

Effect of rapid maxillary expansion and transpalatal arch treatment associated with deciduous canine extraction on the eruption of palatally displaced canines: A 2-center prospective study

Lauren M. Sigler,^a Tiziano Baccetti,^b and James A. McNamara, Jr^c
Ann Arbor, Mich, and Florence, Italy

Introduction: Our aim was to investigate the effect of rapid maxillary expansion and transpalatal arch therapy combined with deciduous canine extraction on the eruption rate of palatally displaced canines (PDCs) in patients in the late mixed dentition in a 2-center prospective study. **Methods:** Seventy subjects were enrolled based on PDCs diagnosed on panoramic radiographs. The treatment group (TG, 40 subjects) underwent RME followed by TPA therapy and extraction of the deciduous canines. The control group (CG, 30 subjects) received no orthodontic treatment. At the start of the trial, panoramic radiographs and dental casts were compared between the TG and the CG with the Mann-Whitney U test ($P < 0.05$). At the second observation (cervical vertebral maturation stage 5 or 6), all subjects were reevaluated, and the eruption of the maxillary permanent canines was assessed. The rates of success in the TG were compared with those in the CG by means of chi-square tests ($P < 0.05$). The association of PDCs with other dental anomalies was reported. **Results:** No statistically significant difference was found for any measurement at the start of the trial between the 2 groups. The prevalence rates of eruption of the maxillary canines were 80% for the TG and 28% in the CG, a statistically significant difference (chi-square = 16.26, $P < 0.001$). The prevalence rate at the start for the pubertal stages of cervical vertebral maturation (63%) was significantly greater in the unsuccessfully treated subjects than in the successfully treated ones (16%). In the CG, all successful subjects had PDCs that overlapped the corresponding deciduous canine or the distal aspect of the lateral incisor. Eruption of PDCs in both groups was associated significantly with an open root apex. **Conclusions:** Rapid maxillary expansion therapy followed by a transpalatal arch combined with extraction of the deciduous canine is effective in treating patients in the late mixed dentition with PDCs. Pretreatment variables indicating success of treatment on the eruption of PDCs were less severe sectors of displacement, prepubertal stages of skeletal maturity, and open root apices of PDCs. Several dental anomalies were associated significantly with PDCs, thus confirming the genetic etiology of this eruption disturbance. (Am J Orthod Dentofacial Orthop 2011;139:e235-e244)

Palatal canine displacement (PCD) is a genetic disorder that is a precursor to palatal canine impaction, a dental anomaly that afflicts 0.2% to 2.3% of orthodontic populations.¹ Treatment for palatal canine impaction involves surgical exposure and guiding

mechanics to bring the canine into normal occlusion.² Patients with PCD must be identified and treated promptly upon diagnosis to reduce the likelihood of impaction.³ Prevention of palatal impaction is of significant importance because canine impaction lengthens orthodontic

^aResearch assistant, Department of Orthodontics and Pediatric Dentistry, University of Michigan, Ann Arbor.

^bAssistant professor, Department of Orthodontics, University of Florence, Florence, Italy; Thomas M. Graber Visiting Scholar, Department of Orthodontics and Pediatric Dentistry, School of Dentistry, University of Michigan, Ann Arbor.

^cThomas M. and Doris Graber Endowed Professor, Department of Orthodontics and Pediatric Dentistry, School of Dentistry; professor, Cell and Developmental Biology, School of Medicine; research scientist, Center for Human Growth and Development, University of Michigan, Ann Arbor; private practice, Ann Arbor, Mich.

The authors report no commercial, proprietary, or financial interest in the products or companies described in this article.

Supported by funds made available through the Thomas M. and Doris Graber Endowed Professorship at the University of Michigan.

Reprint requests to: Tiziano Baccetti, Dipartimento di Odontostomatologia, Università degli Studi di Firenze, Via del Ponte di Mezzo, 46-48 50127, Firenze, Italy; e-mail, tbaccetti@unifi.it.

Submitted, May 2009; revised and accepted, July 2009.

0889-5406/\$36.00

Copyright © 2011 by the American Association of Orthodontists.

doi:10.1016/j.ajodo.2009.07.015

treatment time, complicates orthodontic mechanics, and increases treatment costs.^{3,4} Furthermore, canine impaction can have deleterious consequences for adjacent teeth, causing root resorption or cyst formation.⁵

The most common treatment for the prevention of palatal canine impaction is the extraction of the underlying deciduous canine. In a clinical trial, Ericson and Kuroi⁶ reported an improvement in the eruption path of 78% of palatally displaced canines (PDCs) after extraction of the deciduous canine, and Power and Short⁷ reported a 62% successful eruption rate with the same interceptive technique. Another prospective longitudinal study conducted by Baccetti et al⁸ with an untreated control group indicated that 65% of patients with PDCs who had extraction of the deciduous canine resulted in successful eruption of the permanent canine with no other treatment. The prevalence rate of canine eruption can be improved significantly (up to 88%) by adding forces that prevent mesial migration of the maxillary posterior teeth after extraction of the deciduous canine, such as those exerted by cervical-pull headgear.⁸

