ORIGINAL ARTICLE

Three-dimensional evaluations of the digital casts of morphologic maxillary teeth symmetry in patients with unilateral palatally displaced canines

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Introduction: The goal of this study was to compare the size and morphologic symmetry of the maxillary teeth in subjects with and without unilateral palatally displaced canines (PDCs). **Methods:** Plaster casts of 38 subjects (mean age 14.75 ± 0.95 y) with unilateral PDCs were selected (study group [SG]) and compared with casts from an age- and sex-matched control group (CG). Then dental casts of both groups were scanned into 3-dimensional (3D) models. Tooth sizes (mesiodistal [MD] and buccolingual [BL] widths and volumes) for SG and CG were measured. Afterward, 3D deviation analysis was carried out with the use of Geomagic Control X software. All of the data were normally distributed according to parametric tests. **Results:** All of the maxillary tooth diameters were smaller in SG than in CG. Statistically significant differences ($P \leq 0.001$) were obtained when comparing the widths and volumes of the PDC quadrant and the unaffected quadrant of the same patient. Morphologic tooth symmetry by surface-to-surface matching for SG (PDC side vs non-PDC side) and CG (right vs left quadrant) demonstrated significant ($P \leq 0.001$) but small differences, except for the lateral upper incisors (71.27%). **Conclusions:** Unlike control subjects, PDC patients showed high mismatching of lateral incisor crowns of ~30%. (Am J Orthod Dentofacial Orthop 2019;155:339-46)

Palatally displaced canines (PDCs) are a problem encountered relatively frequently in clinical orthodontics, with a prevalence of 1%-3% and a female predilection,[1,2] occurring 2-3 times more often in female subjects, and being monolateral in approximately two-thirds of cases.[1,3]

Different etiologic factors and theories have been proposed, namely, the guidance theory[4,5] and the genetic theory.[2,6,7] Notwithstanding the ongoing debate in the etiology, the main challenge is the alignment of impacted canines in the dental arch, a process often resulting in extensive orthodontic treatment and possibly further complications. Furthermore, in many cases, the treatment is complicated by delayed diagnosis in late adolescence or adulthood.

PDCs are frequently found in dentition exhibiting various dental anomalies.[2,3,8,9] It has been well documented that peg-shaped lateral incisors and missing teeth are related to PDCs. In addition, PDCs are more frequent in patients with reduced tooth sizes,[10-13] as demonstrated by many studies that have dealt with measuring mesiodistal (MD) and buccolingual (BL) widths[2,3,7,9-12] of the maxillary teeth and evaluating macroscopic tooth morphology. However, the use of traditional morphometrics, such as linear measurement, give limited information, which are pertinent mainly to tooth size and do not describe variation in tooth shape and form visually.[14,15]

Recently, 3-dimensional (3D) images of dental casts, with the aid of surface laser scanners, are available. These digital models are as reliable as traditional plaster models and are highly accurate and reproducible.[16,17] Furthermore, the digital files obtained can be further analyzed with reverse engineering technology, ie, each virtual tooth can be mirrored at arbitrary points. This procedure, also called 3D surface-to-surface matching, matches the morphologic differences between

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homologous teeth in 2 semiarches, as well as obtains precise measurements of tooth sizes (volume and widths) from virtual dental casts. The information captured by surface-to-surface matching, providing full information about tooth shape, form, and surface topography, is impossible to obtain with the use of traditional methods.[14,15]

Even though previous studies have described a reduction of tooth size and dimensions with linear measurements in patients with PDC, there has been no study that evaluated maxillary teeth in 3 dimensions by means of reverse engineering technology and 3D superimpositions. We hypothesized that maxillary tooth crown symmetry in the 2 quadrants in patients with unilateral PDCs is different from that of subjects without any tooth anomalies. Therefore, the aims of the present study were to investigate not only tooth volumes and widths on digital casts but also tooth crown morphologic symmetries, through segmentation, superimposition, and 3D deviation analysis in patients with unilateral PDCs by comparing findings from PDC side and non-PDC side of the same subject and with a control sample.

MATERIAL AND METHODS

This study followed the Helsinki Declaration on medical protocols and ethics, and the Regional Ethical Review Board of the Umberto 1 General Hospital of Rome approved the study. The sample size from a power analysis indicated that data from 31 participants would yield a confidence level of 95% and a Beta error level of 20% and would therefore be adequate to determine statistically significant differences.

