Three-dimensional digital evaluation of tooth symmetry and volume in patients with missing and peg-shaped maxillary lateral incisors

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Introduction: This study aimed to evaluate the 3-dimensional tooth crown symmetry and the crown volumes of maxillary and mandibular teeth in patients with unilateral or bilateral missing or peg-shaped maxillary lateral incisors. **Methods:** Six groups were established for the possible clinical variations in patients with unilateral missing or peg-shaped maxillary lateral incisors, bilateral presence of these tooth anomalies, and a control group (CG) with normal lateral incisors. The study was conducted on digital dental models of 132 patients. The morphologic symmetry of the antimere teeth was investigated using 3-dimensional deviation analysis. Volumes of contralateral teeth were compared within and among groups for the maxilla and mandible. Furthermore, volumes of teeth were compared in missing and peg-shaped quadrants and quadrants of CG. Intergroup differences were tested using one-way analysis of variance and Kruskal-Wallis tests, whereas paired *t* and Wilcoxon tests were used for parametric and nonparametric variables, respectively, for intragroup comparisons. **Results:** Significant deviations in symmetry of antimere teeth were not detected ($P > 0.05$). The volumes of mandibular central and lateral incisors in missing or peg-shaped lateral incisor groups were smaller than in the CG ($P < 0.05$). Per quadrant analysis, volumes of the maxillary central incisor and mandibular central incisors, canines, and first molars in quadrants with missing or peg-shaped lateral incisors were smaller than in the control quadrants ($P < 0.05$). **Conclusions:** Neither unilateral nor bilateral presence of missing or peg-shaped maxillary lateral incisors affected the morphologic symmetry of antimere teeth but did affect tooth volume, especially in the mandibular arch. (Am J Orthod Dentofacial Orthop 2022;162:e82-e95)

Missing or peg-shaped maxillary lateral incisors are among the most frequent developmental anomalies of the permanent dentition.[1-3] The worldwide prevalence of peg-shaped maxillary lateral incisors has been reported to be 1.8% in a recent meta-analysis,[2] whereas maxillary lateral incisor agenesis ranges from 1% to 3%,[4] depending on several factors such as ethnic origin, sex, and epigenetic components.[1,2,5]

Different theories prevail in the literature concerning the etiology of missing maxillary lateral incisors. Although theories related to the migration of neural crest cells or genetic factors suggest a generalized impact of lateral incisor agenesis on the overall dentition, anatomic and embryologic origin theories are more implicative of localized effects confined to the region of interest.[6] Over and above, work has been done to understand whether this type of dental anomaly is a multifactorial result of various interactions in the organism and to assess the possible consequences related to these anomalies on the dimensions and morphology of overall dentition, one of which is symmetry.[7-9] Symmetry is a prerequisite for esthetics and optimal occlusion. Asymmetrical presentation of the teeth in the dentition may also have some clinical implications. Therefore, the unilateral occurrence of peg-shaped or missing lateral incisors might be accompanied by morphologic asymmetries in the rest of the dentition. Any disharmony between the contralateral teeth can result in discrepancies in gingival margins and incisal

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edges, insufficient space for the lateral incisors, midline shifts, asymmetrical arch forms, varying buccal corridors, mismatched coupling of the antagonist teeth, and difficulty in attaining Class I molar and canine relationships.[10,11]

Although the need to determine the impact of the missing or peg-shaped lateral incisors on dentition in terms of reduction in tooth size has been recognized and investigated in the previous studies,[12-16] they all relied on landmark-dependent methods; mesiodistal tooth widths in particular. These approaches have been criticized for unreliable landmark identification and questionable validity in depicting symmetry as only a single measurement in space is considered.[17,18] Recently, 3-dimensional (3D) surface-to-surface comparisons of images of dental casts using advanced engineering techniques have been introduced. With this method, a detailed evaluation of the teeth, including morphologic symmetry of the tooth crown, can be performed, which can overcome the inherent incapabilities of 2-dimensional (2D) measurements. Tooth symmetry from dental models has been investigated with 3D analysis in various malocclusions,[19] patients with impacted canine,[20] and unilateral cleft lip and palate subjects.[21] However, no study has examined the symmetry of both maxillary and mandibular teeth in the presence of peg-shaped or missing maxillary lateral incisors by 3D superimpositions. Furthermore, although previous studies have evaluated mesiodistal crown widths, no study has assessed the tooth volumes in subjects with missing or peg-shaped maxillary lateral incisors.

Therefore, the present study aimed to evaluate morphologic tooth crown symmetry through 3D deviation analysis and the crown volumes of both maxillary and mandibular teeth in patients with uni- or bilateral missing or peg-shaped maxillary lateral incisors. The study was planned to test the following null hypothesis: (1) There are no significant deviations in morphologic symmetry of antimere teeth in patients with unilateral or bilateral missing or peg-shaped lateral incisors regarding maxillary and mandibular dentition, (2) maxillary and mandibular tooth crown volume of subjects with peg-shaped or missing lateral incisors are not different from that of subjects with normal lateral incisors, and (3) per quadrant analysis, the volumes of maxillary and mandibular teeth in quadrants with peg-shaped or missing lateral incisor are not different from that of subjects without any dental anomaly.

MATERIAL AND METHODS

This retrospective study analyzed the pretreatment digital dental cast records of patients selected from the archives of the Department of Orthodontics, Faculty of Dentistry, Gazi University, and Jacksonville University School of Orthodontics. Ethical approval for the study was granted by the ethics committee of Gazi University (2019-235) and the Institutional Review Board of Jacksonville University (2019-068).

This study was conducted on 6 groups to compare all possible clinic variations of missing or peg-shaped lateral incisors with a control group (CG) (Fig 1):

1. Peg-missing group (PMG): Peg-shaped maxillary lateral incisor in one quadrant and missing maxillary lateral incisor in the other quadrant;
2. Normal-missing group (NMG): Normal-shaped maxillary lateral incisor in one quadrant and missing maxillary lateral incisor in the other quadrant;
3. Normal-peg group (NPG): Normal-shaped maxillary lateral incisor in one quadrant and peg-shaped maxillary lateral incisor in the other quadrant;
4. Peg-peg group (PPG): Bilateral presence of peg-shaped maxillary lateral incisors;
5. Missing-missing group (MMG): Bilateral absence of maxillary lateral incisors;
6. CG: Bilateral presence of normal-shaped maxillary lateral incisors in both quadrants.

A limited number of research regarding dental anomalies were carried out using symmetry analysis. Though those studies assessed dental symmetry among specific conditions, including different angle classifications,[19] unilateral cleft lip and palate,[21] and unilateral palatally displaced canines,[20] no study was performed on missing or peg-shaped lateral incisors. Thus, we constructed our a priori power on the basis of the effect sizes recommended by Cohen.[22,23] Based on the power analysis with a power of 80% at the 0.05 level based on a medium size (Cohen's f statistics = 0.33) for a comparison between 6 groups, the minimum sample size for each group was 21.