Recent data suggest that rapid maxillary expansion (RME) is a valid interceptive treatment option in patients with PDCs. A recent randomized clinical trial reported that RME therapy in the early mixed dentition prevented impaction in 66% of the PDC patients when compared with an untreated control group (14%).⁹ This study used posteroanterior radiographs to measure the distance of the palatally displaced canine cusp to the face midline to diagnose a PDC. Recent data have indicated that PDCs are not correlated to narrow maxillary arches.¹⁰ In this study, RME was performed on PCD patients with the primary aim of relieving mild-to-moderate crowding.

Our study was intended to evaluate further the impact of RME on the eruption rates of PDCs when interceptive treatment is carried out in the late mixed dentition; this has been indicated as an appropriate time to improve arch perimeter by maxillary expansion.¹¹ The aim of this prospective controlled study was to assess the prevalence rates of successfully erupted PDCs diagnosed in the late mixed dentition by means of panoramic radiographs and subsequent treatment with RME, TPA, and deciduous canine extraction. Additional aims of this study were (1) to evaluate further the genetic origin of PCD by investigating its association with other dental anomalies of genetic origin and (2) to identify pretreatment variables associated with successful outcomes of interceptive treatment of PDCs with RME and TPA therapy.

MATERIAL AND METHODS

The control and treated groups consisted of patients included in a 2-center prospective longitudinal clinical

trial at the Department of Orthodontics and Pediatric Dentistry of the University Michigan and the Department of Orthodontics at the University of Florence in Italy. Criteria for enrollment of subjects in the clinical trial at the 2 research units were the following.

1. White race.
2. Age from 9.5 to 13.0 years at the start of treatment (T1).
3. Late mixed dentition.
4. Diagnosis of intraosseous malposition of at least 1 maxillary permanent canine, derived from the analysis of panoramic radiographs according to the method of Ericson and Kuroi¹² by means of alpha angle, d distance, and sector measurements. PDCs with an alpha angle $\geq 15^\circ$ were included in the trial (milder forms of PCD were not included). PCD was confirmed by evaluating the position of the canine on the lateral cephalogram and, when necessary, with Clark's tube shift rule by using multiple intraoral radiographs of the canine region.¹³ Such PDCs were either unilateral or bilateral.
5. Stage of skeletal growth from cervical stage (CS) 1 to CS 4 as assessed on lateral cephalograms of the subjects according to the cervical vertebral maturation (CVM) method.¹⁴
6. Dentoskeletal Class II or Class III tendency or mild tooth size-arch length discrepancy.
7. No previous orthodontic treatment.
8. No supernumerary teeth, odontomas, cysts, craniofacial malformations, or sequelae of traumatic injuries.

A total of 70 subjects were enrolled at T1. They were allocated to 2 groups: treatment group (TG; 40 subjects, 25 girls and 15 boys) or control group (CG; 30 subjects, 18 girls and 12 boys). The TG subjects received treatment from 1 faculty group practitioner (J.A.M.) using a standardized treatment protocol, as described below. The CG subjects had no orthodontic treatment and were observed at the Department of Orthodontics of the University of Florence. Ethical approval was obtained for the enrollment of the subjects in the CG. Informed consent was signed by the parents of all subjects enrolled in the trial at both research sites.

Treatment protocol

The 40 subjects in the TG underwent RME. Thirty-five patients were treated with a bonded acrylic splint RME that covered the maxillary first and second deciduous molars and the maxillary first permanent molars, and the remaining 5 subjects, who had exfoliated deciduous molars, were treated with a banded RME with bands on the maxillary first permanent molars and first premolars.

The midline expansion screw was expanded a quarter turn per day until expansion of about 7 mm was achieved (based on the number of turns recorded in the chart. The duration of active expansion was about 1.1 months, or approximately 5 weeks). After expansion, the RME appliance remained in place for an additional 4 to 5 months to allow for the reorganization of the disrupted sutural tissues. After removal of the RME, a TPA was placed on the maxillary first molars and activated according to the protocol described by McNamara and Brudon.¹⁵ Subjects who were not yet in the advanced late mixed dentition phase after expander removal wore a maxillary acrylic maintenance plate until TPA delivery when the maxillary second molars became loose. TPA treatment is postulated to prevent the mesial movement of the maxillary first molars during the transition to the permanent dentition.¹¹ During TPA treatment, the retained maxillary deciduous canines corresponding to the PDCs were extracted. A primary goal for maxillary expansion in the TG was to improve the intraosseous position of PDCs.⁹ The CG received no orthodontic treatment.