Accordingly, consecutive pretreatment plaster casts of 38 subjects (16 male, 22 female, ages 13.5-16.8 years, mean age 14.7 $\pm$ 0.95 years) with unilateral PDCs were collected retrospectively from a large number of patients over a 34-month period (January 10, 2014, to October 20, 2016). Casts were selected from the Department of Orthodontics, University of Roma "La Sapienza," Italy. The diagnosis was made by an experienced orthodontist (E.B.) on the basis of clinical examinations and standardized radiography, and confirmed visually during surgery.

The inclusion criteria for the study group (SG) were: (1) unilateral PCD; (2) a fully erupted permanent dentition except for the third molars in both jaws; (3) no transposition, no missing maxillary or peg-shaped lateral incisors,[15,18] and no tooth agenesis; (4) no restorations and no abrasions; and (5) no clinically visible discrepancies on the gingival margins of collateral teeth. The exclusion criteria for the SG were: (1) buccal or midalveolar impacted canines; (2) previous orthodontic treatment; (3) dental trauma, anterior maxillary dental surgery history, or clinical signs; (4) presence of a cleft lip and palate or other dental or craniofacial anomaly or syndromes; and (5) multireagent chemotherapy.

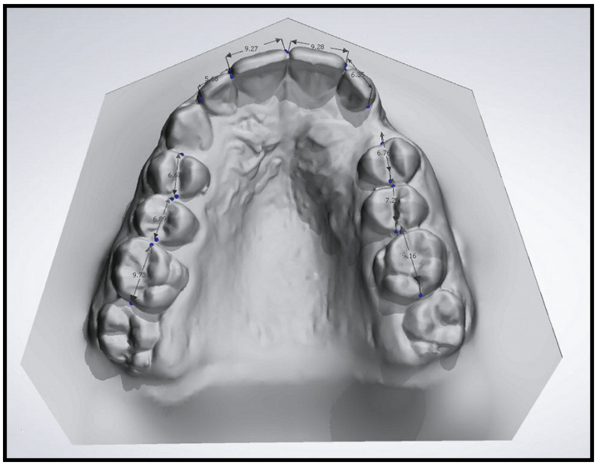

Fig 1. The mesiodistal and buccolingual widths were measured with the use of 3Shape Orthoanalyzer software.

The control group (CG) was randomly selected from orthodontic patients at the same university clinic, and included plaster casts of 40 subjects (20 male and 20 female) of the same ages as the SG in whom the maxillary canines had erupted normally, as diagnosed from their pretreatment plaster casts. The same inclusion and exclusion criteria except for the unilateral maxillary canine impaction were applied to the control group (CG).

All of the investigated subjects (SG and CG) were Caucasian. All records were deidentified before assessment to fulfill the ethics requirements. The maxillary study plaster casts of all subjects were scanned with the use of the D500 3D scanner D500 (3Shape, Copenhagen, Denmark; full arch scan time 90 seconds, resolution 2 cameras of 1.3 megapixels, red laser) featuring an accuracy of 10 μm according to the manufacturer. Each dental cast was scanned from 10 or more views and then combined and rendered into a 3D stereolithographic model by using specific software (Scanit Orthodontics 2015, version 5.6.1.6; 3Shape).

The mesiodistal and buccolingual widths were measured in the upper arches, from the right first molar to first left molar (except the canines). All of the teeth were measured from the direct occlusal view (Fig 1). Measurements were carried out on a 19- inch flat thin-film transistor screen set to an average resolution of 1280 $\times$ 1024 pixels, with the use of a mouse-controlled cursor which was checked for accuracy before the study[19] and analysis tools from the manufacturer