Peg-shape of the maxillary lateral incisor was defined as a condition in which the mesiodistal width at the incisal region is narrower than the width at the cervical part,[24] showing a smaller size with recognizable deviation from the normal condition.[25] The clinicians referred to this definition while grouping the models, and any uncertainty was resolved by the consensus of the researchers.

The inclusion criteria for the study groups were as follows: (1) White patients with unilateral or bilateral missing and peg-shaped maxillary lateral incisors with a fully erupted permanent dentition, (2) no other tooth agenesis or clinically evident shape anomalies of the remaining teeth, (3) no abrasions, restorations of the teeth extending from the first molar to the first molar, (4) no

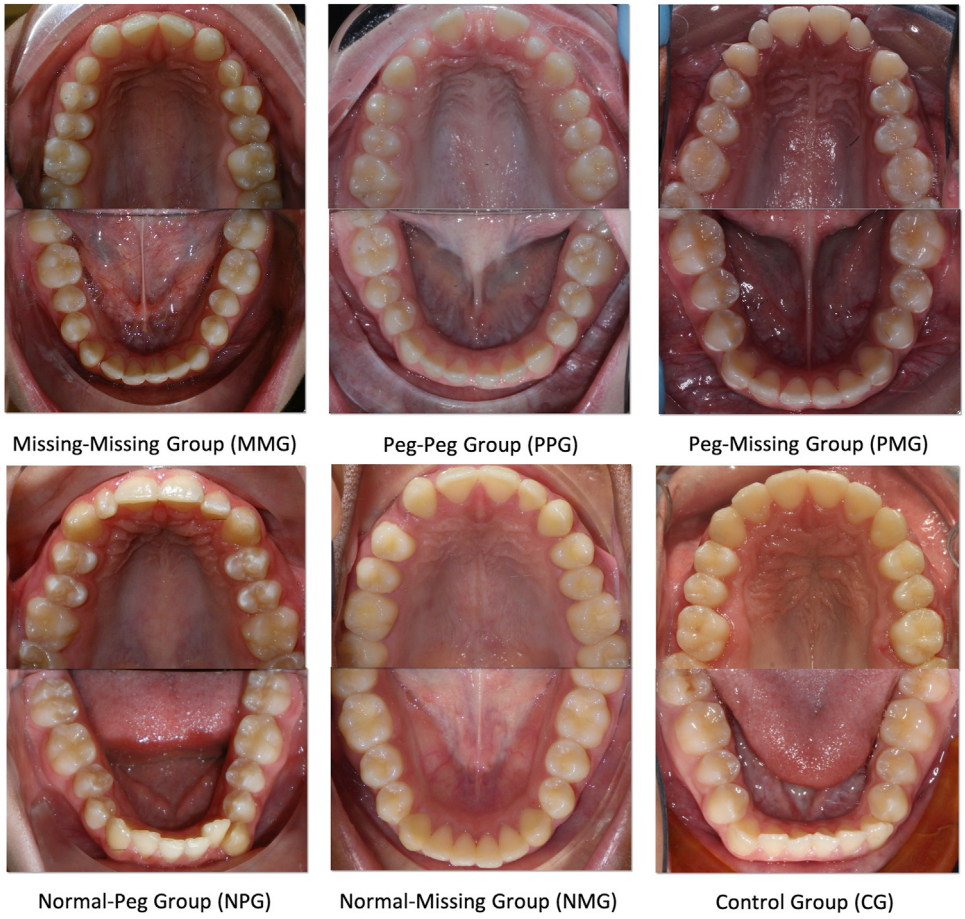


Fig 1. Digital images representing all conditions in the patient cohort.

cleft of the lip and palate, other dental or craniofacial anomalies or syndromes that would affect the tooth size, shape, and number, and (5) no apparent crown height discrepancy because of ectopic eruption, gingival recession/hyperplasia, and wear between the antimere teeth detected during clinical evaluation. The CG consisted of the orthodontic patients from the same clinics. The patients included in the CG consisted of those who had mild to moderate crowding that would not prevent the proper segmentation of the teeth and had normal anterior and overall Bolton ratios. The CG also had to comply with inclusion criteria for the study groups except for the presence of uni- or bilateral missing and peg-shaped maxillary lateral incisors. The sex distribution in the CG was kept parallel to that of the study groups to minimize the effect of the sex on parameters. The demographic characteristics of the groups are presented in Table I.

Dental models of the patients were digitized using an extraoral scanner (R700; 3 Shape, Kopenhagen, Denmark). To define the intra-arch tooth symmetry within the groups, 3D digital dental model records of patients were transformed into stereolithography files. For 3D alignment and deviance inspection, VRMesh Studio Software (VirtualGrid Inc, Bellevue City, Wash) was used. First, the teeth were manually segmented from the mucosa following their gingival margins using this software (Fig 2, *A*). Then the teeth located on one side of the jaw models were fixed in 3D space, and the contralateral teeth on the other side were mirrored regarding the midsagittal plane (Fig 2, *B*). The initial alignment process or raw matching of the anterior teeth was performed by landmark-based superimposition on the mesioincisal point, distoincisal point, and the deepest point of the palatal/lingual gingival curvature (Fig 2, *C*), whereas buccal and lingual cusp tips were used for the posterior teeth. Following this procedure, fine matching was used by the superimposition of the images onto each other using the best-fit method, and the surface deviance was calculated (Fig 2, *D*). An upper limit

Table I. Demographic characteristics of the study sample

Characteristics	*n*	*Female*	*Male*	*Age, y*	*Additional information*
PMG (missing maxillary lateral incisor at one side, the other side is peg-shaped)	22	13	9	15.83 ± 4.92	Missing right lateral incisor (n = 13) Missing left lateral incisor (n = 9)
NMG (normal maxillary lateral incisor at one side, the other side is missing)	22	14	8	15.70 ± 2.64	Missing right lateral incisor (n = 15) Missing left lateral incisor (n = 7)
NPG (normal maxillary lateral incisor at one side, the other side is peg-shaped)	22	15	7	17.41 ± 7.40	Peg right lateral incisor (n = 13) Peg left lateral incisor (n = 9)
PPG (both maxillary lateral incisors are peg-shaped)	24	16	8	16.92 ± 6.13	
MMG (both maxillary lateral incisors are missing)	21	15	6	16.66 ± 5.16	
CG (both maxillary lateral incisors are normal in size and shape)	21	15	6	15.22 ± 3.05	

was opted in order to prevent the data from being affected by the very few outliers and measurement errors that could be encountered due to variations in gingival margins and tooth malpositions which could hinder software processing. When the previous studies[12-16] regarding the mesiodistal dimensions of missing or peg-shaped lateral incisors were scrutinized, all the reported values were below 0.5 mm. Additionally, a symmetry study[20] involving the nonsyndromic patients with impacted canines using reverse engineering methods yielded that all the size deviations were below 0.5 mm. Based on these facts, the maximum deviation calculation was set at 1.00 mm (± 0.5 mm). The maximum deviation calculation was set at 1.00 mm, and the tolerance range used for the present study was ± 0.20 mm. The extent of deviations was presented as absolute values to refrain from introducing any confounding factors as the anomalous lateral incisor was not always at the same quadrant of the maxillary dentition.

