Original Article

Space conditions, palatal vault height, and tooth size in patients with and without palatally displaced canines: *A prospective cohort study*

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ABSTRACT

Objectives: To assess palatal vault height, tooth size, and dental arch dimensions in patients with unilateral and bilateral palatally displaced canines compared with a control group.

Materials and Methods: A sample of 66 patients (mean age: 11.5 ± 1.0 years) with 22 unilateral palatally displaced canines (UPDCs), 22 bilateral palatally displaced canines (BPDCs), and 22 controls (C) were consecutively recruited. All three groups had dental casts that were scanned digitally using the OrthoX three-dimensional model scanner. Tooth size, palatal vault height, dental arch width, dental arch depth, dental arch length, and dental arch space were measured by the same examiner using the GOM software. Remeasurements were made in 10 randomly identified patients.

Results: The palatal vault height was significantly lower in the BPDC group compared with controls. A significantly smaller mesial-distal crown width and, in general, more spacing in the maxilla were found in the UPDC and BPDC groups. No differences in arch length or arch width at the molar region were seen between the groups, while the arch length at the canine region was smaller in the UPDC and BPDC groups. However, this was observed in BPDC patients with both deciduous canines present and in most UPDC patients where the deciduous canine was present, compared with the control group, who had more permanent canines present.

Conclusions: Patients with PDC had greater reduction in tooth size compared with the control group. The arch length and arch width were similar in patients with and without PDC. (*Angle Orthod.* 2018;88:726–732.)

KEY WORDS: Palatal height; Tooth size; Palatally displaced canines

INTRODUCTION

The prevalence of palatally displaced maxillary canines is about 1%–3%. If left untreated or detected late, there is a risk that the canine may resorb the roots of the permanent incisors or, even worse, that an incisor is lost.[1] Therefore, early diagnosis and interceptive measures are associated with better treatment prognosis. Some interceptive procedures presented in the literature are extraction of deciduous canines[2–5] only or, in addition to placement of a transpalatal bar, expansion of the maxilla,[6] and preservation or lengthening of the dental arch length by means of extraoral traction.[7]

Two major theories have been proposed to explain the etiology of palatally displaced canines (PDCs): guidance theory and genetic theory. According to the guidance theory, the canine lacks guidance along the eruption pathway, owing to a hypoplastic or missing lateral incisor. This theory is supported by the fact that

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Accepted: June 2018. Submitted: December 2017.
Published Online: August 13, 2018

PDC are frequently found in dentitions with peg-shaped or missing laterals.[8] The genetic theory points to genetic factors as the primary origin of PDC and includes other possibly associated dental anomalies, such as enamel hypoplasia, infraocclusion of primary molars, microdontia or agenesis of the maxillary lateral incisors or mandibular second premolars, and many other factors. The genetic theory has been documented by findings in several studies.[9–11]

Patients with PDC have many morphological characteristics in common compared with patients with normally erupting canines, for instance, a wider maxilla, shorter interalveolar distance at the level of the maxillary canines, smaller tooth size, and greater spacing in the dental arch.[12–16] However, there is disagreement as to whether the width, depth, and length of the maxilla have an impact or not. In addition, equal,[17,18] smaller,[19] or greater[20] width of the dental arches has been reported in patients with PDC.

In most of the studies cited above, morphological characteristics have been evaluated using measurements made using a variety of methods, such as plaster cast models,[15–17,20–22] panoramic radiographs,[23] cephalograms,[18,24] or cone-beam computed tomography.[25] However, these studies have shortcomings, such as inclusion of selected cases, analysis of retrospective material, or inclusion of impacted canines without specifying their location or whether there is unilateral or bilateral displacement.

Finding-specific morphological differences in patients with PDC could help to revise and maybe add additional interceptive measures to today's accepted interceptive treatment: extraction of the deciduous canine. Therefore, the aim of the present prospective cohort study was to analyze whether there were any differences in palatal vault height, tooth size, or dental arch dimensions in patients with unilateral or bilateral PDCs in comparison with a control group. The null hypothesis was that there were no differences regarding palatal vault height, tooth size, or dental arch dimensions between the PDC and control group.