Diagnostic measurements at T1

The panoramic radiographs of all subjects at T1 were analyzed. The following measurements proposed by Ericson and Kuroi¹² were made on the panoramic radiographs (Fig):

1. Alpha angle: mesial inclination of the crown of the permanent canine to the midline (Fig, A).
2. d distance: distance of the cusp tip of the permanent canine from the occlusal line (Fig, B).
3. Sector: the mesial position of the crown of the displaced canine with respect to the central and lateral incisors (5 sectors, with sector 1 indicating the position of the crown of the displaced canine posterior to the distal aspect of the lateral incisor and sector 5 in correspondence with the mesial half of the maxillary central incisor) (Fig, C).

As indicated by Ericson and Kuroi,¹² these measurements are valid diagnostic variables for PDCs in the age range studied in this trial.

The CVM stage was evaluated on the lateral cephalograms of all subjects at T1.¹⁴ The development of the roots of all PDCs was appraised according to the method developed by Nolla.¹⁶

The following measurements proposed by Tollaro et al¹⁷ were made on the dental casts at T1.

1. Maxillary intermolar width: the distance between the central fossae of the maxillary right and left first molars.

2. Mandibular intermolar width: the distance between the tips of the distal cusps of the mandibular right and left first molars.
3. Posterior transverse discrepancy: the difference between the maxillary and mandibular intermolar widths.

In subjects with normal occlusion, the distobuccal cusp of the mandibular first molar occludes with the central fossa of the maxillary first molar.¹⁷ Consequently, in subjects with normal occlusion, maxillary and mandibular intermolar widths are equal. A negative posterior transverse discrepancy between the dental arches indicates a narrower maxillary measurement compared with the mandibular one.¹⁷

Appraisal of dental anomalies associated with PCD

PDCs have been hypothesized to be part of a genetic cluster that includes other dental anomalies clinically associated with canine displacement.¹⁸ The TG and CG subjects analyzed in this study provided a sample of adequate size to investigate significant associations between PCD and the following dental anomalies¹⁸⁻²¹: small maxillary lateral incisors, agenesis of second premolars, distally displaced erupting mandibular second premolars, and infraocclusion of deciduous molars. Small maxillary lateral incisors were defined as a severe crown-size reduction, in some cases associated with narrowing in diameter from the cervix to the incisal edge (peg-shaped lateral incisors). Distally displaced erupting mandibular second premolars were defined as an intraosseous anomalous position of the second premolar with its main axis cutting through the outline of the crown of the adjacent first permanent molar. Infraocclusion of deciduous molars occurs with ankylosis of the deciduous tooth, and the occlusal plane of the deciduous molar is apically positioned relative to the occlusal plane of the adjacent teeth.

The prevalence rates for these associations were contrasted with previously published control data from similar orthodontic populations of similar age ranges.^{18,19}

Reevaluation

According to the prospective design of the trial, all subjects were reevaluated at a second observation time (T2) when they were in the early permanent dentition with a postpubertal stage of CVM (CS 5 or 6). At T2, unerupted canines were considered impacted because the maxillary permanent canines will not erupt spontaneously after CS 5.²²

The number of dropouts was recorded. The main outcome investigated at T2 was successful or unsuccessful eruption of the maxillary permanent canines. A "successful