In addition to symmetry analysis, the volume of each tooth was also assessed on the same segmented teeth using the same software (Fig 3). The volumes of the teeth in the right and left maxillary and mandibular quadrants were compared. Additional to the conventional comparisons of the groups, quadrant analysis based on the study of Bozkaya et al[14] was also used to understand the volumetric differences, particularly in the unilaterally affected clinical representations. Quadrants were regrouped according to the state of the maxillary lateral incisors as missing (86 quadrants; quadrants with missing lateral incisors from the PMG, NMG, and MMG), peg-shaped (92 quadrants; quadrants comprising peg-shaped lateral incisors from the PMG, NPG, and PPG), or normal-shaped (42 quadrants; quadrants of the CG only, not including the quadrants with so-called normal lateral incisors of the anomalous groups). To eliminate the possible effect of the unilateral presence of missing or peg-shaped lateral on the contralateral quadrant with normal-shaped maxillary lateral incisor, data of those quadrants were not included in the normal-shaped quadrant data. After that, statistics were rerun comparing the tooth sizes in the aforementioned maxillary and corresponding mandibular quadrants.

Statistical analysis

Statistical analyses were performed with JASP statistical software (version 0.11.1; http://www.jasp-stats.org). Data were given as mean and standard deviation for all variables. The normality of the data was assessed by the Shapiro-Wilk test. Differences between 3 or more groups were tested using a one-way analysis of variance (ANOVA) followed by the post-hoc Tukey for parametric variables, whereas the Kruskal-Wallis test followed by post-hoc Dunn was used for the analysis of nonparametric variables. Paired *t* test was used for 2 group comparisons of parametric variables, whereas the Wilcoxon test was used for nonparametric variables. Bonferroni correction was used for multiple comparisons. Chi-square tests were used for the intergroup comparisons of gender distributions. A one-way ANOVA test was used to compare the ages of the groups. Intraobserver reliability of the measurements was assessed by resegmenting and remeasuring the 40 randomly picked digital images using intraclass correlation coefficients. In addition, Dahlberg's formula was used to assess the method error in linear and volumetric measurements.[26]

RESULTS

The intraclass correlation coefficient numbers for the repeated measurements ranged between 0.956 and 0.988 and showed good reliability. The highest method errors were detected for the mandibular molars, and they did not exceed 0.029 mm and 37.76 mm^3.

Demographic data of the groups are presented in Table I. Neither the age nor the sex distribution of the groups showed significant differences, with $P = 0.724$

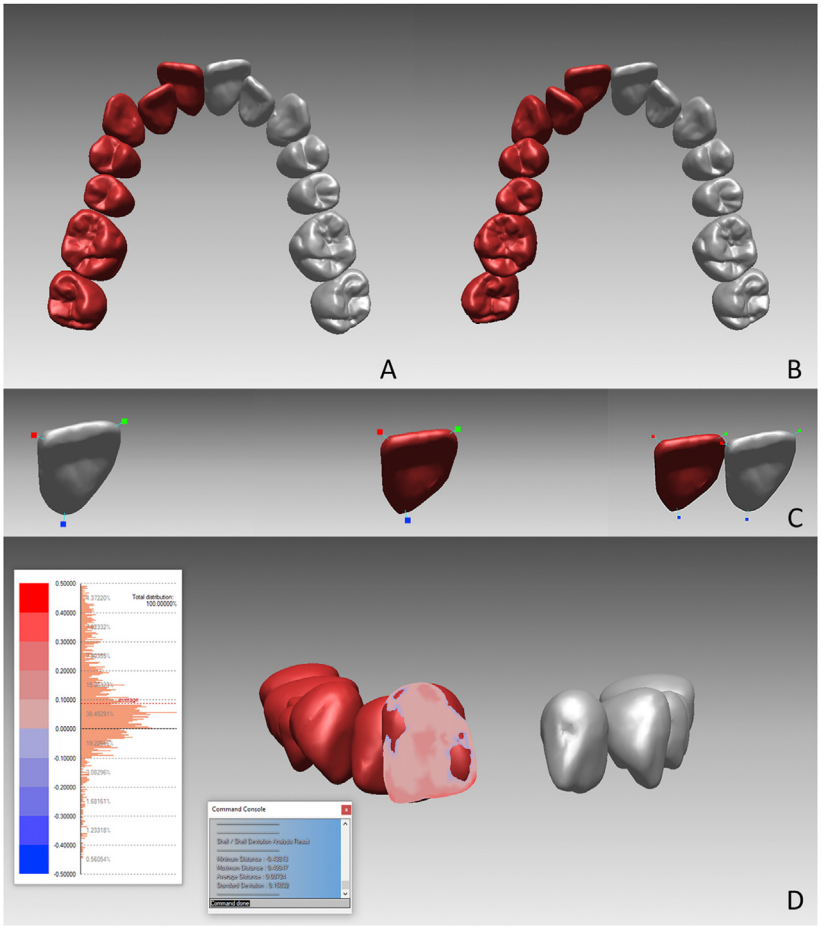


Fig 2. **A,** Segmentation of the teeth at their gingival margin; **B,** Fixation of the teeth on one side of the jaw, with the other quadrant being mirrored relative to the midsagittal plane; **C,** Selection of 3 points and implementation of initial alignment; **D,** Execution of best-fit and result of the superimposition.