MATERIALS AND METHODS

Subjects

Sixty-six patients, divided into three groups with 22 patients in each group, were included in the study: unilateral palatally displaced canine (UPDC), bilateral palatally displaced canines (BPDCs), and controls (Figure 1). Patients in the UPDC (mean age, 11.8 ± 1.0 years) and BPDC groups (mean age 11.3 ± 1.0 years) were collected from a previously published prospective randomized clinical trial evaluating the effect of interceptive extraction of the deciduous canines.[2]

Patients were consecutively recruited from public dental clinics in Gothenburg, Västra Götaland County Council, Sweden, between September 2008 and January 2011. The inclusion criteria were Caucasians aged 10–13 years with either UPDC or BPDCs and persisting deciduous canine(s). Patients with crowding in the posterior part of the maxilla (>2 mm), previous or ongoing orthodontic treatment, and root resorption of the permanent incisor were not included in the original study. The maxillary canine was considered palatally displaced when clinical palpation of a labial canine bulge was absent and when the canine crown was diagnosed on intraoral radiographs as palatally positioned, using Clark's rule.[26]

Patients in the control group (mean age, 11.6 ± 0.9 years) were consecutively recruited at their annual visit to the public dental clinic in Gothenburg, Västra Götaland County Council, Sweden, between March and October 2016. The inclusion criteria were children aged 10–13 years with normally erupting canines in the maxilla, neutral sagittal and transverse relation, horizontal and vertical overbite of 1–4 mm, and a maximum of 2 mm of spacing or crowding in the maxilla. Normal eruption of the maxillary canine was diagnosed as the presence of a labial canine bulge and vertical eruption with no overlapping of the adjacent teeth, as seen on intraoral radiographs. The exclusion criteria were earlier orthodontic treatment and agenesis in the maxilla.

Impressions for study casts were taken of the upper and lower arches before any intervention was undertaken in all three patient groups.

The study was approved by the research ethics committee of Sahlgrenska Academy at the University of Gothenburg, Sweden (Reg. No. 150-16). Children and parents received verbal and written information, and informed consent was provided by the child and the parent or by an adult with parental responsibilities and rights in accordance with the Declaration of Helsinki.

Measurements

All dental casts were scanned digitally using the OrthoX 3D model scanner (REF075-000-00) and OrthoX file version 2.4 beta software (REF075-001-00) from Dentaurum GmbH & Co (Ispringen, Germany). All digital measurements were made in GOM Inspect v2.0.1, GOM software 2016 (2016 Hotfix 6, Rev. 99277, Braunschweig, Germany).

Measurements were blinded and made by one examiner who had no knowledge of the group to which the casts belonged. No more than 10 casts per day were measured to avoid eye fatigue and to minimize the possibility of subjective error. The following linear

