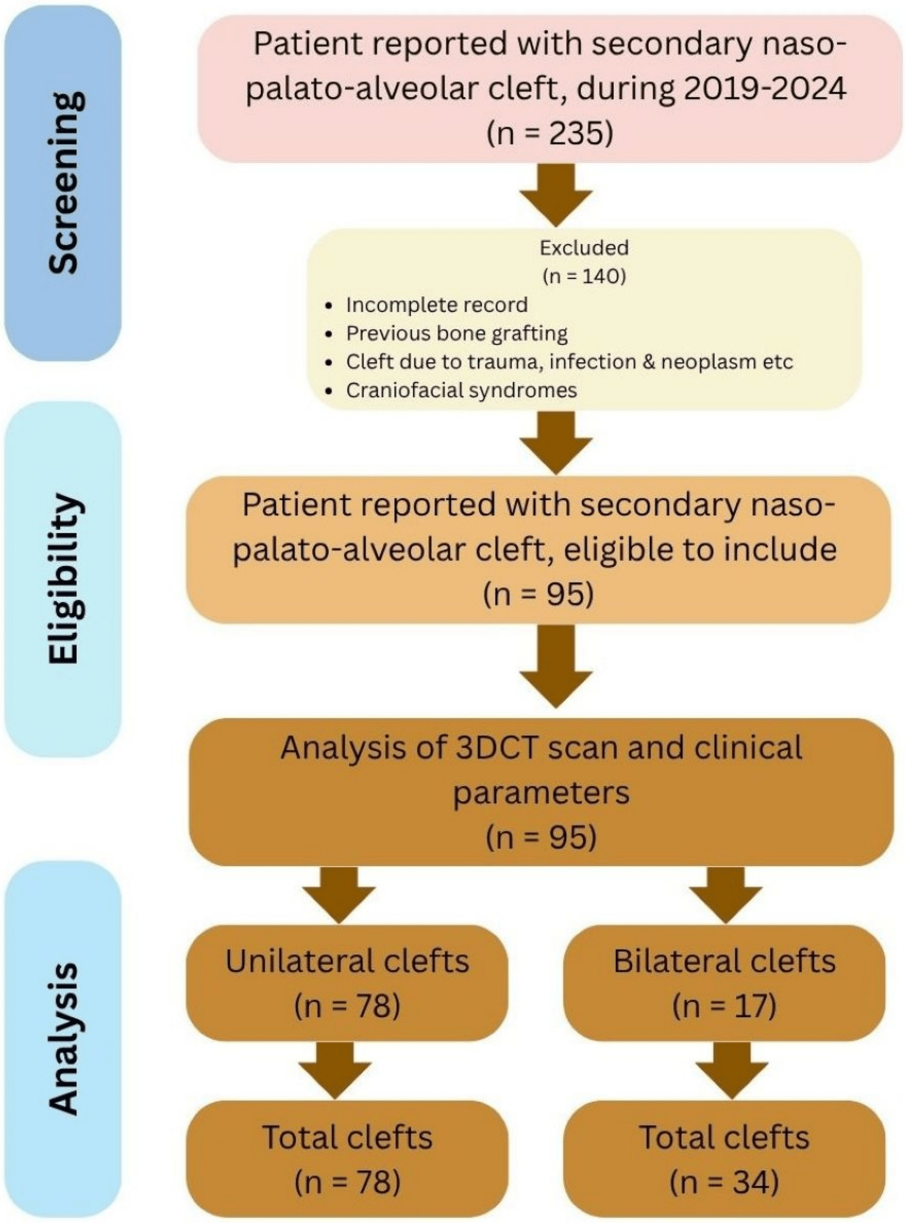


FIGURE 1: Screening for patient selection.

3DCT: three-dimensional computed tomography

The image was created by the authors using Canva software (Canva Pty Ltd., Sydney, Australia).