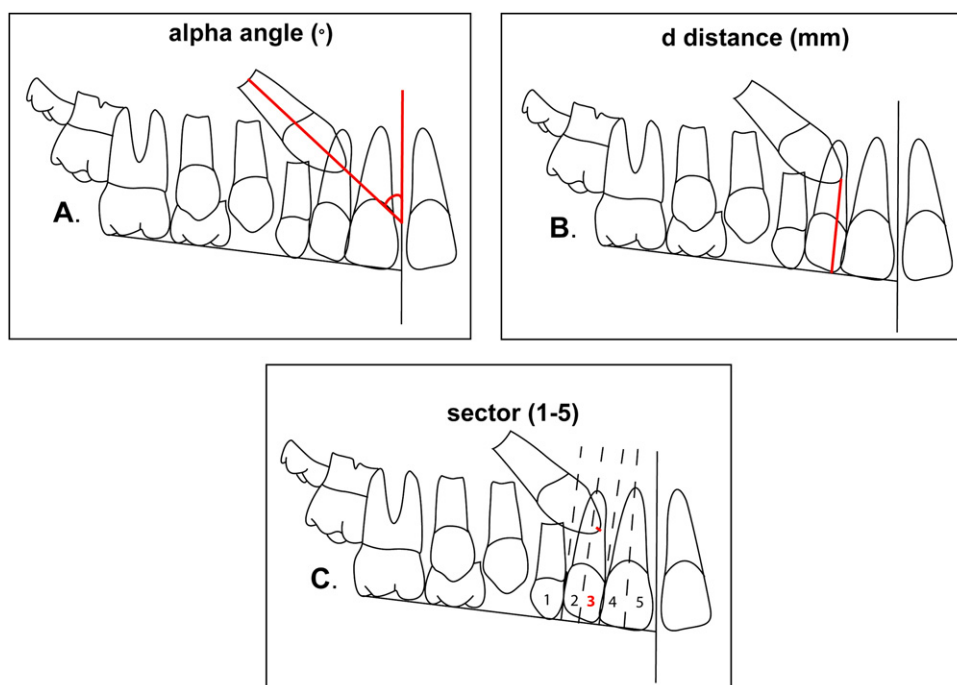


Fig. A, B, and C, Graphic representations of measurements on panoramic radiographs of PCD subjects at T1.

outcome” for PCD was defined as the full eruption of the canine, thus permitting bracket positioning for final arch alignment when needed.²³ An “unsuccessful outcome” was evident when there was no eruption of the permanent canine (impaction) at T2.

The magnification factor for the panoramic films in both groups was 18%. All measurements were performed with the primary investigator (L.M.S.) blinded to the groups.

Power of the study and method error

The estimate of the power of the study was performed before the clinical part of the trial. By considering the standard deviations of the diagnostic measures on the panoramic radiographs from a previous study and by using nonparametric or categorical statistics, the calculated power of the study exceeded 0.90 at an alpha of 0.05 with the sample sizes of 40 and 30 subjects in the 2 groups.⁸

The accuracy of the measurements on panoramic radiographs and dental casts was calculated with Dahlberg’s formula²⁴ on measurements repeated on 15 subjects selected randomly from the 2 groups. The method errors were 1.3° for alpha angle, 0.7 mm for d distance, and <0.2 mm for the 2 dental cast measures. The appraisal of the sector of canine displacement showed reproducibility of 100%. Reproducibility for

the assessment of dental anomalies associated with PCD was 100%.

Statistical analysis

The starting forms at T1 for measurements on panoramic films and dental casts were compared between the TG and the CG with the Mann-Whitney *U* test ($P < 0.05$). Maxillary and mandibular intermolar widths were contrasted with the same test to evaluate a possible interarch transverse discrepancy at T1. The rates of development of the roots of the displaced canines were compared in the 2 groups at T1 as well. The prevalence rates for sectors of canine displacement and for the stages in the CVM in the 2 groups at T1 were compared by means of the chi-square test ($P < 0.05$).

The prevalence rates for successful and unsuccessful subjects at T2 in the TG were compared with those in the CG with chi-square tests ($P < 0.05$).

The successful and unsuccessful groups as defined at the T2 reevaluation were compared with the following variables at T1: alpha angle, d distance, sector, age, CVM stage, and rate of bilateral PDCs. The rates of development of the root of displaced canines at T1 were compared in successful and unsuccessful subjects. These comparisons were carried out with Mann-Whitney *U* tests ($P < 0.05$) for metric measures and chi-square tests ($P < 0.05$) for categorical measures.

Table I. Demographics for the TG and CG at T1

Age and age intervals	Treated group n = 39		Control group n = 29		TG vs CG
	Mean	SD	Mean	SD	Mann-Whitney test
Age T1	10 y 5 mo	10 mo	10 y 5 mo	10 mo	NS
Age T2	14 y 1 mo	1 y 3 mo	13 y 6 mo	10 mo	NS
Average T2-T1 interval	3 y 7 mo	1 y 5 mo	3 y 1 mo	1 y 2 mo	NS
Sex	Patients (n)	Percentage	Subjects (n)	Percentage	Chi-square test
Male	15	38.5%	12	41.4%	
Female	24	61.5%	17	58.6%	NS

NS, Not significant.

Table II. Dental cast measures for the TG vs the CG at T1

Dental cast measurements	Treated group n = 39		Control group n = 29		TG vs CG
	Mean	SD	Mean	SD	Mann-Whitney test
Maxillary intermolar width (mm)	43.3	2.1	44.1	2.1	NS
Mandibular intermolar width (mm)	43.7	1.9	44.3	2.0	NS
Posterior transverse discrepancy (mm)	-0.7	0.2	-0.6	0.3	NS

NS, Not significant.

The TG and the CG were combined to calculate the prevalence rates for dental anomalies associated with PDCs. These rates were compared with those reported by Baccetti et al in 1998¹⁸ and 2009⁹ with chi-square tests ($P < 0.05$). The CG subjects in this study were derived from the same orthodontic population from which these prevalence rates were calculated. Statistical analysis was performed with software (version 16.0.1, Statistical Package for the Social Sciences, SPSS, Chicago, Ill).