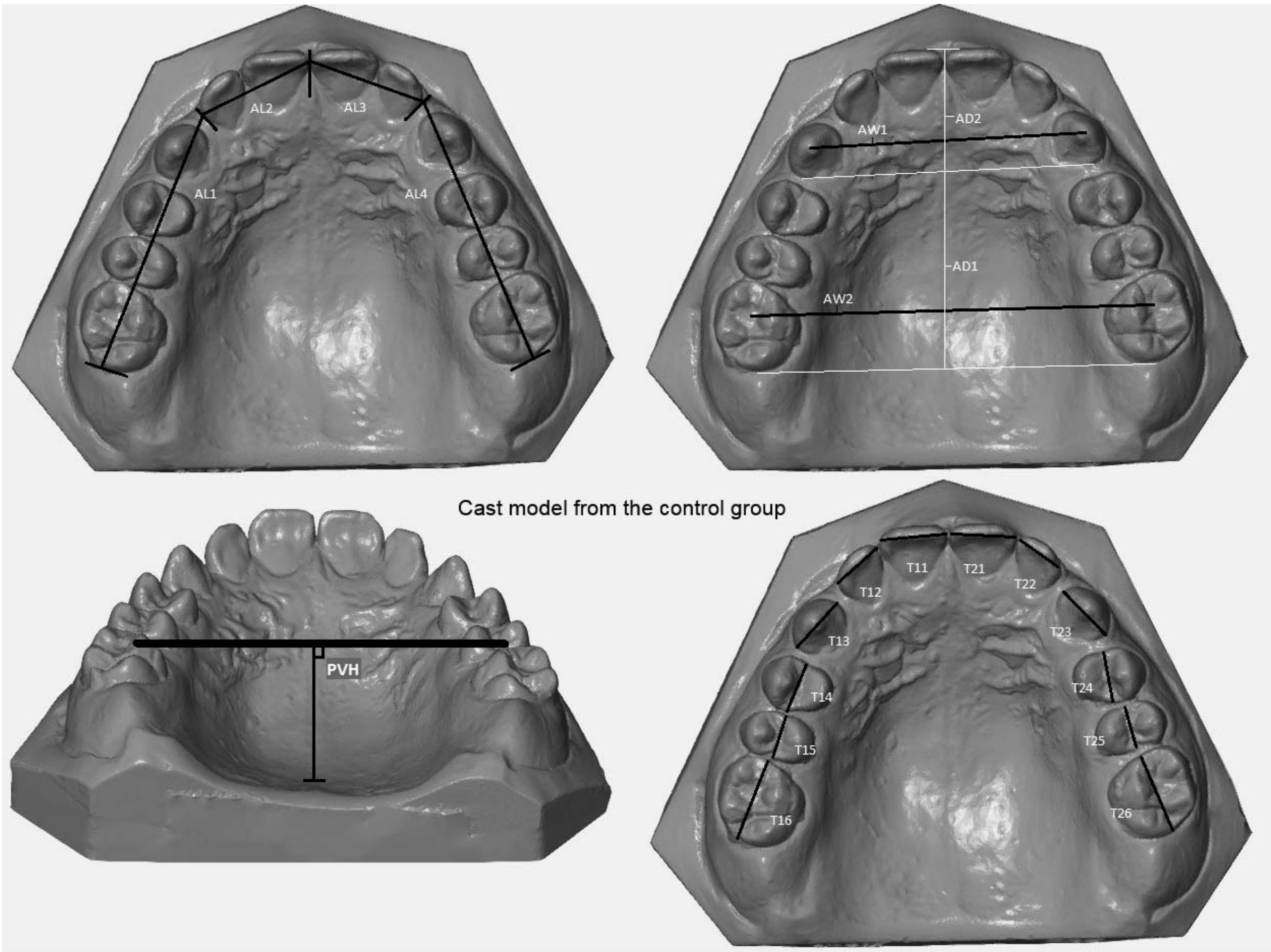

Figure 1. Measurements made on the digital cast models. T indicates tooth size; PVH, palatal vault height; AW1, arch width at canine; AW2, arch width at first permanent molar; AD1, arch depth at first permanent molar; AD2, arch depth at canine; sum of arch length AL1–AL4, total arch length; sum of spacing AL1–AL4, total arch space.

measurements (Figure 1; Table 1) were made according to Thilander[27]: tooth size (T), palatal vault height, dental arch width at the canine (AW1) and at the first permanent molar (AW2), dental arch depth at the first permanent molar (AD2) and at the canine (AD1), dental arch length, and dental arch space.

Remeasurements

Remeasurements were made by the same examiner on 10 randomized plaster casts and included patients from all three groups. The remeasurements were done after 2 weeks to eliminate memory bias.

Statistics

Sample size calculation. The sample size was based on an alpha significance level of .05 and a beta significance level of .10 to achieve 90% power to detect a difference of 2 $\pm$ 1 mm between the groups with respect to all morphological measurements. The calculation indicated that 18 patients were needed in each group. To increase the power and to compensate for possible dropouts, 22 patients were enrolled in each group.

The data were statistically analyzed using SAS, version 9.3, for Windows (SAS Institute Inc, Cary, NC). Descriptive statistics with mean values and standard deviations were calculated for each measurement. The random error was calculated using the standard deviation of a single measurement according to Dahlberg[28]: $s = \sqrt{\sum d^2/2n}$, where d = the difference between duplicate determinations and n = the number of determinations. Differences in categorical values were tested with Fisher exact test. Analysis of variance and Newman-Keuls were used to test whether there were any significant differences for all numerical values between the groups. A *P* value of $<.05$ was considered statistically significant.