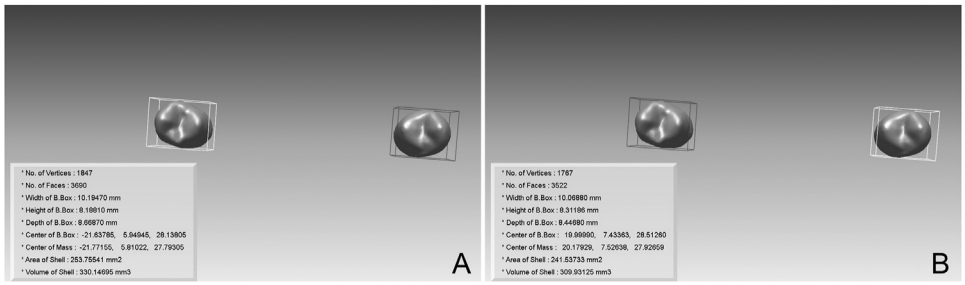


Fig 3. Volumetric assessment of the segmented right **(A)** and left **(B)** first premolar tooth.

and $P = 0.953$, respectively. For the remaining tables, while the statistical calculations that relied on nonparametric methods indicated a symbol and subsequent symbol as a table legend, the absence of a symbol meant parametric tests were used. A comparison of the mean surface deviations in maxillary and mandibular teeth is presented in Table II. The mean deviations among contralateral teeth were less than 0.05 mm in all groups,

Table II. Based on the 3D surface deviation analysis, a comparison of mean deviations within and among the groups (mm)

	PMG		NMG		NPG		PPG		MMG		CG		
Teeth	*Mean ± SD*	*95% CI*	*Mean ± SD*	*95% CI*	*Mean ± SD*	*95% CI*	*Mean ± SD*	*95% CI*	*Mean ± SD*	*95% CI*	*Mean ± SD*	*95% CI*	*P value*
Maxilla													
11-21	0.068 ± 0.035	0.054-0.082	0.052 ± 0.031	0.039-0.065	0.057 ± 0.042	0.039-0.074	0.065 ± 0.041	0.049-0.082	0.059 ± 0.037	0.043-0.075	0.057 ± 0.042	0.039-0.075	0.668[†]
13-23	0.062 ± 0.030	0.049-0.074	0.059 ± 0.037	0.043-0.074	0.051 ± 0.038	0.035-0.066	0.059 ± 0.028	0.048-0.070	0.060 ± 0.044	0.041-0.078	0.043 ± 0.037	0.027-0.058	0.468
14-24	0.051 ± 0.036	0.035-0.066	0.051 ± 0.048	0.031-0.071	0.038 ± 0.026	0.028-0.049	0.054 ± 0.040	0.038-0.070	0.049 ± 0.033	0.035-0.063	0.057 ± 0.039	0.041-0.074	0.735
15-25	0.056 ± 0.037	0.040-0.071	0.052 ± 0.035	0.037-0.066	0.045 ± 0.034	0.031-0.059	0.047 ± 0.030	0.035-0.059	0.052 ± 0.032	0.038-0.065	0.041 ± 0.033	0.027-0.055	0.805
16-26	0.053 ± 0.033	0.039-0.067	0.053 ± 0.029	0.041-0.065	0.048 ± 0.036	0.033-0.063	0.047 ± 0.035	0.033-0.061	0.038 ± 0.028	0.026-0.050	0.061 ± 0.097	0.020-0.103	0.636
Mandible													
31-41	0.060 ± 0.051	0.039-0.082	0.060 ± 0.033	0.046-0.074	0.063 ± 0.049	0.043-0.084	0.064 ± 0.036	0.050-0.079	0.052 ± 0.038	0.035-0.068	0.048 ± 0.029	0.036-0.060	0.770[†]
32-42	0.096 ± 0.200	0.012-0.179	0.061 ± 0.043	0.043-0.079	0.046 ± 0.038	0.030-0.062	0.054 ± 0.042	0.037-0.071	0.057 ± 0.037	0.041-0.073	0.050 ± 0.034	0.035-0.065	0.845[†]
33-43	0.050 ± 0.045	0.032-0.069	0.037 ± 0.028	0.025-0.048	0.055 ± 0.043	0.037-0.073	0.063 ± 0.036	0.049-0.078	0.064 ± 0.037	0.049-0.080	0.056 ± 0.032	0.042-0.070	0.044[†]
34-44	0.059 ± 0.036	0.044-0.074	0.034 ± 0.029	0.021-0.046	0.067 ± 0.038	0.051-0.083	0.105 ± 0.109	0.029-0.181	0.050 ± 0.039	0.033-0.066	0.042 ± 0.025	0.032-0.053	0.004[†]
35-45	0.050 ± 0.036	0.035-0.065	0.058 ± 0.043	0.040-0.076	0.054 ± 0.037	0.038-0.069	0.060 ± 0.041	0.044-0.076	0.054 ± 0.045	0.035-0.073	0.045 ± 0.030	0.032-0.058	0.897[†]
36-46	0.050 ± 0.041	0.033-0.067	0.064 ± 0.036	0.049-0.079	0.046 ± 0.034	0.032-0.061	0.045 ± 0.036	0.030-0.059	0.049 ± 0.028	0.037-0.061	0.049 ± 0.031	0.036-0.063	0.396[†]

SD, standard deviation; *CI*, confidence interval.
[†]Kruskal-Wallis test.

and there were no significant differences among groups in terms of the mean deviations for all tooth pairs ($P > 0.05$).

Table III gives the descriptive statistics and comparisons for maxillary teeth volumes. There were no significant differences in the volumes of antimere teeth except for maxillary canines in PMG and PPG and first molars in NPG ($P < 0.05$). In addition, the one-way ANOVA statistics revealed no significant differences among the groups in terms of each maxillary tooth volume (adjusted $P > 0.003$).

Table IV displays descriptive statistics and comparisons for the volumes of the mandibular teeth. No significant differences were observed between the antimere teeth except for the mandibular first premolars in CG. The one-way ANOVA statistics revealed differences among the groups concerning tooth volumes were significant for mandibular central incisors and right lateral incisors (adjusted $P < 0.003$). Left and right central incisors were significantly larger in CG than MMG, PMG, and PPG, whereas right central incisors were significantly larger in CG than NMG ($P < 0.05$). In addition, in NMG, both right and left central incisors were significantly larger than the corresponding teeth in PPG. Right lateral incisors in CG were again significantly larger than the PPG and PMG ($P < 0.05$). Furthermore, right lateral incisors in NMG were significantly larger than the corresponding teeth in the PPG ($P < 0.05$).

The comparison of the maxillary lateral incisor volumes in quadrants classified on the basis of normal or peg anatomy is presented in Table V. As expected, maxillary lateral incisor volumes in CG were significantly larger than the peg-shaped lateral incisors ($P < 0.05$). On the other hand, although maxillary lateral incisors in contralateral quadrants of a missing or a peg-shaped maxillary lateral incisor displayed normal morphology, the volume of these teeth was significantly smaller than the lateral incisors in CG ($P < 0.05$). Nonetheless, the volumes of these so-called normal maxillary lateral incisors in unilateral groups were significantly ($P < 0.05$) larger than the peg-shaped lateral incisors, except for the nonsignificant difference between the peg-shaped lateral incisors in PMG and normal lateral incisors in NPG. There were no significant differences between the volume of the normal lateral incisors in NMG and NPG ($P > 0.05$).