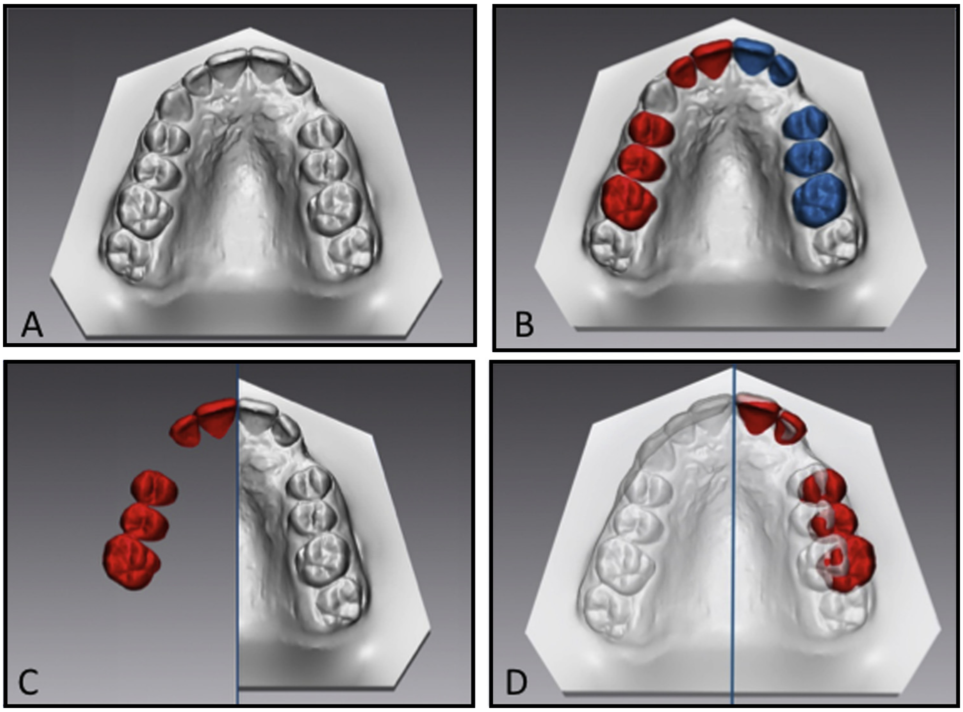

Fig 2. A, B, The scanned stereolithographic maxillary model was processed with the use of 3D engineering software (Geomagic Control X, version 2017.0.0). The anterior and posterior crowns, except for the second molars and canines, were segmented at the gingival margin; **C, D,** The crowns of the segmented right-side teeth were mirrored relative to a plane through the median palatine suture to obtain the specular crown models.

(Orthoanalyzer, version 1.6.1.6; 3Shape) to the nearest 0.01 mm (Fig 1).

The segmentation, superimposition, and 3D deviation analyses were carried out as previously described[15] on digital cast models. The digital models of the scanned plaster models were exported to a specific software (Geomagic Control X, version 2017.0.0; 3D Systems, Rock Hill, SC) to perform tooth crown superimposition. Briefly, the digital models of the scanned plaster models were analyzed with the use of the specific software (Geomagic Control X) to perform tooth crown superimposition and 3D deviation analyses of any deviations between the crown pairs.

The workflow for the 3D deviation analysis is described below in 5 steps.

Step 1—Segmentation: The crowns of anterior and posterior crowns teeth were segmented at the gingival margin (Fig 2, *A* and *B*) with the use of the "crop" function of the Geomagic software to obtain the 3D digital model of each tooth crown (from first primary molar to first primary molar, except for the canines).

Step 2—Mirroring: The crowns of the right-side teeth crowns were mirrored relative to a plane passing through the median palatine suture and perpendicular to the occlusal plane to obtain specular models of the segmented right-side teeth (Fig 2, *C* and *D*).

Step 3—First registration point-based registration: Initial manual superimposition of the 2 models was performed to shorten the time needed for the subsequent automatic superimposition. This point-based registration was made by selecting the same 3 points designated on the tooth surface in both the left and the right maxillary quadrants. These points were the mesiobuccal, distobuccal, and mesiopalatinal cusp tips for the posterior teeth (Fig 3, *A*); the deepest points in the gingival buccal contour; and the mesial and distal points on the anatomic equator for the anterior teeth and premolars (Fig 3, *B*).

Step 4—Final registration: Final registration was performed with the use of the "best fit alignment" option in the Geomagic software. After defining the reference dataset, the precision of the registration was set to at least 0.3 mm (tolerance type: "3D deviation") and the number of polygons used for surface representation was set to the maximum of 100,000 (Fig 3, *C*).