Table 1. Abbreviations and Detailed Description on How the Measurements Were Done on the Cast Models

Measurement	Abbreviation	Description of the Measurement
Tooth size	T	Mesial-distal crown width for each tooth. Missing teeth were estimated using the size of the contralateral tooth and in the absence of contralateral tooth; reference values were used from healthy Swedish children.[28]
Palatal vault height	PVH	A line was drawn between the highest point of the palatal cusp of each first permanent molar. PVH was measured perpendicular to that line.
Dental arch width at canine	AW1	Measured between the edge of the canine cusp. If the cusp was eroded, the measurement was made from the middle of the eroded surface. If a canine was missing, the measurement was made from the edge of the ridge for the absent tooth in question.
Dental arch width at first permanent molar	AW2	Measured between the central fossa of each first permanent molar.
Dental arch depth at first permanent molar	AD1	A line between the most buccal surface of each central incisor and the most distal surface of each first permanent molar was made. AD1 was measured between these lines at the maxillary midline.
Dental arch depth at canine	AD2	A line between the most buccal surface of each central incisor and the most distal surface of each canine was made. AD2 was measured between these lines at the maxillary midline. If a canine was missing, the distal surface was estimated at the ridge in proximity to the mesial surface of the first permanent premolar or the first primary molar.
Dental arch length	Total AL	Total AL as measured in four segments, from the distal surface of the first permanent molar to the mesial surface of the distal surface of the lateral incisor on each side (AL1, AL2) and then from the mesial surface of the lateral incisor to the midline between the mesial surface of the central incisors on each side (AL3, AL4). The four segments were added for the total arch length.
Dental arch space	Space total	Space total was measured by subtracting the sum of each mesial-distal tooth size from the total arch length.

RESULTS

The random error was small, 0.02–0.84 for all variables, indicating that the measurement method was reliable. There were neither any significant differences between the number of boys and girls in the three groups ($P = .409$) nor any age differences ($P = .913$).

All patients in the UPDC and BPDC groups had an Angle Class I malocclusion, with a normal transverse relation and a horizontal and vertical overbite similar to that in the control group. The palatal vault height was significantly lower in the BPDC group compared with the control group. The mesial-distal crown width of all permanent incisors was significantly smaller in the BPDC group compared with the control group, while in the unilateral group, the mesial-distal crown width was significantly smaller than in the control group for the following teeth: 16, 14, 13, 12, 23, and 24. The arch width in the canine region was significantly smaller in the UPDC and BPDC groups compared with the control group, while no difference was seen for the arch width in the molar region. The total arch space in the arch and the space in the anterior part of the arch were significantly greater in the UPDC and BPDC groups compared with the control group. No significant difference was observed between the groups with respect to arch length (Table 2).

DISCUSSION

Early diagnosis of ectopic erupting permanent canines could lead to early interceptive treatment with the goal of preventing PDC and reducing the need for later costly surgical exposure and subsequent orthodontic treatment. The focus of the present study was, therefore, to compare different morphological measurements of consecutively recruited patients with UPDC and BPDC to a control group. Measurements were made on digitized plaster casts, which have been shown to have a high degree of validity as compared with direct measurements made on plaster models.[29]

The findings showed that the palatal vault height was lower in the bilateral group compared with the control group, which was in contrast to the study conducted by Anic-Milosevic et al.,[30] in which no differences were found. This contradiction could be attributed to the fact that only 11 patients with BPDC were included in that previous study.