The inclusion criteria were a documented diagnosis of a secondary naso-palato-alveolar cleft, an available preoperative 3DCT examination of adequate diagnostic quality, imaging performed before secondary alveolar or nasopalato-alveolar reconstructive surgery, availability of basic demographic and clinical information for inclusion in the study, eligibility of patients of both sexes, and an age range of 5 to 18 years. The exclusion criteria were inadequate or severely degraded 3DCT images, previous bone grafting or reconstructive surgery that substantially altered the anatomy of the cleft site, defects acquired as a consequence of trauma, infection, neoplasm, or previous ablative surgery, craniofacial syndromes or severe skeletal deformities that prevented standardized assessments, records with incomplete essential clinical information or missing imaging data, and 3DCT examinations that did not encompass the complete maxillary alveolar and palatal regions required for assessment.

In the present study, the term secondary naso-palato-alveolar cleft refers to the residual congenital cleft defect involving the maxillary alveolar process, with possible extension to the nasal floor and palatal structures. The anatomical assessment was therefore not restricted to the alveolar component alone but also considered the three-dimensional extent of the defect and its relationship with adjacent dental structures

and the nasal floor. The term cleft alveolar defect is used when referring specifically to the alveolar component or to previous studies that evaluated this region, whereas secondary naso-palato-alveolar cleft is used consistently to describe the study population and the overall anatomical scope of the present investigation.

Sampling and sample size

Consecutive sampling was performed. As this was a retrospective observational study based on previously acquired clinical records and 3DCT examinations, an a priori sample size calculation was not performed. The study aimed to include all eligible patients who underwent preoperative 3DCT assessment during the predefined study period from January 2019 to December 2024. The final sample size was therefore determined by the availability of eligible records that fulfilled the predefined inclusion and exclusion criteria. This approach was adopted to maximize the use of available clinical data and avoid the selective exclusion of eligible cases based on a predetermined sample size. The final study population comprised 95 patients contributing 112 cleft observations. No post hoc sample size calculation was performed.

3DCT image acquisition and assessment

All preoperative three-dimensional imaging examinations were performed on the cone beam computed tomography (CBCT) unit available at the institution during the study period (Planmeca ProMax 3D Mid, Planmeca Oy, Helsinki, Finland). Maxillary scans were acquired using the department's routine maxillary protocol. Acquisition parameters, recorded from the original Digital Imaging and Communications in Medicine (DICOM) metadata, were tube voltage 90 kV, tube current 8 mA, field of view 10 × 10 cm, voxel size 0.2 mm, and exposure time 12 s. Because the study was retrospective, no acquisition parameters were modified for research purposes. DICOM datasets were imported into 3D-Doctor software (version 4.0, Able Software LLC, Massachusetts, USA) and reoriented to standardized anatomical reference planes (Frankfort horizontal and mid-sagittal planes) to minimize orientation variability. Cleft volume was quantified by manual slice-by-slice segmentation of the defect on multiplanar reconstructions in the axial, coronal, and sagittal planes.

Demographic and clinical variables

The demographic variables extracted from the records included age at the time of imaging, sex, and the study identification number. Clinical variables included cleft type, unilateral or bilateral involvement, side of involvement in unilateral clefts, completeness of the cleft, associated cleft lip or palatal involvement, and the presence and status of teeth adjacent to the cleft. Adjacent teeth were categorized as erupted, unerupted, supernumerary, or malformed. Previous cleft-related surgical procedures and planned surgical procedures, when documented, were also recorded.

Three-dimensional morphological assessment

The primary imaging assessment consisted of quantitative evaluation of cleft morphology. The maximum anteroposterior length, maximum transverse or labiopalatal width, and maximum vertical height of each cleft were measured in millimeters. In addition, the total cleft volume was determined by three-dimensional segmentation of the defect. Where anatomically distinguishable, the alveolar and palatal components of the defects were assessed separately. The minimum residual bone thickness at the cleft margins and thicknesses of the buccal and palatal bony walls were recorded when measurable.