Step 5—3D deviation analysis: After superimposition, the specular teeth were ready for the 3D surface deviation analysis. The Geomagic software automatically

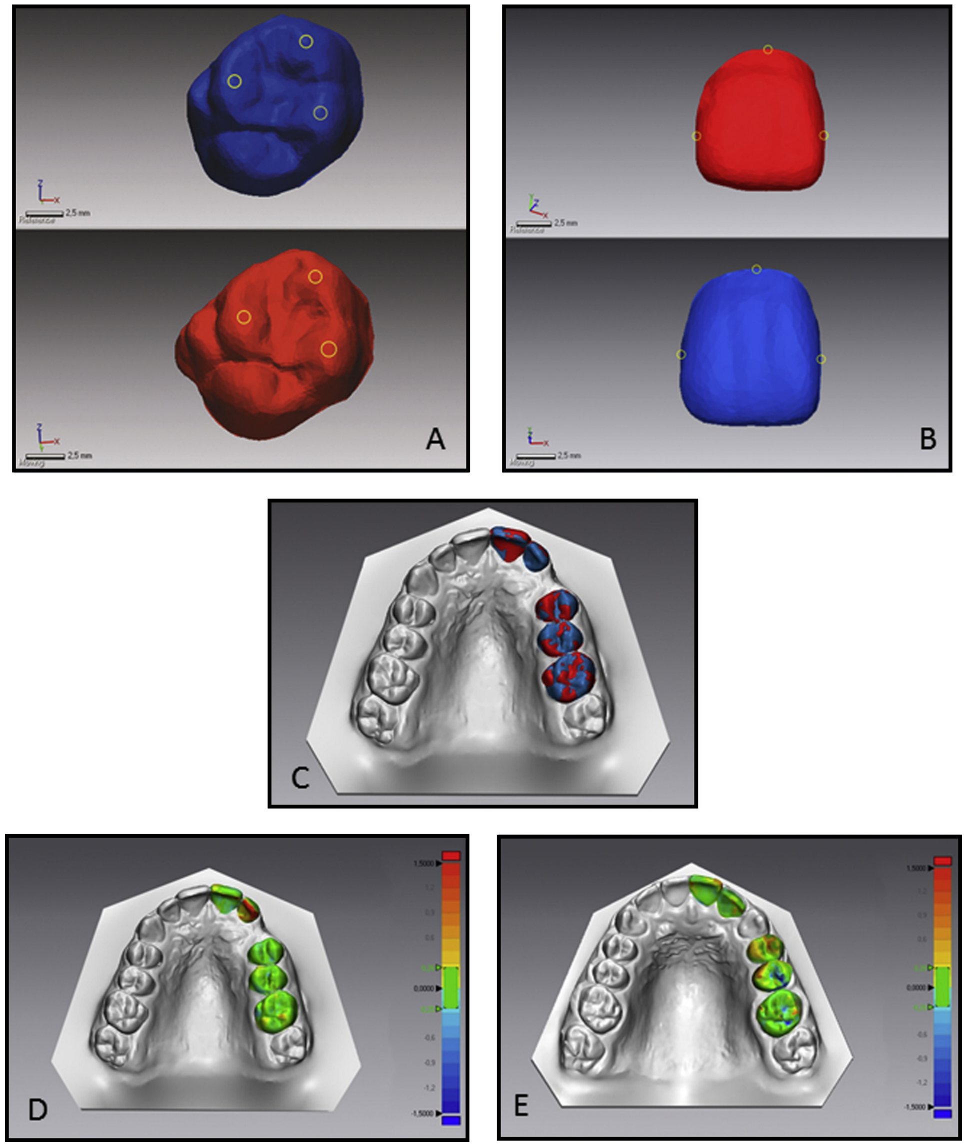

Fig 3. A, B, The initial alignment was conducted with the use of a points-based registration by selecting the same 3 designated points on the tooth surface in both the right (*red*) and left (*blue*) quadrants. **C,** Tooth crowns were accurately aligned with the use of surface-based registration. This method is also called "best fit" and automatically aligns the crown models. **D, E,** After the alignment process, the 3D models were analyzed with the use of the 3D deviation analysis function of the Geomagic Control X software, which calculates the positive (*red*) and negative (*blue*) deviations between the mesh points of the tooth-crown pair models **(D)** from PDC and non-PDC sides in the study group and **(E)** from the right and left side for the control group. In the scale bar, the range of tolerance is set from −0.25 mm to +0.25 mm.

calculated the means and maximum values of the distances between the 3D crown models, measured between the 100% of surface mesh points, and represented them on a color analysis map. These values were visually displayed on a color map that showed the deviation in different colors (blue for maximum negative, red for maximum positive, green for the range tolerance; Fig 3, *C-E*). The maximum deviation calculation was set at 1.5 mm and the tolerance range of tolerance used for this study was ±0.25 mm.