The arch width in the canine region was significantly smaller in both the UPDC and BPDC patients compared with the control group, while the width at the molar region was similar in all three groups. On this point, there are many different explanations in the literature. There were studies reporting wider arches in the posterior region,[31,32] whereas others did not observe any differences[17,18,30] and some detected narrower arches.[12,19] The reason for these disparities

Table 2. Means and Standard Deviations (SD) for All Measured Variables and Significant Differences (marked in bold) Between the Groups[a]

Variable	UPDC, n = 22 (F: 15, M: 7), Mean ± SD	BPDCs, n = 22 (F: 11 M: 11), Mean ± SD	C, n = 22 (F: 11, M: 11), Mean ± SD	*P* Value	Significant Difference Between Groups
Age	11.8 ± 1.0	11.3 ± 1.0	11.6 ± 0.9	.9128	NS
PVH	**16.3 ± 1.8**	**15.4 ± 1.9**	**17.1 ± 1.8**	**.0125**	**BPDCs < C***
AW 1	**31.9 ± 1.5**	**31.7 ± 2.5**	**33.7 ± 2.7**	**.0103**	**UPDC, BPDCs < C***
AW 2	46.7 ± 2.7	46.5 ± 2.9	47.6 ± 2.7	.3787	NS
AD 1	40.8 ± 2.1	41.4 ± 1.6	40.8 ± 2.6	.5373	NS
AD 2	15.3 ± 1.3	15.4 ± 1.3	15.1 ± 1.8	.8271	NS
AL 1	22.8 ± 1.4	23.0 ± 1.2	23.0 ± 1.5	.8486	NS
AL 2	15.1 ± 0.9	15.2 ± 1.3	15.4 ± 1.1	.6977	NS
AL 3	15.4 ± 0.9	15.4 ± 1.1	15.4 ± 1.1	.9902	NS
AL 4	22.7 ± 1.6	23.0 ± 0.9	23.1 ± 1.4	.6697	NS
T16	**10.2 ± 0.6**	**10.4 ± 0.6**	**10.7 ± 0.7**	**.0424**	**UPDC < C***
T12	**6.5 ± 0.4**	**6.2 ± 1.0**	**7.0 ± 0.4**	**.0015**	**UPDC, BPDCs < C****
T11	**8.5 ± 0.5**	**8.3 ± 0.5**	**8.7 ± 0.5**	**.0343**	**BPDCs < C***
T21	**8.5 ± 0.5**	**8.1 ± 0.9**	**8.8 ± 0.5**	**.004**	**BPDCs < C****
T22	**6.6 ± 0.5**	**6.4 ± 0.6**	**6.9 ± 0.6**	**.0202**	**BPDCs < C***
T26	10.1 ± 0.5	10.4 ± 0.6	10.5 ± 0.7	.1004	NS
Space (total)	**2.4 ± 2.4**	**3.0 ± 2.9**	**0.8 ± 3.0**	**.0263**	**C < UPDC, BPDCs ***
Space (front)	**0.5 ± 1.5**	**1.5 ± 2.3**	**−0.6 ± 1.4**	**.0008**	**C < UPDC, BPDCs *****
Total AL	76.1 ± 4.2	76.6 ± 3.8	76.9 ± 4.6	.8179	NS
T15 (n = 17)	6.4 ± 0.2 (n = 4)	6.2 ± 0.2 (n = 2)	6.7 ± 0.4 (n = 11)	.3078	NS
T55 (n = 49)	8.7 ± 0.6 (n = 18)	8.9 ± 0.5 (n = 20)	9.0 ± 0.4 (n = 11)	.1791	NS
T14 (n = 35)	**6.3 ± 0.7 (n = 11)**	**6.6 ± 0.6 (n = 6)**	**6.9 ± 0.4 (n = 18)**	**.0206**	**UPDC < C***
T54 (n = 31)	7.0 ± 0.4 (n = 11)	6.8 ± 0.4 (n = 16)	7.0 ± 0.2 (n = 4)	.3898	NS
T13 (n = 22)	**7.1 ± 0.9 (n = 5)**	**—**	**7.8 ± 0.6 (n = 17)**	**.0450**	**UPDC < C***
T53 (n = 44)	6.9 ± 0.4 (n = 17)	6.9 ± 0.5 (n = 22)	7.0 ± 0.4 (n = 5)	.9430	NS
T23 (n = 20)	**6.9 ± 1.0 (n = 4)**	**—**	**7.9 ± 0.4 (n = 16)**	**.0065**	**UPDC < C****
T63 (n = 46)	6.8 ± 0.4 (n = 18)	6.9 ± 0.4 (n = 22)	7.0 ± 0.4 (n = 6)	.4283	NS
T24 (n = 37)	**6.3 ± 0.5 (n = 12)**	**6.6 ± 0.6 (n = 7)**	**7.0 ± 0.5 (n = 18)**	**.0020**	**UPDC < C****
T64 (n = 29)	7.0 ± 0.5 (n = 10)	6.8 ± 0.5 (n = 15)	7.1 ± 0.6 (n = 4)	.3029	NS
T25 (n = 17)	6.5 ± 0.2 (n = 4)	6.1 ± 0 (n = 1)	6.7 ± 0.5 (n = 12)	.4441	NS
T65 (n = 49)	8.7 ± 0.6 (n = 18)	8.7 ± 0.5 (n = 21)	8.9 ± 0.6 (n = 10)	.6782	NS