RESULTS

The number of dropouts from T1 to T2 was 1 subject in both the TG and the CG. These dropouts were due to the subjects' relocating with their families during the observation period. The final samples (Table I) comprised 39 subjects (24 girls and 15 boys with 65 PDCs) in the TG and 29 subjects (17 girls and 12 boys with 48 PDCs) in the CG. The few dropouts did not affect the power of the study. The mean age at T1 for both groups was 10 years 5 months \pm 10 months. The average age for the TG at T2 was 14 years 1 month \pm 1 year 3 months, and the mean duration of observation was 3 years 7 months. The average age for the CG at T2 was 13 years 6 months \pm 10 months, and the mean duration of observation was 3 years 1 month. There was no statistically significant difference in sex distribution between the TG and the CG.

The descriptive statistics for the measurements on the dental casts and panoramic films at T1 in the 2 groups are reported in Tables II and III. The average maxillary

intermolar widths were 43.3 ± 2.1 mm in the TG and 44.1 ± 2.1 mm in the CG; the average mandibular intermolar widths were 43.7 ± 1.9 mm in the TG and 44.3 ± 2.0 mm in the CG. Posterior transverse discrepancies were -0.7 ± 0.3 mm in the TG and -0.6 ± 0.3 mm in the CG. No statistically significant differences between the TG and CG were evident for any variable. The posterior transverse discrepancy in neither group was significant.

The comparison between the TG and the CG as to alpha angle, d distance, sector of canine displacement, CVM stage, and unilateral vs bilateral occurrence of PCD did not show any significant differences at T1. Root development of PDCs was similar in the 2 groups at T1 as well.

The prevalence rates for successful eruption of PDCs were 79.5% (31 subjects) in the TG and 27.6% (8 subjects) in the CG. The comparison was statistically significant (chi-square = 16.26; likelihood ratio = 19.05; $P < 0.001$).

The comparison between successful vs unsuccessful subjects in the TG (Table IV) showed that, although there was no statistically significant difference for the alpha angle or the d distance, the prevalence rate for less severe sectors of canine displacement (sectors 1 and 2) was significantly greater in successfully treated subjects than in the unsuccessful ones. The prevalence rate at T1 for the pubertal stages of CVM (CS 3 or 4, 62.5%) was significantly greater in unsuccessfully treated subjects than in successful ones, when 84% were in a prepubertal stage. In the CG (Table V), in all successful subjects,

Table III. Radiographic data comparisons for the TG and the CG at T1

Radiographic measurements	Treated group <i>n</i> = 39		Control group <i>n</i> = 29		TG vs CG
	Mean	SD	Mean	SD	Mann-Whitney test
Alpha angle (°)	29.5	7.9	28.5	11.0	
d distance (mm)	16.9	2.8	17.5	3.9	NS
	Patients (<i>n</i>)	Percentage	Subjects (<i>n</i>)	Percentage	Chi-square test
Sector 1	6	15.4%	8	27.6%	NS
Sector 2	20	51.3%	14	48.3%	
Sector 3	10	25.6%	3	10.3%	
Sector 4	3	7.7%	4	13.8%	
CS 1	14	35.9%	7	24.1%	NS
CS 2	15	38.5%	12	41.4%	
CS 3	8	20.5%	10	34.5%	
CS 4	2	5.1%	0	0.0%	
Unilateral	12	30.8%	10	34.5%	NS
Bilateral	27	69.2%	19	65.5%	
	Median	Range	Median	Range	Mann-Whitney test
Root development of PCD	8.75	7.25-9.50	9.00	7.50-9.75	NS

NS, Not significant.

Table IV. Comparison between successful vs unsuccessful subjects in the TG

Radiographic measurements	Unsuccessful <i>n</i> = 8		Successful <i>n</i> = 31		Mean difference	Mann-Whitney test	
	Mean	SD	Mean	SD			
Alpha angle at T1 (°)	33.2	9.6	28.5	5.1	-4.7	NS	
d distance at T1 (mm)	15.8	3.8	17.5	2	1.7	NS	
	Patients (<i>n</i>)	Percentage	Patients (<i>n</i>)	Percentage		Chi-square test	
Sector 1	0	0.0%	5	16.1%	Mild/moderate = 25%	†	
Sector 2	2	25.0%	19	61.3%	Mild/moderate = 77.4%		
Sector 3	4	50.0%	6	19.4%	Severe = 75%		
Sector 4	2	25.0%	1	3.2%	Severe = 22.6%		
CS 1	0	0.0%	14	45.2%	Prepubertal = 37.5%	†	
CS 2	3	37.5%	12	38.7%	Prepubertal = 83.9%		
CS 3	3	37.5%	5	16.1%	Pubertal = 62.5%		
CS 4	2	25.0%	0	0.0%	Pubertal = 16.1%		
Unilateral	2	25.0%	10	32.3%		NS	
Bilateral	6	75.0%	21	67.7%			
	Median	Range	Stage 9	Median	Range	Stage 9	Mann-Whitney test
Root development of PCD	9.00	8.25-9.75	9.6%	8.00	7.25-9.25	50%	*