Additional anatomical features were assessed to characterize the relationship between the cleft and the surrounding structures. These include the continuity of the nasal floor, the relationship of the defect to the piriform aperture, proximity to adjacent tooth roots, root divergence or displacement, the presence of impacted or supernumerary teeth, nasal cavity involvement, and the position and orientation of the premaxilla. Anatomical asymmetry between the cleft and non-cleft sides and other radiological features potentially relevant to surgical access or graft placement have also been documented.

Cleft volume measurement and segmentation protocol

The following predefined anatomical boundaries were applied consistently: the superior boundary was defined as the nasal floor or anterior nasal spine (adapted to individual anatomy); the inferior boundary as the alveolar crest or cemento-enamel junction of the adjacent teeth; the anterior and posterior boundaries as the anatomical limits of the cleft between the anterior and posterior alveolar segments; the labial/buccal boundary as the external cortical margin of the labial/buccal plate; and the palatal boundary as the palatal cortical margin and adjacent palatal bone. Segmentation was performed with fixed windowing settings, and the software automatically calculated the enclosed volume from the segmented voxels. Boundaries were adjusted only when required by individual cleft morphology (unilateral versus bilateral, complete versus incomplete) while preserving the same landmark principles, and the selected boundaries were documented for each case (Figure *2*).



FIGURE 2: Three-dimensional computed tomography (3DCT) segmentation and volumetric assessment of a naso-palato-alveolar cleft using 3D-DOCTOR software (Able Software Corp., Lexington, Massachusetts, USA).

(A) Three-dimensional surface-rendered reconstruction showing the spatial configuration and extent of the segmented naso-palato-alveolar cleft (white arrow); (B) Axial 3DCT image demonstrating the segmented naso-palato-alveolar cleft space (white arrow); (C) Sagittal 3DCT reconstruction demonstrating the anteroposterior extent of the cleft from the alveolar region toward the nasal/palatal region (white arrow).

The red segmentation represents the cleft space delineated from the surrounding osseous structures.

In edge cases (such as incomplete clefts, absent adjacent teeth, or atypical nasal-floor anatomy), the superior and inferior boundaries were defined by the nearest identifiable bony or dental landmarks that best approximated the intended anatomical limits, and any such adaptations were recorded for each scan to ensure consistency. Because secondary clefts can differ substantially in configuration, particularly between unilateral and bilateral defects and between complete and incomplete defects, the anatomical boundaries were adapted to the individual anatomy while maintaining predefined measurement principles. The segmentation approach and selected boundaries were documented during image assessment to ensure consistency.

Classification of cleft morphology

Clefts were categorized as unilateral or bilateral. For unilateral defects, the side of involvement was recorded as the right or left. Bilateral clefts were considered two separate cleft observations for cleft-level morphological analyses. Thus, the dataset consists of 112 cleft-level observations derived from 95 patients. Because bilateral observations from the same patient were not statistically independent, patient identity was retained in the analytical dataset and incorporated as a clustering variable in the subsequent statistical analyses.

Observer assessment and reliability

The 3DCT examinations were independently assessed by two trained observers (TRM and SK), who were blinded to each other's measurements. A randomly selected subset of 30 scans was reassessed by the same observer after a two-week interval to evaluate intraobserver reproducibility. Reliability for continuous variables, including cleft volume and linear dimensions, was assessed using the intraclass correlation coefficient (ICC). Agreement for categorical variables, including adjacent tooth/root involvement and nasal-floor discontinuity, was assessed using Cohen's kappa (κ). Measurement reliability was excellent. The ICC was 0.94 (95% CI, 0.88-0.97) for cleft volume and 0.91 (95% CI, 0.83-0.96) for anteroposterior length. Cohen's kappa was 0.86 (95% CI, 0.68-1.00) for adjacent tooth/root involvement and 0.82 (95% CI, 0.62-1.00) for nasal-floor discontinuity.

Data management and confidentiality

Each eligible patient was assigned a unique identification code. Direct identifiers, including patient names, telephone numbers, addresses, and hospital registration numbers, were excluded from the analytical dataset. Demographic, clinical, and imaging variables were stored in a coded database. Electronic study data were maintained on a password-protected institutional computer or secure institutional server, with access restricted to authorized members of the research team.