Because of the volume differences of maxillary lateral incisors between CG quadrants and other normal lateral incisors in unilateral groups, control quadrants for quadrant analysis only comprised the quadrants in CG and were compared with the volume of the teeth in maxillary and mandibular quadrants with missing or peg-shaped lateral incisors (Table VI and VII). Except

Table III. Comparisons of volumes of maxillary teeth with their antimere and comparisons of groups for each maxillary tooth volume (mm^3)

	PMG		*NMG*		*NPG*		*PPG*		*MMG*		*CG*		
Teeth	*Mean ± SD*	*95% CI*	*Mean ± SD*	*95% CI*	*Mean ± SD*	*95% CI*	*Mean ± SD*	*95% CI*	*Mean ± SD*	*95% CI*	*Mean ± SD*	*95% CI*	*P value**
Central incisors													
11	269.162 ± 55.529	245.958-292.366	284.287 ± 69.980	255.045-313.530	285.128 ± 52.508	263.187-307.070	273.317 ± 62.474	248.322-298.312	271.528 ± 54.139	248.372-294.684	306.781 ± 36.377	291.223-322.340	0.261
21	273.045 ± 55.657	249.787-296.303	285.436 ± 64.564	258.456-312.415	276.225 ± 57.637	252.140-300.311	267.081 ± 52.801	245.956-288.206	270.597 ± 52.688	248.062-293.132	307.484 ± 39.211	290.713-324.255	0.164
P value	0.565		0.792		0.090		0.348		0.848		0.895		–
Canines													
13	227.208 ± 53.863	204.700-249.717	242.267 ± 72.296	212.056-272.477	239.567 ± 55.347	216.438-262.695	232.997 ± 58.003	209.791-256.203	245.133 ± 54.186	221.958-268.309	269.755 ± 36.939	253.956-285.554	0.204
23	244.348 ± 54.764	221.463-267.232	253.228 ± 66.897	225.274-281.183	236.187 ± 53.074	214.009-258.366	247.806 ± 62.406	222.838-272.773	240.777 ± 45.341	221.385-260.170	268.957 ± 36.475	253.357-284.558	0.444
P value	0.002		0.141		0.520		0.045		0.437		0.866		–
First premolars													
14	261.474 ± 64.153	234.666-288.282	261.987 ± 58.810	237.412-286.562	262.838 ± 62.555	236.698-288.977	255.957 ± 62.914	230.244-281.669	265.560 ± 52.339	243.174-287.945	285.965 ± 34.772	271.093-300.837	0.612
24	259.269 ± 62.848	233.006-285.532	258.427 ± 53.421	236.104-280.750	263.198 ± 63.988	236.459-289.937	258.288 ± 57.412	235.319-281.258	268.549 ± 46.660	248.592-288.506	280.920 ± 34.650	266.100-295.740	0.726
P value	0.703		0.593		0.921		0.695		0.610		0.259		–
Second premolars													
15	236.142 ± 57.614	212.066-260.217	239.539 ± 54.510	216.760-262.317	234.457 ± 54.735	211.585-257.329	237.349 ± 56.251	214.844-259.854	241.795 ± 46.034	222.105-261.484	256.820 ± 30.171	243.916-269.724	0.742
25	240.148 ± 56.125	216.695-263.601	245.302 ± 51.871	223.627-266.978	236.522 ± 57.495	212.496-260.547	236.541 ± 52.931	215.364-257.718	246.991 ± 45.359	227.591-266.392	261.278 ± 27.088	249.692-272.864	0.583
P value	0.649		0.213		0.685		0.814		0.282		0.322		–
First molars													
16	494.772 ± 97.302	454.112-535.432	498.759 ± 100.548	456.742-540.775	487.227 ± 115.247	439.068-535.385	529.059 ± 94.917	491.084-567.033	510.835 ± 77.636	477.629-544.041	553.241 ± 68.508	523.939-582.542	0.191
26	494.861 ± 96.615	454.489-535.234	508.906 ± 92.521	470.244-547.568	508.038 ± 113.597	460.568-555.507	524.723 ± 97.211	485.831-563.615	516.465 ± 69.229	486.856-546.075	551.317 ± 59.678	525.793-576.842	0.432
P value	0.990		0.849†		0.047		0.472		0.539†		0.783		–

Note. Significance at $P < 0.05$.
SD, standard deviation; *CI*, confidence interval.
†Wilcoxon test; *Adjusted $P < 0.003$.

Table IV. Comparisons of volumes of mandibular teeth with their antimere and comparisons of groups for each mandibular tooth volume (mm^3)

	PMG		*NMG*		*NPG*		*PPG*		*MMG*		*CG*			
Teeth	*Mean ± SD*	*95% CI*	*Mean ± SD*	*95% CI*	*Mean ± SD*	*95% CI*	*Mean ± SD*	*95% CI*	*Mean ± SD*	*95% CI*	*Mean ± SD*	*95% CI*	*P value*[*]	*Pairwise comparisons displaying statistical significance*
Central incisors														
31	97.521 ± 25.955	86.675-108.366	117.152 ± 25.291	106.583-127.720	106.956 ± 28.709	94.959-118.952	93.493 ± 27.247	82.592-104.394	101.259 ± 21.043	92.259-110.259	124.662 ± 17.450	117.198-132.125	<0.001	CG-MMG: 0.031 CG-PMG: 0.006 CG-PPG: <0.001 NMG-PPG: 0.021
41	99.350 ± 20.893	90.619-108.080	116.170 ± 24.284	106.022-126.317	105.307 ± 30.294	92.648-117.966	94.207 ± 25.265	84.099-104.315	104.815 ± 23.244	94.874-114.757	127.126 ± 18.293	119.302-134.950	<0.001	CG-MMG: 0.037 CG-NPG: 0.041 CG-PMG: 0.003 CG-PPG: <0.001 NMG-PPG: 0.029
P value	0.663		0.744		0.567		0.843		0.227		0.341		–	–
Lateral incisors														
32	119.076 ± 25.764	108.310-129.842	130.811 ± 34.113	116.556-145.066	121.943 ± 36.227	106.804-137.081	112.210 ± 28.010	101.004-123.417	119.827 ± 23.453	109.796-129.858	144.212 ± 19.884	135.707-152.716	0.006	–
42	118.968 ± 18.409	111.275-126.660	134.057 ± 28.810	122.018-146.096	122.498 ± 35.137	107.815-137.181	108.454 ± 26.819	97.724-119.184	123.815 ± 27.217	112.174-135.455	144.759 ± 19.567	136.390-153.128	<0.001	CG-PMG: 0.023 CG-PPG: <0.001 NMG-PPG: 0.018
P value	0.979		0.357		0.766		0.329		0.199		0.900		–	–
Canines														
33	183.005 ± 40.136	166.233-199.777	192.529 ± 45.869	173.362-211.697	180.742 ± 44.452	162.167-199.317	179.476 ± 47.711	160.387-198.564	180.990 ± 35.862	165.651-196.328	219.426 ± 40.458	202.122-236.730	0.020	–
43	187.972 ± 45.612	168.912-207.032	191.123 ± 44.511	172.523-209.723	187.700 ± 39.562	171.169-204.232	180.696 ± 47.381	161.740-199.653	179.304 ± 30.211	166.382-192.225	216.135 ± 36.120	200.687-231.584	0.054	–
P value	0.329		0.290[†]		0.222		0.790		0.725		0.508		–	–
First premolars														
34	239.323 ± 57.031	215.491-263.154	217.665 ± 43.929	199.308-236.022	218.481 ± 50.738	197.278-239.683	221.284 ± 56.027	198.868-243.699	207.643 ± 32.444	193.767-221.520	231.881 ± 34.306	217.208-246.554	0.285	–
44	241.037 ± 56.261	217.527-264.547	220.988 ± 40.228	204.177-237.798	217.756 ± 50.515	196.647-238.865	218.272 ± 63.869	192.719-143.824	208.883 ± 38.619	192.365-225.401	240.589 ± 36.085	225.155-256.023	0.177	–
P value	0.708		0.156[†]		0.857		0.453		0.772		0.036		–	–
Second premolars														
35	235.861 ± 51.554	214.318-257.404	234.173 ± 45.838	215.018-253.327	229.486 ± 48.007	209.425-249.547	211.301 ± 59.605	187.454-235.147	223.693 ± 45.113	204.398-242.988	246.952 ± 27.720	235.095-258.808	0.213	–
45	240.412 ± 54.731	217.541-263.282	231.398 ± 45.813	212.254-250.542	221.845 ± 49.412	201.197-242.492	218.648 ± 52.184	197.770-239.526	222.348 ± 42.943	203.981-240.714	251.748 ± 39.884	234.689-268.806	0.173	–