After the deviation analysis, the percentages of all the deviation values included in the tolerance range of tolerance (from -0.25 mm to $+0.25$ mm) were calculated. These values indicated the matching percentages between the pairs of specular crown models. Furthermore, the minimum and maximum matching percentage values for each crown pair were calculated.

To minimize random error and systematic errors, all measurements were performed by a single examiner with 25 years of orthodontic experience (R.L.). The examiner measured 8 models a day in random order. Furthermore, to assess intrarater repeatability, 10 digital casts from the SG and 10 from the CG were randomly selected from the original set of casts and measured again by the same operator after an interval of 4 weeks.

Statistical analysis

All measurements were recorded in a Microsoft Excel spreadsheet (Microsoft, Redmond, Wash) and analyzed with the use of SPSS version 24 statistics software (IBM Corp, Armonk, NY). P values of ≤ 0.05 were considered statistically significant. Intraexaminer reliability was assessed by means of intraclass correlation coefficient (ICC). The Kolmogorov-Smirnov test was used to test the normality of the data. Because all of the data were normally distributed with homogeneous variance, parametric tests were used to evaluate and compare measurements from the PDC side, the non-PDC side, and the CG. A paired t test was used to compare crown sizes and volumes from the right and left quadrants of the CG and to evaluate tooth sizes and volumes from the PDC side and non-PDC side of the SG. Measurements of the PDC side, non-PDC side, and CG were further analyzed by means of 1-way analysis of variance (ANOVA) to evaluate if they were statistically significant to accept or reject the null hypothesis. Mesh value percentages from the SG and CG were compared by means of independent t test.

RESULTS

The location of the PDC was similar for the right side (18 patients) and the left side (20 patients). The ICC values of the mesiodistal and buccolingual widths showed high correlations (all ICC values ranged from 96.2% to 99.1%). As in the CG, MD and BL measurements from the right and the left quadrants were not statistically significantly different, so by convention the right side was used for further comparisons. Descriptive statistics for mesiodistal widths (mm), for the SG (PDC side and non-PDC side) and CG are presented in Table I.

All of the mesiodistal crown diameters were on average smaller in the PDC quadrant than in the CG. Although the lateral incisors of the PDC quadrant were smaller than those of the CG by ~0.30 mm, they were larger than those on the non-PDC side in the same patient by ~0.58 mm.

The descriptive statistics for buccolingual tooth widths for SG and CG also are presented in Table I. Every tooth from the PDC side had a smaller buccolingual width than the CG. Buccolingual tooth widths on the PDC and non-PDC sides yielded similar results to those obtained for mesiodistal widths. In particular, the lateral incisor crowns were larger (buccolingual aspect) on the PDC side than on the non-PDC side of the same patient by ~0.42 mm and smaller than those of the CG by ~0.16 mm.

Table I also presents descriptive statistics for SG and CG volumes. Generally, the tooth volumes of patients with unilateral PDCs were smaller (both PDC side and non-PDC side) than values obtained from the CG. The most striking finding, was that the lateral incisor mean volume on the PDC side was greater than on the non-PDC side.

Statistically significant differences were obtained for the lateral incisor and first molar mesiodistal and buccolingual widths and volume comparing the PDC side and the non-PDC side ($P \leq 0.001$). Furthermore, tooth measurements from the PDC-side, the non-PDC side, and the CG (Table I) demonstrated statistically significant differences, based on 1-way ANOVA, mainly for MD width and volume ($P \leq 0.001$).