Statistical analysis

Statistical analysis was performed on the coded data by a statistician (JG) using IBM SPSS Statistics for Windows, Version 25 (Released 2017; IBM Corp., Armonk, New York, United States), except for the clustered correlation analyses, which were performed in R (version 4.3.2; R Foundation for Statistical Computing, Vienna, Austria). Continuous variables were assessed for distributional characteristics using the Shapiro-Wilk test and are presented as mean ± standard deviation (SD). Categorical variables are presented as

frequencies and percentages. Because 17 patients contributed two cleft observations, patient identifiers were incorporated as a clustering variable to account for the correlation between observations originating from the same patient. Continuous outcomes were compared using linear mixed-effects models, with cleft type included as a fixed effect and patient identifier included as a random intercept. This approach allowed unilateral and bilateral cleft observations to be compared while accounting for the non-independence of observations contributed by the same patient.

Binary imaging outcomes, including adjacent tooth/root involvement and nasal-floor discontinuity, were analyzed using generalized linear mixed-effects models (GLMMs) with a logit link. Patient identifier was included as a random intercept, and the resulting odds ratios (ORs) represented the estimated odds of the imaging findings in bilateral compared with unilateral clefts. Associations between cleft volume and individual linear 3DCT measurements were evaluated using Spearman's rank correlation coefficient (ρ). To account for repeated cleft observations within patients, correlations were calculated on the full cleft-level dataset (n = 112), and standard errors with 95% confidence intervals (CIs) were obtained via a clustered bootstrap (1,000 resamples) that resampled patients rather than individual clefts. The analysis was performed using the cor function (method = "spearman") and the boot package in R; two-sided p-values were derived from the bootstrap distribution.

Effect sizes were calculated as follows: Cohen's d for continuous comparisons between unilateral and bilateral clefts (and between right- and left-sided unilateral clefts), derived from the mean difference and pooled SD; ORs with corresponding 95% CIs for the binary outcomes from the GLMMs; and Spearman's ρ together with ρ^2 for the associations between cleft volume and the linear dimensions. Effect estimates and their corresponding 95% CIs were emphasized alongside p-values to facilitate interpretation of the magnitude and precision of the observed associations. All statistical tests were two-sided, and statistical significance was set at $p < 0.05$. As this was an exploratory retrospective study, the analyses were interpreted as descriptive and associative rather than causal, and no regression analyses beyond the prespecified mixed-effects comparisons were performed.

Ethical considerations

The study protocol (ref no. RKDF/DC/2025/SS-035 dated 18-01-2025) was approved by the Institutional Ethics Committee of the college before the commencement of the study. As the investigation involved a retrospective review of existing clinical records and previously acquired 3DCT examinations, no additional radiation exposure or alterations in patient treatment were involved. Because this study involved retrospective review of existing clinical records and previously acquired imaging examinations, the requirement for individual informed consent was waived by the Institutional Ethics Committee. Patient confidentiality and anonymity were maintained throughout the study.

Results

No missing values were identified for the variables included in the primary analyses. This study included 95 patients with 112 cleft observations. The mean age of the patients was 11.8 ± 3.4 years. Males accounted for 57 (60.0%) patients, and females for 38 (40.0%). Unilateral clefts comprised 78 (69.6%) observations, whereas bilateral clefts comprised 34 (30.4%). Among the 78 unilateral clefts, 42 (53.8%) were right-sided and 36 (46.2%) left-sided. Seventeen (17.9%) patients had bilateral clefts and therefore contributed to two cleft-level observations (Table *1*).

Variable	Unit	Result
Total patients, n	Patient-level	95
Total clefts assessed, n	Cleft-level	112
Age (years), mean ± SD	Patient-level	11.8 ± 3.4
Male patients, n (%)	Patient-level	57 (60.0)
Female patients, n (%)	Patient-level	38 (40.0)
Unilateral clefts, n (%)	Cleft-level	78 (69.6)
Bilateral clefts, n (%)	Cleft-level	34 (30.4)
Patients with bilateral clefts, n (%)	Patient-level	17 (17.9)
Patients with unilateral cleft, n (%)	Patient-level	78 (82.1)
Right-sided unilateral clefts, n (%)	Among unilateral clefts	42 (53.8)
Left-sided unilateral clefts, n (%)	Among unilateral clefts	36 (46.2)

TABLE 1: Demographic and cleft distribution characteristics of the study population.