Table IV. Continued

Teeth	PMG		NMG		NPG		PPG		MMG		CG			
	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI	P value*	Pairwise comparisons displaying statistical significance
P value	0.367		0.562		0.117		0.182		0.750		0.387		–	–
First molars														
36	463.061 ± 92.176	424.543-501.579	482.934 ± 91.239	444.807-521.060	466.868 ± 82.138	432.545-501.191	454.430 ± 94.814	416.496-492.363	481.718 ± 62.801	454.857-508.579	520.282 ± 62.341	493.619-546.946	0.130	–
46	459.730 ± 107.623	414.757-504.703	464.965 ± 90.517	427.141-502.790	472.153 ± 95.010	432.451-511.856	446.087 ± 104.026	404.468-487.707	479.863 ± 71.187	449.416-510.311	507.182 ± 67.936	478.126-536.239	0.339	–
P value	0.801		0.161		0.899†		0.197†		0.825		0.135		–	–

Note. Significance at $P < 0.05$.
SD, standard deviation; *CI*, confidence interval.
†Wilcoxon test; *Adjusted $P < 0.003$.

for the central incisors, the comparisons revealed no significant differences among groups for all the maxillary tooth groups investigated (adjusted $P < 0.016$). Central incisor volumes in CG were higher than the volumes of central incisors in the quadrants with missing or peg-shaped lateral incisors ($P < 0.05$). In contrast, mandibular central incisors, lateral incisors, and canines had significantly smaller volumes in quadrants corresponding to either missing or peg-shaped maxillary lateral incisors with respect to control quadrants (Table VII). In addition, the volume of first molars in quadrants corresponding to a peg-shaped lateral incisor was significantly smaller than in the control quadrants.

DISCUSSION

Following the 2012 meeting of the Angle Society of Europe, it was reported that the evidence regarding the treatment decision-making process was judged to be relatively weak for agenesis of lateral incisors.[27] Although, as orthodontists, we start with esthetics in mind, we cannot overlook the functional aspects of dentition and ideal occlusion. Any disharmony within or between the dental arches has a negative impact on the smile esthetics, the occlusal relationship and function. This situation may hinder the clinician's ability to achieve some occlusal parameters during the finishing stage of orthodontic treatment. Therefore, the best interest of the patient demands morphologic deviations be investigated thoroughly in the presence of unilateral or bilateral missing or peg-shaped maxillary lateral incisors.

The sex distribution of the study groups showed a predilection for females similar to previous studies concerning agenesis of lateral incisors and their anomalous conditions.[2,15,28-30] Thus, the gender distribution of the CG was matched accordingly. Dental symmetry in groups with missing or peg-shaped lateral incisors had been evaluated in literature via analyzing mesiodistal crown widths.[12-16] However, the tooth shape is not just across from contact to contact, as done so far. Robustness in portraying the symmetry and the precise assessment of the deviations is impossible with traditional methods like linear measurements because of variation in tooth shape and form. The current study evaluated tooth volumes and tooth crown morphologic symmetries using deviation analysis to control the 3D nature and complexity of tooth surfaces. Based on the results, our first null hypothesis was accepted. There were no significant differences in crown morphology of antimere teeth in patients with unilateral or bilateral

Table V. Comparison of maxillary lateral teeth volumes (mm^3) among quadrants (Q)

	U2	
Groups	*Mean ± SD*	*95% CI*
1. Control Q (n = 42)	197.782 ± 33.564	187.631-207.933
2. Normal Q from NMG (n = 22)	155.165 ± 36.131	140.067-170.263
3. Normal Q from NPG (n = 22)	138.344 ± 43.213	120.287-156.402
4. Peg Q (n = 48)	103.267 ± 38.123	92.482-114.052
5. Peg Q from PMG (n = 22)	106.823 ± 49.341	86.205-127.442
6. Peg Q from NPG (n = 22)	101.540 ± 33.467	87.556-115.525
P value*	<0.001	
Pairwise comparison displaying statistical significance	1-2: <0.001; 1-3: <0.001; 1-4: <0.001; 1-5: <0.001; 1-6: <0.001; 2-4: <0.001; 2-5: <0.001; 2-6: <0.001; 3-4: 0.007; 3-6: 0.022	

SD, standard deviation; *CI*, confidence interval.
*Adjusted P <0.003.

missing or peg-shaped maxillary lateral incisors regarding maxillary and mandibular teeth. Deviations were observed below the designated limits of ± 0.5 mm in all groups (maximum mean deviation, 0.074 mm). The second null hypothesis was partially accepted because there were no differences in the maxillary tooth volumes between CG and the other groups investigated. On the other hand, the volumes of the mandibular central and lateral incisors in the CGs were greater than in the groups with missing or peg-shaped lateral incisors in general. The last hypothesis was also partially accepted. The volumes of maxillary and mandibular teeth in quadrants with missing or peg-shaped lateral incisors are not different from that of the homologous teeth in the quadrants of CG, except for the maxillary central incisors as well as mandibular incisors, canines, and first molars. The latter teeth were smaller in the peg-shaped or missing lateral incisor quadrants.