* $P < 0.01$; † $P < 0.001$; NS, not significant.

the PDCs were exclusively in sectors 1 and 2. The unsuccessful subjects in both groups had significantly more advanced development of the root of the displaced canine than did the successful cases. The percentage of subjects with root development stage 9 according to Nolla¹⁶ (closed root apex) was 4 times greater in unsuccessfully treated subjects than in successfully treated subjects (Table IV), and 2 times greater in unsuccessful control subjects than in successful control subjects

(Table V). No differences were found regarding bilateral vs unilateral PCD with regard to canine eruption (Tables IV and V).

Subjects with PDCs exhibited significantly greater prevalences of small lateral incisors ($P < 0.001$, 6 times greater than in the CG; Table VI), distally displaced erupting mandibular second premolars ($P < 0.001$, 3 times greater than in the control population), and infraocclusion of deciduous molars ($P < 0.05$, 2.5 times greater than in

Table V. Comparison between successful vs unsuccessful subjects in the CG

Radiographic measurements	Unsuccessful <i>n</i> = 21		Successful <i>n</i> = 8		Mean difference	Mann-Whitney test	
	Mean	SD	Mean	SD			
Alpha angle at T1 (°)	31.0	11.5	21.7	5.8	-9.3	NS	
d distance at T1 (mm)	17.3	4.5	18.3	1.8	1.0	NS	
	Subjects (<i>n</i>)	Percentage	Subjects (<i>n</i>)	Percentage	Chi-square test		
Sector 1	2	9.5%	Mild/moderate = 66.7%		6	75.0%	
Sector 2	12	57.1%	Severe = 33.3%		2	25.0%	
Sector 3	3	14.3%	0	0.0%	0	0.0%	
Sector 4	4	19.0%	0	0.0%	0	0.0%	
Unilateral	8	38.1%	2	25.0%	NS		
Bilateral	13	61.9%	6	75.0%			
	Median	Range	Stage 9	Median	Range	Stage 9	Mann-Whitney test
Root development of PCD	9.00	8.00-9.75	57.2%	8.25	7.25-9.25	25%	*

**P* <0.05; NS, not significant.

Table VI. Prevalence of dental anomalies in the TG and CG (combined sample at T1) vs control data

Dental anomaly	Total			Prevalence	Control data	Chi-square test
	CG <i>n</i> = 29	TG <i>n</i> = 39	(CG + TG) <i>n</i> = 68			
Small lateral incisors	10	11	21	30.9%	4.7%	†
Agenesis of mandibular second premolars	2	2	4	5.9%	5.8%	NS
Distally displaced erupting mandibular second premolars	11	8	19	27.9%	8.2%	†
Infraocclusion of deciduous molars	4	5	9	13.2%	5.6%	*

**P* <0.05; †*P* <0.001; NS, not significant.

the control population). No significantly increased prevalence rate for agenesis of the second premolars was found in either group.

DISCUSSION

In this 2-center prospective longitudinal study, we investigated the effectiveness of RME combined with TPA and extraction of the deciduous canine as an interceptive treatment modality for PCD in subjects in the late mixed dentition. PCD was diagnosed via measurements developed by Ericson and Kuroi¹² using panoramic films. A canine with an alpha angle of ≥15° in sectors 2 through 5 and an intraosseous position in the palate as observed on the patient's corresponding lateral cephalogram was deemed to be a PCD. A canine was considered to have erupted successfully at T2 (in the permanent dentition) when bracket placement on its crown became possible without surgical intervention.²³

In the patients, the RME protocol was carried out with the main objective of improving the eruption process of PDCs with other orthodontic indications (eg, mild-to-moderate crowding of the dental arches

or tendency toward Class II or Class III malocclusion). When transverse interarch relationships at T1 were evaluated, the treated and untreated subjects did not have significant amounts of maxillary transverse deficiency. This confirms previous observations in the literature that show that PDCs are not associated with a narrow maxilla.^{9,10}

The outcomes of this study provide further evidence for the genetic origin of PCD, in that it was found to be associated with other dental anomalies of known genetic origin such as small lateral incisors.^{1,18} PDCs also were associated significantly with increased occurrence of both infraocclusion of deciduous molars and distally displaced erupting mandibular second premolars. The significant associations between PCD and these 3 dental anomalies confirm previous data.^{18,19,25} In particular, PCD subjects exhibited a greater prevalence of small lateral incisors (6 times greater compared with control data from previous studies), distally displaced premolars (3 times greater than in the same control data), and infraocclusion of deciduous molars (2.5 times greater).^{18,19} Because these tooth disturbances manifest

before PCD becomes apparent, these dental anomalies can be considered early risk indicators for PCD (especially when they are combined in the same subject), and they indicate that the patient is a candidate for future interceptive treatment of eruption anomalies of the maxillary permanent canines.^{1,18,19,25}