The descriptive statistics for morphologic maxillary tooth symmetry analyzed with the use of 3D surface-to-surface matching for the SG (PDC quadrant vs normally erupted canine quadrant of the same patient) and the CG (right vs left quadrant) are presented in Table II. There were statistically significant differences ($P \leq 0.001$) between the deviation percentages of the SG versus the CG for every tooth except the central incisor. However, even though the percentage of match differences between SG and CG were statistically significant, they would be small amounts (ranging from 0.16% to 8.33%), except for the lateral incisors of the study group. In fact, comparing the morphologic symmetry of the lateral incisor in the PDC quadrant with the quadrant with normally erupted canines, there was on average ~18.04% difference according the surface-to-surface matching technique.

DISCUSSION

In this study on digital casts, we compared tooth size widths, volumes, and morphologic symmetry by means of 3D deviation analysis for all maxillary teeth except canines of patients with unilateral PDCs. Teeth from the impaction sides were compared with the normal

Table I. Comparison between PDC side, non-PDC side, and control group for mesiodistal (MD) and buccolingual (BL) widths (mm) and volume (mm^3)

		PDC		Non-PDC			Control		
Measure	Tooth	Mean	SD	Mean	SD	P value (t test)	Mean	SD	P value (ANOVA)
MD width	Central incisor	8.36	0.80	8.32	0.88	NS	8.79	0.32	NS
	Lateral incisor	6.59	0.44	6.11	0.48	≤0.0001	6.89	0.09	≤0.0001
	First premolar	6.39	0.77	6.39	0.80	NS	6.95	0.18	≤0.01
	Second premolar	6.47	0.83	6.42	0.89	NS	7.01	0.25	≤0.05
	First molar	9.94	0.61	10.20	0.61	≤0.0001	10.28	0.36	NS
BL width	Central incisor	6.39	1.02	6.49	1.04	NS	6.93	0.21	NS
	Lateral incisor	5.60	0.74	5.18	0.79	≤0.0001	5.72	0.18	≤0.01
	First premolar	8.80	0.86	8.82	0.83	NS	9.21	0.16	NS
	Second premolar	9.12	0.93	9.09	0.95	NS	9.45	0.25	NS
	First molar	10.79	0.61	11.07	0.73	≤0.0001	11.15	0.17	NS
Volume	Central incisor	308.73	21.29	309.70	21.22	NS	342.96	12.85	≤0.0001
	Lateral incisor	228.73	15.37	186.95	14.39	≤0.0001	234.27	12.20	≤0.0001
	First premolar	266.49	24.65	272.44	22.79	≤0.05	279.21	10.42	NS
	Second premolar	266.11	18.91	265.39	17.63	NS	281.67	14.54	≤0.01
	First molar	482.87	25.89	515.14	31.99	≤0.0001	527.55	10.88	≤0.0001

P value between PDC and non-PDC side calculated by *t* test; *P* value between PDC side, non-PDC side, and control group calculated by 1-way ANOVA.

Table II. Deviation analysis between sample and control group for matching (%). Percentage (%) of mesh point included in a range of tolerance from −0.25 mm to +0.25 mm

	Study group				Control group				
Match	Min	Max	Mean	SD	Min	Max	Mean	SD	P value
Central incisor	87.14	93.25	90.31	1.50	88.24	92.15	90.13	1.19	NS
Lateral incisor	68.18	75.45	71.27	1.81	87.18	91.25	89.31	1.29	≤0.0001
First premolar	82.65	88.47	85.22	1.59	85.45	88.65	86.84	1.09	≤0.0001
Second premolar	86.58	92.26	89.50	1.65	84.56	88.72	86.51	1.54	≤0.0001
First molar	77.21	84.2	80.42	1.77	85.69	90.12	88.31	1.39	≤0.0001

P values based on independent *t* tests.

eruption sides in the same patients with PDC as well as with crowns of a control sample.

The results of this study corroborate previous findings,[3,10,12,20,21] in that a pattern of a smaller tooth size is associated with the anomaly of palatal displacement of the canine,[21] and provide new evidence of a significant increase in frequency of upper tooth crown morphologic asymmetry and PDC malposition.