Because the dimensional stability of irreversible hydrocolloid materials showed a shrinkage of 0.34-0.38 mm and the accuracy of desktop scanners is reported to be 0.02-0.04 mm, the tolerance value was set at 0.40 mm for the current study. The percentage of surface-to-surface matching of maxillary teeth of anomaly groups and CG demonstrated similarities with no statistically significant differences between the groups in terms of matching. The mean deviations in the anomaly and CGs ranged between 0.00006 and 0.074 mm (Table II). However, there were no statistically significant intergroup differences. Therefore, the results of this study suggest that regardless of the condition of maxillary lateral incisors (unilateral or bilateral as well as missing or peg-shaped), morphologic and volumetric involvements are across the board. Despite the lack of a study with a similar methodology, the absence of an apparent mesiodistal width discrepancy between the right and left sides in a previous study involving oligodontia cases support our findings.[31] On the other hand, a difference was expected in the unilaterally affected groups, which would help explain the clinical problems faced with these patients, such as midline deviations, subdivision molar relationships, or lack of intercuspation. Despite our presumptions, there was symmetry in unilaterally affected patients as well. This result pointed out that even if the condition of maxillary lateral incisors was disparate in adjacent quadrants, the dentition was affected as a whole, and there was a harmony in symmetry of the contralateral teeth. This may have implied the involvement of genetic background for the occurrence of peg or missing maxillary lateral incisors and that it may not solely be due to a local developmental anomaly.

The current study detected no significant intragroup differences between the volumes of the antimere teeth in mandibular dentition and the majority of the maxillary dentition (Table III and IV). In the maxilla, intragroup differences were observed for the canines in PMG and PPG and the molars in NPG. These volumetric mismatches can result from differential buccolingual thicknesses on either side of the jaw because of the asymmetric occurrence and structure of the cusp of carabelli,[32] and differential wear of the occlusion.[33] In the mandibular dentition, right and left side volumetric asymmetry was only present in the first premolars in the CG. We believe that this was an incidental finding of the current study, which can result from epigenetic or environmental factors. In addition, it has been shown that genetic variants in transcription factors can cause tooth-size alteration in seemingly normal dentitions.[8] Also, unilateral occlusal wear can be another possible explanation. The majority of the intragroup comparisons showing nonsignificant outcomes are in agreement with

Table VI. Comparisons of volumes of maxillary teeth (mm^3) among quadrants (Q) based on the condition of maxillary lateral incisor

Groups	U6		U5		U4		U3		U1	
	Mean ± SD	*95% CI*	*Mean ± SD*	*95% CI*	*Mean ± SD*	*95% CI*	*Mean ± SD*	*95% CI*	*Mean ± SD*	*95% CI*
Control Q (n = 42)	552.279 ± 63.464	533.085-571.473	259.049 ± 28.409	250.457-267.641	283.442 ± 34.380	273.045-293.840	269.356 ± 36.259	258.390-280.322	307.133 ± 37.358	295.834-318.431
Miss Q (n = 86)	506.993 ± 86.112	488.793-525.193	241.520 ± 52.288	230.469-252.571	264.762 ± 56.047	252.916-276.607	242.795 ± 55.612	231.042-254.549	273.829 ± 58.615	261.441-286.218
Peg Q (n = 92)	511.766 ± 103.182	490.681-532.851	237.285 ± 52.969	226.462-248.109	257.761 ± 59.414	245.620-269.902	238.135 ± 57.317	226.423-249.848	274.376 ± 56.034	262.926-285.826
P value*	0.069		0.067†		0.165		0.034		0.002†	
Pairwise comparisons for groups									Control Q-Miss Q: 0.01 Control Q-Peg Q: 0.013	

SD, standard deviation; *CI*, confidence interval.
†Kruskal-Wallis test; *Adjusted $P < 0.016$.

the results of the symmetry analysis (Table II). Although the expectation favors the total concordance between the symmetry and volume analysis, the very few differences observed related to the intragroup comparison outcomes between symmetry and volumetric evaluations can be attributed to the variations in methodologies: volumetric measurements were based on mean averages, whereas symmetry analysis was based on mean discrepancies. Similarly, the intergroup comparisons in terms of individual tooth volumes showed no tooth volume discrepancy for maxillary teeth. On the contrary, there were significant volumetric reductions in several study groups regarding mandibular incisors compared with the CG. These findings are partially in agreement with the results of previous studies in which the nearby teeth to the anomalous lateral incisor showed the greatest amount of width discrepancies that decreased gradually toward the posterior portion of the dentition.[12,14] Former studies detected the most pronounced differences in maxillary central incisors followed by maxillary canines[14] or mandibular incisors[12] compared with the CG. Similarly, our study showed that the volumetric decreases of mandibular anterior teeth compared with the CG faded away in premolars and molars in the mandibular arch. In contrast, Coskuner et al[16] detected a significant difference in the posterior part of the dentition in their study group comprising unilateral maxillary lateral incisor agenesis. The pendulum swings between these 2 types of views, which might suggest that Wright et al's[13] perspective that no specific tooth group could be held accountable for this discrepancy is valid. The researchers documented significantly diminished overall tooth sizes in patients with unilateral and bilateral missing lateral incisors without being able to identify any specific tooth group. This finding of theirs can be interpreted as partially being in line with the results of this study because not all of the tooth groups showed significantly smaller volumes. Above and beyond all these discussions, the results of this study cannot be entirely compared with the previous studies in the literature. The 3D technique employed in our manuscript and the 2D measurement of mesiodistal tooth sizes used in previous studies are completely different methodologies. The current research is unique in its methodology in that it analyzes volumetric data with very detailed subgroups and uses symmetry analysis. Therefore, they cannot be compared directly but can provide different insights into the same clinical problem. In that sense, they can be complementary to each other. When our outcomes of symmetry and volumetric evaluations are interpreted together, it would be fair to say that the decreases in volumes were similar among antimere teeth in the study groups

Table VII. Comparisons of volumes of mandibular teeth (mm^3) among quadrants (Q) based on the condition of maxillary lateral incisor

Groups	L6		L5		L4		L3		L2		L1	
	Mean ± SD	*95% CI*	*Mean ± SD*	*95% CI*	*Mean ± SD*	*95% CI*	*Mean ± SD*	*95% CI*	*Mean ± SD*	*95% CI*	*Mean ± SD*	*95% CI*
Control Q (n = 42)	513.732 ± 64.739	494.153-533.311	249.350 ± 34.010	239.064-259.635	236.235 ± 35.053	225.634-246.836	217.781 ± 37.916	206.313-229.248	144.485 ± 19.486	138.592-150.379	125.894 ± 17.701	120.541-131.247
Miss Q (n = 86)	475.448 ± 80.757	458.380-492.516	229.720 ± 45.862	220.027-239.413	219.630 ± 44.863	210.148-229.112	184.843 ± 38.759	176.651-193.035	123.863 ± 26.074	118.352-129.373	105.446 ± 23.530	100.473-110.419
Peg Q (n = 92)	456.460 ± 96.748	436.690-476.230	222.294 ± 54.035	211.252-233.336	223.893 ± 56.167	212.415-235.370	181.331 ± 43.123	172.519-190.143	115.577 ± 29.477	109.554-121.600	98.173 ± 26.937	92.668-103.677
P value*	0.014		0.016†		0.174†		<0.001†		<0.001†		0.001†	
Pairwise comparisons for the groups	Control Q-Peg Q: 0.004						Control Q-Miss Q: <0.001 Control Q-Peg Q: <0.001		Control Q-Miss Q: <0.001 Control Q-Peg Q: <0.001		Control Q-Miss Q: <0.001 Control Q-Peg Q: <0.001	

Note. Significance at $P < 0.05$.
SD, standard deviation; *CI*, confidence interval.
†Kruskal-Wallis test; *Adjusted $P < 0.016$.

such that though no significant differences in symmetry were detected, there was an overall diminution of volume.