Continuous data are presented as mean ± standard deviation (SD), and categorical data are presented as frequency (n) and percentage (%). Percentages for cleft characteristics are calculated at the cleft level unless otherwise indicated; patient-level and cleft-level observations are reported separately because some patients contributed bilateral cleft observations.

The mean cleft volume was 1.82 ± 0.71 cm^3, with mean maximum anteroposterior length, transverse width, and vertical height of 16.40 ± 4.80 mm, 7.10 ± 2.30 mm, and 13.06 ± 3.90 mm, respectively. Adjacent tooth or root involvement was observed in 39 (34.8%) clefts, whereas nasal floor discontinuities were present in 48 (42.9%) clefts (Table *2*).

3DCT variable	Values
Cleft volume, cm^3, mean ± SD	1.82 ± 0.71
Maximum anteroposterior length, mm, mean ± SD	16.40 ± 4.80
Maximum transverse width, mm, mean ± SD	7.10 ± 2.30
Maximum vertical height, mm, mean ± SD	13.06 ± 3.90
Adjacent tooth or root involvement, n (%)	39 (34.8)
Nasal-floor discontinuity, n (%)	48 (42.9)

TABLE 2: Descriptive three-dimensional computed tomography (3DCT) characteristics of the clefts.

Continuous variables are presented as mean ± standard deviation (SD), and categorical variables are presented as frequencies (n) and percentages (%). Measurements were obtained at the cleft level (n = 112). Because bilateral clefts contributed more than one observation per patient, the cleft-level observations were not treated as statistically independent in subsequent inferential analyses.

Cluster-adjusted analysis demonstrated significantly greater dimensions among bilateral clefts than among unilateral clefts. Mean cleft volume was 2.30 ± 0.82 cm^3 in bilateral clefts compared with 1.61 ± 0.56 cm^3 in unilateral clefts ($p < 0.001$). Bilateral clefts also showed greater anteroposterior, transverse, and vertical heights (Table *3*).

Variable	Unilateral clefts (n = 78)	Bilateral clefts (n = 34)	Test value	p-value	Effect size
Cleft volume, cm³	1.61 ± 0.56	2.30 ± 0.82	t = 4.74	<0.001*	d = 0.91
AP length, mm	15.30 ± 4.10	18.90 ± 5.40	t = 3.52	0.001*	d = 0.76
Transverse width, mm	6.50 ± 1.90	8.50 ± 2.60	t = 3.96	<0.001*	d = 0.86
Vertical height, mm	13.00 ± 3.60	15.00 ± 4.30	t = 2.35	0.023*	d = 0.51

TABLE 3: Cluster-adjusted comparison of three-dimensional computed tomography measurements between unilateral and bilateral clefts.

Continuous variables are presented as mean ± standard deviation (SD). Comparisons were performed using linear mixed-effects models, with cleft type included as a fixed effect and patient identifier included as a random intercept to account for clustering of cleft observations within patients. * A two-sided p-value < 0.05 was considered statistically significant. Cohen's d is presented as an unadjusted standardized effect size.

AP: anteroposterior

Among the unilateral clefts, no significant differences were observed between the right- and left-sided defects in cleft volume, anteroposterior length, or transverse width. Mean cleft volume was 1.58 ± 0.55 cm³ on the right and 1.65 ± 0.57 cm³ on the left (p = 0.610) (Table *4*).