[a] For some variables, there were fewer than 66 subjects because of variations in tooth exfoliation. These variables are marked with **n** (number of subjects) for each variable and group. UPDC, unilateral palatally displaced canines; F, female; M, male; BPDC, bilateral palatally displaced canine; C, control; PVH indicates palatal vault height; AW1, arch width at canine; AW2, arch width at first permanent molar; AD1, arch depth at first permanent molar; AD2, arch depth at canine; AL1, arch length from 16m–12d; AL2, arch length from 12d–midline; AL3, arch length from midline–22d; AL4, arch length from 22d–26m; T, mesial-distal crown width for each tooth; space (total), total spacing in the dental arch (AL1–AL4); space (front), spacing in the anterior part of the arch (AL2–AL3); total AL, sum of arch length (AL1–AL4); NS, non significant; * $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$.

may be due to differences in the measurement method used: cast models[12,17,31,32] or radiographs.[18,32] Moreover, the anterior arch width has been measured either as the intercanine[12,18] or the interpremolar alveolar width,[17,30–32] and the patient sample included both palatally and buccally displaced canines,[12] only UPDC,[17,31] or an unequal distribution of UPDC and BPDCs.[30] However, the absence of at least one permanent canine in the dental arch is probably the cause of the narrow width found in the canine region rather than the idea that it is the narrow arch width that causes impaction.[17,18] On the other hand, expansion therapy on patients with PDC has been suggested by McConnell et al.,[12] since they found transverse deficiencies in the intercanine width. However, their sample consisted of both palatally and buccally displaced canines, and the authors did not report either the presence or absence of deciduous and permanent canines. Sair et al.[18] found that patients with two deciduous canines had a smaller intercanine width than a group with both or at least one permanent canine present. The current study corroborated the finding that a smaller intercanine width was observed in the BPDC patients in whom both deciduous canines were present, whereas most of the UPDC patients had one deciduous canine. This was in contrast to the subjects in the control group, in which most had both permanent canines. Several longitudinal studies have also shown that the maxillary intercanine width can increase up to the age of 16.[27,33–35] For this reason, it is not possible to issue a recommendation for expansion based on the decreased intercanine width. Further prospective research assessing expansion therapy is needed before clinical recommendations can be made in order to prevent PDC.

Arch length in the current study was measured as the total arch length but also divided into an anterior and posterior arch length (Figure 1). None of these measurements differed significantly from those in the control group, indicating that interceptive treatment aimed to increase the arch length might be unnecessary. As there is a lack of data in the literature regarding the arch length in patients with PDC, it is not possible to compare the results with previous studies.

In general, the mesial-distal crown width was smaller for almost all maxillary permanent teeth in patients with PDC, particularly all permanent incisors in the BPDC group compared with the control group. These findings are in agreement with previous studies,[17,21–23,31] but contradict findings of other studies[20,32] reporting no differences in tooth size between patients with and without PDC. An explanation for this could be the method of selection of the control groups but also of the PDC group, with either unilateral or bilateral displacement or unequal distributions of unilateral and bilateral displacement. In the present study, patients in all three groups had Class I malocclusion, while in the study by Al-Nimri et al.,[31] most of the patients had Class II, Division 2. PDC has been reported to occur most frequently in Class II, Division 2 malocclusion,[31,36] but there are also studies reporting that it is most frequently seen in Class I malocclusion.[8,30]

Crowding in the maxilla has been associated with buccal canine displacement,[14] while a spaced dentition or a dentition with sufficient space has been associated with palatal displacement,[7,13,17,37,38] which may be due to small teeth or the result of an excessive arch length.[15] The results of the present study, with significantly more spacing in the dental arch, confirm these findings. However, a shortcoming of the current study should be mentioned, namely, that patients with crowding were excluded. Spacing in the maxilla was most probably observed due to significantly smaller mesial-distal crown widths in patients with PDC and not because of the arch length, as this was found to be similar in all three groups in the current study.