Intriguingly, the comparison among the volumes of normal lateral incisors in anomaly groups with that of the lateral incisors in the CG revealed that the so-called normal lateral incisors in anomaly groups (NMG and NPG) were significantly smaller than lateral incisors in patients without any agenesis or shape anomalies (Table V). Our finding implies that even if only one of the lateral incisors is anomalous, the antimere lateral incisor is also affected by this developmental anomaly. Supporting this data, Hua et al[2] reported hypodontia of the contralateral lateral incisors in 55.5% of patients with unilateral peg-shaped lateral incisors. Based on these findings, we decided to use the data of the CG (only the patients displaying normal-shaped maxillary lateral incisors in both quadrants) in the quadrant analysis for the control quadrant; this allowed for a further reduction in potential selection biases in the establishment of the groups. Our methodology differs from Bozkaya et al[14] in this particular aspect, who used quadrants incorporating normal-shaped lateral incisors in the unilateral groups to serve as a CG for their quadrant analysis. With the current methodology, the homogeneity in the CG was secured. The observed discrepancies in the results of quadrant analysis in these studies could partially be due to this very same reason. In addition, Coskuner et al[16] also opted to use only the CG data in their quadrant analysis, similar to our methodology, and omitted the seemingly normal side of the unilaterally affected maxillary arch.

When the results of quadrant analysis were evaluated, all maxillary and mandibular teeth were smaller in the quadrants with peg-shaped or missing lateral incisors. However, only a fraction of the comparisons showed statistically significant outcomes. In the maxillary dental arch, only the volumes of central incisors in the quadrants with missing and peg-shaped lateral incisors were significantly smaller than the central incisors in the CG (Table VI). On the other hand, the decrease in all mandibular anterior teeth was significant in peg-shaped and missing lateral incisor groups compared with their normal correspondents. For the posterior dentition, the reduction was significant for the first molars alone and only among the peg-shaped and control groups (Table VII). By and large, no significant differences were observed between the quadrants with peg-shaped and missing lateral incisors. The comparison of volumetric data in the present study yielded partially similar outcomes to those reported by Bozkaya et al[14] for 2D measurements. In that study, almost all comparisons displayed statistical significance with the CG. Their

findings were consistent with Coskuner et al,[16] who detected a diminished mesiodistal width in almost all the tooth groups investigated compared with the CG when they ran their quadrant analysis. The only exceptions were the maxillary and mandibular first molars and mandibular second premolars of the nonmissing side, yielding similar outcomes with the CG. Furthermore, Bozkaya et al[14] detected no differences between quadrants with peg-shaped and missing lateral incisors in conformity with our findings. When the results of this study and ours are evaluated collectively, it is evident that the presence of a peg-shaped lateral incisor and its agenesis acted similarly on the dimensions of the remaining teeth in the arch.

There were discrepancies between the results of the 2 comparison methods used in this study (ie, the traditional method based on tooth numbering vs the quadrant analysis). The interaction of 2 reasonable mechanisms can be held accountable for this dissimilarity. First of all, when the evaluation is solely based on the tooth numbering method, the atypical lateral incisor's location is purely random. Thus, the statistical analysis is affected by the ambiguity of the locus, particularly in the unilaterally affected groups in which the chance of an anomalous lateral incisor being present on the right or left side is equal. Thus, quadrant analysis proves to be the most appropriate method to assess the extent of the variations observed in the presence of hypodontia or agenesis. Secondly, although we perceive the other side as normal in unilateral groups simply because they lack the atypical condition, they are also affected by the anomaly as depicted by the nonsignificant outcomes of the symmetry analysis. This finding provided evidence that even the seemingly normal quadrant also exhibited a similar anomalous condition but to a lesser extent, with the resultant symmetry evaluation failing to prove any significant deviations.

Although it is not easy to identify a clinical cutoff value, some clinical inferences can still be drawn from our findings. Considering the key parameters of the American Board of Orthodontics grading system[34] such as alignment, marginal ridge discrepancy, occlusal contacts, and overjet being sensitive to threshold values of 0.5-1.0 mm in this grading system, the volumetric discrepancies detected in the current study amounting up to one-third to one-fifth of the total crown volumes may lead the clinicians to make a more informed decision during treatment planning. Although the exact mechanism remains uncertain, most of the impediments to ideal finishing seem to involve the esthetic zone. Current results might suggest implementing restorative procedures on the antimere lateral incisors with unilateral peg-shaped or missing lateral incisors to obtain ideal finishing. In the instance of an implant site preparation, it might be worthwhile to treatment plan the case bearing in mind that a narrow-diameter implant might be a better choice eventually because of the overall decreased tooth dimensions and achieving the ideal inter-and intra-arch relationships. This approach of using platform-switched implants is also supported by the most recent consensus in implant dentistry in dealing with the decreased buccolingual bone dimensions we face in patients with tooth agenesis.[35-37] Thus, informing the patients and their parents of the consequences related to orthodontic treatment of peg-shaped or missing maxillary lateral incisors would help manage the expectations and prevent further restorative interventions from being taken as an unanticipated outcome of the treatment. Finally, the diminished size of mandibular first molars in patients with peg-shaped lateral incisors might also be responsible for the difficulties (>1 mm)[38] in attaining the appropriate molar classification as the size of the maxillary molars seems to lie within the dimensional parameters of the control quadrants.

CONCLUSIONS

1. The morphologic symmetry of antimere teeth was not affected by the presence of uni- or bilateral missing or peg-shaped maxillary lateral incisors.
2. Only mandibular incisor volumes were affected by missing or peg-shaped lateral incisors based on the traditional comparison, which ommitted the quadrants.
3. Per quadrant analysis, mandibular incisors, canines, first molars, and maxillary central incisors were affected by the missing or peg-shaped maxillary lateral incisors in terms of tooth volumes.
4. The tooth volume reducing the effect of peg or missing maxillary lateral incisors on the quadrants was similar.

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