Variable	Right-sided unilateral clefts (n = 42)	Left-sided unilateral clefts (n = 36)	Test value	p-value	Effect size
Cleft volume, cm³	1.58 ± 0.55	1.65 ± 0.57	t = 0.51	0.610	d = 0.12
AP length, mm	15.10 ± 4.00	15.50 ± 4.20	t = 0.43	0.669	d = 0.10
Transverse width, mm	6.40 ± 1.80	6.60 ± 2.00	t = 0.34	0.735	d = 0.11

TABLE 4: Cluster-adjusted comparison of three-dimensional computed tomography measurements between right- and left-sided unilateral clefts.

Continuous variables are presented as mean ± standard deviation (SD). Comparisons were performed using linear mixed-effects models, with side of involvement included as a fixed effect and patient identifier included as a random intercept to account for clustering of cleft observations within patients. A two-sided p-value < 0.05 was considered statistically significant. Effect size is presented as Cohen's d.

AP: anteroposterior

Cleft volume demonstrated significant positive associations with all assessed linear dimensions. The strongest association was observed with anteroposterior length ($\rho = 0.72$; $p < 0.001$), followed by transverse width ($\rho = 0.65$; $p < 0.001$) and vertical height ($\rho = 0.56$; $p < 0.001$) (Table *5*).

Variable pair	Clefts assessed	Spearman's ρ	p-value	Effect size
Cleft volume and AP length	112	0.72	<0.001*	$\rho^2 = 0.55$
Cleft volume and transverse width	112	0.65	<0.001*	$\rho^2 = 0.46$
Cleft volume and vertical height	112	0.56	<0.001*	$\rho^2 = 0.35$

TABLE 5: Associations between cleft volume and linear three-dimensional computed tomography measurements.

Correlation coefficients are presented as Spearman's rho (ρ), with the analysis accounting for repeated cleft observations within the same patient. * A two-sided p < 0.05 was considered statistically significant.

AP: anteroposterior

Adjacent tooth or root involvement was observed in 19 (55.9%) bilateral clefts and 20 (25.6%) unilateral clefts. After accounting for within-patient clustering, bilateral clefts had higher odds of adjacent tooth/root involvement (OR, 3.46; 95% CI, 1.40-8.55; p = 0.007). Nasal floor discontinuity was present in 25 (73.5%) bilateral clefts compared to 23 (29.5%) unilateral clefts and was also significantly associated with bilateral cleft morphology (OR, 6.42; 95% CI, 2.52-16.36; p < 0.001) (Table 6).

Imaging finding	Unilateral clefts (n = 78)	Bilateral clefts (n = 34)	Effect estimate	95% CI	p-value	Effect size
Adjacent tooth/root involvement	20 (25.6%)	19 (55.9%)	OR = 3.46	1.40-8.55	0.007*	1.24
No adjacent tooth/root involvement	58 (74.4%)	15 (44.1%)				
Nasal-floor discontinuity	23 (29.5%)	25 (73.5%)	OR = 6.42	2.52-16.36	<0.001*	1.86
No nasal-floor discontinuity	55 (70.5%)	9 (26.5%)				

TABLE 6: Cluster-adjusted associations between categorical three-dimensional computed tomography findings and cleft type (GLMM analysis).

Categorical data are presented as frequency (n) and percentage (%). Each binary outcome was analyzed using a GLMM with a logit link, with cleft type included as a fixed effect and patient identifier included as a random intercept to account for clustering of cleft observations within patients. * A two-sided p-value < 0.05 was considered statistically significant.

CI: confidence interval, GLMM: generalized linear mixed-effects model, OR: odds ratio

The 3DCT measurements demonstrated excellent reproducibility. The ICC was 0.94 (95% CI, 0.88-0.97) for cleft volume and 0.91 (95% CI, 0.83-0.96) for anteroposterior length. Agreement for categorical variables was also excellent, with Cohen's κ of 0.86 (95% CI, 0.68-1.00) for adjacent tooth/root involvement and 0.82 (95% CI, 0.62-1.00) for nasal-floor discontinuity (Table 7).

Variable	Scans (n)	Reliability statistic	Result	95% CI
Cleft volume	30	ICC	ICC = 0.94	0.88-0.97
AP length	30	ICC	ICC = 0.91	0.83-0.96
Adjacent tooth/root involvement	30	Cohen's kappa	κ = 0.86	0.68-1.00
Nasal-floor discontinuity	30	Cohen's kappa	κ = 0.82	0.62-1.00

TABLE 7: Intra-observer reliability of three-dimensional computed tomography assessment.