RME followed by TPA in conjunction with extraction of the deciduous canines in late mixed dentition patients was significantly more effective at inducing successful eruption of PDCs (80%) than was no treatment (28%). These results can be contrasted with those from a recent randomized clinical trial in which RME was found to increase the rate of successful canine eruption in early mixed dentition PCD patients (65%) when compared with an untreated control group (14%).⁹ However, in that study, diagnosis of PCD had been carried out on posteroanterior radiographs before the age of 9 years, and no TPA was used during treatment.

When comparing the prevalence rates for successful eruption of PDCs between RME interceptive treatment in this study with previous studies that used other interceptive treatment modalities, the RME and TPA protocol had a slightly higher rate of effectiveness (80%) than what was reported for extraction of the deciduous canine alone (78% according to Ericson and Kuroi,⁶ and 62% according to Power and Short⁷). However, the prevalence rate for favorable outcomes in the study by Ericson and Kuroi⁶ included both canine eruption and improvement of the canine eruption path; in our clinical trial, only full eruption of the canines was considered. Also, the prevalence rates reported in both the studies by Ericson and Kuroi and Power and Short referred to individual PDCs, whereas the prevalence rates for success and failure in our study refer to subjects who had unilateral or bilateral PDCs. Because palatal displacement of maxillary canines has been shown to have a fundamental component of genetic origin, the use of single canines as statistical units is not recommended, since general etiologic factors can affect the eruption process of both maxillary canines in the same subject.^{1,18}

The success rate of RME and TPA treatment compared with extraction of the deciduous canine combined with fixed appliance therapy (75% according to Olive²⁶) was similar, whereas the success rate was slightly lower than the prevalence rate for the eruption of the canines after the use of cervical-pull headgear and extraction of the deciduous canine (88%) as determined by Baccetti et al.⁸ However, when the prevalence rates for successful eruption of PDCs were compared between the TG and the CG in this study and the study by Baccetti et al.⁸ in 2008, the proportion of favorable outcomes in the RME, TPA, and deciduous canine extraction sample over the respective controls (2.9 times more) was greater

than the proportion in subjects treated with cervical-pull headgear and deciduous canine extraction over the respective controls (2.4 times more).

Pretreatment variables associated with a successful outcome of interceptive treatment of PDCs with RME, TPA, and extraction of the deciduous canine protocol were identified. RME treatment in the late mixed dentition was less successful in facilitating canine eruption in patients who began treatment at CS 3 or 4 in CVM (pubertal patients) than in patients who began treatment at CS 1 or 2 (prepubertal patients). Sixty-three percent of patients in the unsuccessful TG were at pubertal stages in skeletal maturation, and 84% of patients in the successful TG were at prepubertal stages. Moreover, canines with more severe displacement as shown by the sector measurement were less likely to erupt successfully. Similarly, recent retrospective studies by Olive²⁷ and Zuccati et al.⁴ found that the more mesial the cusps of the PDCs (a measurement analogous to the sector measurement) before treatment, the longer the treatment for impacted canines. These results are also similar to findings by Baccetti et al.,²⁸ who found the sector measurement to be a valuable prognostic indicator for the success of combined surgical and orthodontic treatment of impacted canines. In contrast to these previous studies, the pretreatment alpha angle was not associated with success or unsuccess of PCD interceptive treatment.^{4,28} The sector of canine displacement at T1 was significantly related to the possibility of spontaneous eruption of the canine in the CG as well.

PDCs with a fully developed root demonstrated significantly less probability of successful eruption. Both groups showed lower prevalences of successful eruption of PDCs when the root apex was closed (Nolla's stage 9).¹⁶ A higher prevalence rate of eruption was seen for PDCs in which the root apex was still developing (even when more than two thirds of the root had already formed, as in Nolla's stage 8).¹⁶ These data confirm previous observations by Kokich and Mathews,²⁹ who reported a high probability of impaction when the root apex of the tooth is complete. When the information derived from the canine root development was combined with the data concerning the CVM staging of our subjects, it could be concluded that interceptive treatment for PDCs at a prepubertal stage in skeletal maturation and before the closure of the canine's root apex leads to significantly more successful outcomes than postponing treatment until puberty or when its apex is formed completely.