CONCLUSIONS

- Tooth size reduction was found in patients with PDC compared with the control group.
- Arch length and arch width were similar in Class I patients with and without PDC. For this reason, no recommendation for expansion or change of the arch length can be made on the basis of the current findings.

ACKNOWLEDGMENTS

The authors would like to acknowledge all orthodontists and general dental practitioners for their help in collecting the patients. We would also like to express our gratitude to all the patients for attending the study.

REFERENCES

1. Thilander B, Myrberg N. The prevalence of malocclusion in Swedish schoolchildren. *Scand J Dent Res*. 1973;81:12–21.
2. Naoumova J, Kurol J, Kjellberg H. Extraction of the deciduous canine as an interceptive treatment in children with palatal displaced canines—part I: shall we extract the deciduous canine or not? *Eur J Orthod*. 2014;37:209–218.
3. Ericson S, Kurol J. Early treatment of palatally erupting maxillary canines by extraction of the primary canines. *Eur J Orthod*. 1988;10:283–295.
4. Bazargani F, Magnuson A, Lennartsson B. Effect of interceptive extraction of deciduous canine on palatally displaced maxillary canine: a prospective randomized controlled study. *Angle Orthod*. 2014;84:3–10.
5. Power SM, Short MB. An investigation into the response of palatally displaced canines to the removal of deciduous canines and an assessment of factors contributing to favourable eruption. *Br J Orthod*. 1993;20:215–223.
6. Baccetti T, Sigler LM, McNamara JA Jr. An RCT on treatment of palatally displaced canines with RME and/or a transpalatal arch. *Eur J Orthod*. 2011;33:601–607.
7. Leonardi M, Armi P, Franchi L, Baccetti T. Two interceptive approaches to palatally displaced canines: a prospective longitudinal study. *Angle Orthod*. 2004;74:581–586.
8. Brin I, Becker A, Shalhav M. Position of the maxillary permanent canine in relation to anomalous or missing lateral incisors: a population study. *Eur J Orthod*. 1986;8:12–16.
9. Peck S, Peck L, Kataja M. The palatally displaced canine as a dental anomaly of genetic origin. *Angle Orthod*. 1994;64:249–256.
10. Pirinen S, Arte S, Apajalahti S. Palatal displacement of canine is genetic and related to congenital absence of teeth. *J Dental Res*. 1996;75:1742–1746.
11. Garib DG, Alencar BM, Lauris JR, Baccetti T. Agenesis of maxillary lateral incisors and associated dental anomalies. *Am J Orthod Dent Orthop*. 2010;137:732.e1–e6.
12. McConnell TL, Hoffman DL, Forbes DP, Janzen EK, Weintraub NH. Maxillary canine impaction in patients with transverse maxillary deficiency. *J Dent Child*. 1996;63:190–195.
13. Stellzig A, Basdra EK, Komposch G. The etiology of canine tooth impaction—a space analysis. *Fortschr Kieferorthop*. 1994;55:97–103.
14. Jacoby H. The etiology of maxillary canine impactions. *Am J Orthod*. 1983;84:125–132.
15. Becker A, Sharabi S, Chaushu S. Maxillary tooth size variation in dentitions with palatal canine displacement. *Eur J Orthod*. 2002;24:313–318.
16. Langberg BJ, Peck S. Tooth-size reduction associated with occurrence of palatal displacement of canines. *Angle Orthod*. 2000;70:126–128.
17. Langberg BJ, Peck S. Adequacy of maxillary dental arch width in patients with palatally displaced canines. *Am J Orthod Dent Orthop*. 2000;118:220–223.
18. Saiar M, Rebellato J, Sheats RD. Palatal displacement of canines and maxillary skeletal width. *Am J Orthod Dent Orthop*. 2006;129:511–519.
19. Kim Y, Hyun HK, Jang KT. Interrelationship between the position of impacted maxillary canines and the morphology of the maxilla. *Am J Orthod Dent Orthop*. 2012;141:556–562.