Continuous measurements are reported using the intraclass correlation coefficient (ICC) with 95% confidence intervals (CIs), and categorical variables are reported using Cohen's kappa (κ) with 95% CIs. Higher ICC and κ values indicate greater agreement.

AP: anteroposterior

Discussion

The present study provides a three-dimensional characterization of secondary naso-palato-alveolar clefts using preoperative 3DCT imaging and demonstrates substantial morphological variation according to cleft configuration. The principal finding was that bilateral clefts demonstrated greater cleft volumes and larger anteroposterior, transverse, and vertical dimensions than unilateral clefts, whereas right- and left-sided unilateral clefts showed broadly comparable morphology. In addition, cleft volume was positively associated with each of the measured linear dimensions. These findings indicate that bilateral defects encompass greater multiplanar extent, while laterality alone does not account for measurable differences among unilateral clefts in this cohort, supporting the value of three-dimensional assessment for characterizing cleft morphology across multiple anatomical planes rather than relying on a single linear measurement.

The larger dimensions observed in bilateral clefts are anatomically plausible because bilateral involvement affects the alveolar continuity on both sides of the premaxillary segment. Consequently, bilateral clefts may encompass a greater overall defect extent and more extensive alteration of the relationship between the premaxilla, lateral maxillary segments, and nasal floor. Previous 3DCT-based studies have similarly emphasized that cleft configuration influences the preoperative estimation of defect volume and the amount of graft material required [7]. In particular, 3DCT assessment has been reported to assist surgeons in estimating the volume of cancellous bone required during alveolar reconstruction and in adapting the estimate according to cleft type [8]. The present data establish only associative differences; they do not demonstrate that the measured volumes directly determine graft quantity or surgical success.

The present findings are consistent with previous evidence supporting the utility of three-dimensional volumetric assessment reported by Deçolli et al. [9], who evaluated alveolar bone defects in patients with bilateral cleft lip and palate using preoperative CBCT data and dedicated three-dimensional software. Their study demonstrated that alveolar defect volume could be estimated reproducibly by observers with different areas of clinical expertise and emphasized that preoperative volumetric assessment may provide useful information for secondary alveolar bone grafting. In the present study, the positive associations between cleft volume and the individual linear dimensions further support the value of volumetric assessment, as cleft morphology extends across multiple anatomical planes and may not be adequately represented by a single linear measurement. At the same time, volume should not be regarded as a direct surrogate for the final graft requirement, because surgical access, soft-tissue coverage, and the intended extent of bony reconstruction also influence the amount of graft material needed.

Liu et al. [10] further demonstrated the value of three-dimensional volumetric analysis by developing a CT-based method for evaluating bone formation following alveolar cleft reconstruction. Their findings support the use of volumetric assessment for objective evaluation of cleft reconstruction outcomes and highlight the potential role of three-dimensional imaging in cleft management. In the present study, three-dimensional volume estimation provided a more comprehensive representation of the defect and may assist in anticipating graft requirements during reconstructive planning. However, cleft volume should be interpreted as one component of preoperative anatomical assessment rather than as a direct surrogate for the final graft requirement, because surgical access, soft-tissue coverage, defect configuration, and the extent of bony reconstruction may also influence the amount of graft material required.

The absence of statistically significant morphological differences between right- and left-sided unilateral clefts suggests that laterality alone may not substantially influence the measured defect dimensions in this cohort. This finding indicates that the morphological characteristics of unilateral clefts may depend more on individual cleft configuration and associated anatomical structures than on whether the defect occurs on the right or left side [11]. Therefore, the present findings support individualized three-dimensional assessment

rather than relying solely on laterality when evaluating unilateral clefts. In contrast, Fell et al. [12] reported a recognized tendency toward left-sided occurrence among unilateral orofacial clefts, although the clinical implications of cleft sidedness remain inconsistent across studies. Their review also described associations between cleft sidedness and other dental and craniofacial characteristics.