Although numerous factors are involved in PDCs, the most debated opinions of respected researchers are the genetic theory[2,6,7] and the guidance theory.[2-4,6,7] On one hand, the "genetic" theory postulates that palatal canine displacement belongs to a complex of genetically determined tooth anomalies.[11] Besides tooth agenesis, shape anomalies such as hypoplastic or peg-shaped teeth, tooth impactions, and retarded tooth mineralization are considered to be covariables of this genetic developmental anomaly, and it appears that PDCs are a product of polygenic multifactorial inheritance.[2,11] On the other hand, the "guidance" theory has also reported a significantly higher incidence of hypoplastic and peg-shaped upper lateral incisors in patients with PDCs. According to this latter theory the root of the maxillary lateral incisor plays an important role in inducing the normal eruption of the maxillary canine.

Previous investigations have demonstrated that subjects with malpositioned maxillary canines, such as in palatal displacement, show a tooth size reduction, ranging from extreme forms of "peg-shape" anomaly to mild reduction in size.[1,22] In this respect, previous studies that measured the buccolingual and mesiodistal widths of maxillary teeth demonstrated that crown diameters, on average, were smaller in the PDC sample than in the control sample, indicating a generalized pattern of reduced tooth size as a characteristic associated with PDC anomalies.[3,10,13,20,21]

Because reduced tooth size is associated with hypodontia and this in turn is related to differences in tooth crown shape, a variation in tooth form can be hypothesized also for PDC patients.[14] Therefore, in the present study besides the crown sizes, crown symmetries also were investigated.

Data obtained from our investigation corroborate some of these previous findings, in that crown diameters are slightly smaller in PDC quadrants than in control groups. Furthermore, a reduction of tooth crown volume dimension was observed in PDC patients compared with the CG.

As far as tooth 3D crown symmetry is concerned, to the knowledge of authors only 1 previous study[15] has evaluated 3D morphology of teeth with the aid of reverse engineering technology. Results from that investigation demonstrated low and insignificant morphologic deviations. However, because the data from that study were obtained from subjects with various malocclusions but no tooth anomalies, the authors encouraged further investigations, especially in patients with congenital tooth anomalies.[15]

In our study, the most noticeable and significant findings were the differences in the percentage of surface-to-surface matching of upper teeth of patients with unilateral PDCs and those of controls. Interestingly, the lateral incisors of the PDC group displayed a very low matching percentage (71.27 $\pm$ 1.81%) compared with the lateral incisors of the CG (89.31 $\pm$ 1.29%). This kind of measurement pointed out that there is a shape variation of ~30% between the 2 upper incisors in subjects with PDC. Thus according to our results, a crown dysmorphism of the upper lateral incisor, which could not be identified clinically, is associated with PDC malposition.

The present findings, relating the PDC malposition to the occurrence of other dental anomalies, are consistent with the "genetic" theory in that they are a complex of genetically controlled dental disturbances that are associated in occurrence but not causally related to each other.[21]

Furthermore, our findings are in line with a recent published article[5] that states that the guidance theory and the genetic theory share the belief that certain genetic features occur in association with the cause of palatal displacement of the maxillary canine, and among these factors the lateral incisor is involved.[5]

Our findings may also have some clinical implications. When conventional brackets are used for PDC patients, the final upper lateral incisor positions may not be optimal, because the built-in prescriptions are based on the tooth shape of control patients.[14] For this reason, clinically irrelevant morphologic difference in shapes between upper lateral incisors could indirectly affect the esthetic success.[15]

Finally, it may also be speculated that the presence an upper lateral incisor dysmorphism, especially in combination with other associated dental anomalies, could serve as a useful indicator of a future PDC occurrence.

There are some limitations in this study inherent to the sample size. A larger sample would have improved the reliability of the results. However, the calculation of the sample size which was obtained by a power analysis, which assured adequate power to detect statistical significance. Furthermore, because we looked at Caucasian patients only, our findings may not translate to patients of other races, because in odontometrics both population and sex dimorphisms have been documented.[23,24]

CONCLUSIONS

1. The hypothesis of our study was accepted. Mesiodistal and buccolingual widths in patients with unilateral PDCs were significantly smaller compared to controls.
2. The tooth volumes of patients with unilateral palatally displaced canines were smaller (both PDC side and non-PDC side) than values obtained from the CG.
3. The upper lateral incisor crowns of the PDC group showed a very low percentage of matching, according to the "best fit alignment," compared with the other upper teeth and the CG.

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