20. Al-Nimri K, Adwan I, Gharaibeh T, Hazza'a AM. Tooth size discrepancies in female patients with palatally impacted canines. *Aust Orthod J*. 2008;24:129–133.
21. Artmann L, Larsen HJ, Sørensen HB, Christensen IJ, Kjaer I. Differences between dentitions with palatally and labially located maxillary canines observed in incisor width, dental morphology and space conditions. *Eur J Paediatr Dent*. 2010;11:82–86.
22. Fraga MR, Vitral RW, Mazzieiro ET. Tooth size reduction and agenesis associated with palatally displaced canines. *Pediatr Dent*. 2012;34:216–219.
23. Al-Khateeb S, Abu Alhaija ES, Rwaite A, Burqan BA. Dental arch parameters of the displacement and nondisplacement sides in subjects with unilateral palatal canine ectopia. *Angle Orthod*. 2013;83:259–265.
24. Cernochova P, Izakovicova-Holla L. Dentoskeletal characteristics in patients with palatally and buccally displaced maxillary permanent canines. *Eur J Orthod*. 2012;34:754–761.
25. Hong WH, Radfar R, Chung CH. Relationship between the maxillary transverse dimension and palatally displaced canines: a cone-beam computed tomographic study. *Angle Orthod*. 2015;85:440–445.
26. Clark C. A method of ascertaining the position of unerupted teeth by means of film radiographs. *Proc R Soc Med*. 1909;3:87–90.
27. Thilander B. Dentoalveolar development in subjects with normal occlusion: a longitudinal study between the ages of 5 and 31 years. *Eur J Orthod*. 2009;31:109–120.
28. Dahlberg G. Statistical Methods for Medical and Biological Students. George Allen and Unwin, Berlin, 1940; 122–132.
29. Fleming PS, Marinho V, Johal A. Orthodontic measurements on digital study models compared with plaster models: a systematic review. *Orthod Craniofac Res*. 2011;14:1–16.
30. Anic-Milosevic S, Varga S, Mestrovic S, Lapter-Varga M, Slaj M. Dental and occlusal features in patients with palatally displaced maxillary canines. *Eur J Orthod*. 2009;31:367–373.
31. Al-Nimri K, Gharaibeh T. Space conditions and dental and occlusal features in patients with palatally impacted maxillary canines: an aetiological study. *Eur J Orthod*. 2005;27:461–465.
32. Sambataro S, Baccetti T, Franchi L, Antonini F. Early predictive variables for upper canine impaction as derived from posteroanterior cephalograms. *Angle Orthod*. 2005;75:28–34.
33. Sillman JH. Dimensional changes of the dental arches: longitudinal study from birth to 25 years. *Am J Orthod*. 1964;50:824–841.
34. Bishara SE, Jakobsen JR, Treder J, Nowak A. Arch width changes from 6 weeks to 45 years of age, *Am J Orthod Dent Orthop*. 1997;11:401–409.
35. Arslan SG, Kama JD, Sahin S, Hamamci O. Longitudinal changes in dental arches from mixed to permanent dentition in a Turkish population, *Am J Orthod Dent Orthop*. 2007;132:15–21.
36. Basdra EK, Kiokpasoglou M, Stellzig A. The Class II Division 2 craniofacial type is associated with numerous congenital tooth anomalies. *Eur J Orthod*. 2000;22:529–535.
37. Mahaini L. The relationship between palatal displacement of upper canines and incisors widths in a Syrian sample of patients with uncrowded arches. *J Contemp Dent Pract*. 2015;16:873–875.
38. Zilberman Y, Cohen B, Becker A. Familial trends in palatal canines, anomalous lateral incisors, and related phenomena. *Eur J Orthod*. 1990;12:135–139.