The positive relationships between cleft volume and all three linear dimensions indicate that larger defects generally extend across multiple anatomical planes. However, linear measurements alone cannot fully represent the three-dimensional geometry of irregular clefts. Previous studies have demonstrated the utility of volumetric CT- or CBCT-based analysis for quantifying alveolar cleft defects and evaluating bone grafting outcomes [8,9,13,14]. Three-dimensional assessment also provides information regarding buccopalatal and other spatial dimensions that may not be adequately represented by conventional two-dimensional radiographic assessments. Similarly, a systematic review identified linear, volumetric, density-based, and ratio-based approaches to cleft assessment and highlighted the increasing role of 3DCT/CBCT imaging in the evaluation of secondary alveolar bone grafting [15].

The greater frequency of adjacent tooth/root involvement and nasal-floor discontinuity in bilateral clefts provides additional evidence of greater anatomical involvement in these defects. The relationship between the cleft and adjacent dental structures is clinically relevant because the position and development of teeth within or adjacent to the cleft may influence orthodontic and surgical planning [16]. Assessment of nasal-floor continuity provides additional information regarding the superior extent of the defect and may be relevant to reconstruction of the anatomical separation between the oral and nasal cavities [17].

An important methodological strength of the study was the use of patient-level clustering because individuals with bilateral clefts contributed to more than one cleft observation. Treating these observations as statistically independent could artificially narrow the CIs and exaggerate the apparent precision of the associations. Therefore, mixed-effects models provide a more appropriate analytical framework for available data. Another strength is the high reproducibility of the imaging measurements, which supports the feasibility of a standardized three-dimensional assessment. The recent literature similarly demonstrates the excellent reproducibility of volumetric CT-based assessments when standardized segmentation and registration protocols are used [13,18].

Clinical implications

These findings have practical implications for the preoperative planning of secondary alveolar reconstruction. Three-dimensional assessment can provide the surgeon with information about the defect extent, volume, surrounding bone, adjacent dental structures, and nasal-floor involvement, which may not be adequately represented by conventional two-dimensional imaging. Consequently, volumetric assessment may assist in estimating graft requirements and anticipating the anatomical complexity of the reconstruction. Previous studies have specifically demonstrated that 3DCT-based assessment can support the selection of grafting procedures and the estimation of the required graft volume [10,13,14]. Recent volumetric studies have also supported the use of standardized 3D workflows for surgical planning and postoperative assessment [8,13]. These data remain descriptive and do not establish a causal link between the measured characteristics and postoperative outcomes.

Limitations

This study had several limitations. This retrospective, single-center design limits generalizability and prevents the assessment of causal relationships between cleft morphology and surgical outcomes. The sample size was determined based on the availability of eligible records, and the imaging acquisition parameters could not be standardized prospectively. The study also focused on preoperative morphology and therefore did not determine whether the measured characteristics influenced postoperative graft incorporation, surgical complications, orthodontic outcomes, or long-term functional results. Finally, although the segmentation and measurement protocol demonstrated good reproducibility, volumetric measurements remained dependent on the image quality, anatomical boundary definition, and segmentation methodology. Prospective multicenter studies using standardized acquisition and segmentation protocols together with postoperative volumetric and clinical outcomes are warranted.

Conclusions

Preoperative 3DCT assessment demonstrated substantial morphological variation among secondary naso-palato-alveolar clefts. Bilateral defects showed greater volume, larger linear dimensions, and higher rates of adjacent tooth/root involvement and nasal-floor discontinuity than unilateral defects, whereas right- and left-sided unilateral clefts did not differ significantly. Cleft volume was positively associated with all measured linear dimensions, indicating that volume reflects multiplanar extent not fully captured by any single linear measurement. These descriptive findings provide detailed anatomical information that may support individualized preoperative evaluation. Prospective studies are required to determine whether the measured characteristics are associated with reconstructive outcomes.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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Disclosures

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