A general overview of the possibilities of various protocols of interceptive treatment for PCD suggests that extraction of the deciduous canine alone can double the chance of eruption of the palatally displaced

maxillary permanent canine between 10 and 13 years of age (about 60%-65% eruption).⁶⁻⁸ The addition of other therapeutic adjuncts in the late mixed dentition, such as the RME and TPA approach described here or the cervical-pull headgear investigated by Baccetti et al,⁸ increases the prevalence rate of successful eruption of the canine after interceptive treatment up to 80% to 90%. However, a greater burden of treatment is placed on the patient when these more complex approaches are used compared with the simple extraction of the associated deciduous tooth. In patients with an indication for either of the 2 combination treatment protocols, such as maxillary transverse deficiencies for the RME approach, need for molar distalization for the headgear approach, or Class II or Class III tendencies or mild-to-moderate tooth size-arch length discrepancy, the highly significant facilitation of eruption of PDCs should be considered an extremely favorable side effect of these orthodontic treatment options in the late mixed dentition.^{11,30,31}

CONCLUSIONS

We found that RME followed by TPA coupled with extraction of the deciduous canine is an effective interceptive treatment option for patients from 9 years 5 months to 13 years of age with PDCs. The use of this protocol in subjects in the late mixed dentition increases the rate of eruption of PDCs significantly (80%) when compared with an untreated PCD control group (28%).

The following radiographic factors are significantly associated with palatal canine impaction after interceptive treatment including RME and TPA therapy: pubertal CVM stages vs prepubertal, more mesial sectors of intraosseous displacement of the canine, and closure of the canine root apex. This study confirmed that several dental anomalies are significantly associated with PDCs and are valuable as early risk indicators for PCD: small lateral incisors, infraocclusion of deciduous molars, and distally displaced erupting mandibular second premolars.

We thank Heidi Novak for her assistance in evaluating the stages of root development of PDCs.

REFERENCES

1. Peck S, Peck L, Kataja M. The palatally displaced canine as a dental anomaly of genetic origin. *Angle Orthod* 1994;64:249-56.
2. Kohavi D, Becker A, Zilberman Y. Surgical exposure, orthodontic movement, and final tooth position as factors in periodontal breakdown of treated palatally impacted canines. *Am J Orthod* 1984;85:72-7.
3. Barlow ST, Moore MB, Sherriff M, Ireland AJ, Sandy JR. Palatally impacted canines and the modified index of orthodontic treatment need. *Eur J Orthod* 2009;31:362-6.
4. Zuccati G, Ghobadlu J, Nieri M, Clauser C. Factors associated with the duration of forced eruption of impacted maxillary canines: a retrospective study. *Am J Orthod Dentofacial Orthop* 2006;130:349-56.
5. Becker A, Chaushu S. Long-term follow-up of severely resorbed maxillary incisors after resolution of an etiologically associated impacted canine. *Am J Orthod Dentofacial Orthop* 2005;127:650-4.
6. Ericson S, Kuroi J. Early treatment of palatally erupting maxillary canines by extraction of the primary canines. *Eur J Orthod* 1988;10:283-95.
7. Power SM, Short MB. An investigation into the response of palatally displaced canines to the removal of primary canines and an assessment of factors contributing to favourable eruption. *Br J Orthod* 1993;20:215-23.
8. Baccetti T, Leonardi M, Armi P. A randomized clinical study of two interceptive approaches to palatally displaced canines. *Eur J Orthod* 2008;30:381-5.
9. Baccetti T, Mucedero M, Leonardi M, Cozza P. Interceptive treatment of palatal impaction of maxillary canines with rapid maxillary expansion: a randomized clinical trial. *Am J Orthod Dentofacial Orthop* 2009;136:657-61.
10. Langberg BJ, Peck S. Adequacy of maxillary dental arch width in patients with palatally displaced canines. *Am J Orthod Dentofacial Orthop* 2000;118:220-3.
11. McNamara JA Jr, Baccetti T, Franchi L, Herberger TA. Rapid maxillary expansion followed by fixed appliances: a long-term evaluation of changes in arch dimensions. *Angle Orthod* 2003;73:344-53.
12. Ericson S, Kuroi J. Radiographic examination of ectopically erupting maxillary canines. *Am J Orthod Dentofacial Orthop* 1987;91:483-92.
13. Bishara SE, Kommer DD, McNeil MH, Montagano LN, Oesterle LJ, Youngquist W. Management of impacted canines. *Am J Orthod* 1976;69:371-87.
14. Baccetti T, Franchi L, McNamara JA Jr. The cervical vertebral maturation (CVM) method for the assessment of optimal treatment timing in dentofacial orthopedics. *Semin Orthod* 2005;11:119-29.
15. McNamara JA Jr, Brudon WL. *Orthodontics and dentofacial orthopedics*. Ann Arbor, Mich: Needham Press; 2001.
16. Nolla CM. The development of permanent teeth. *J Dent Child* 1960;27:254-66.
17. Tollaro I, Baccetti T, Franchi L, Tanasescu CD. Role of posterior transverse interarch discrepancy in Class II, Division 1 malocclusion during the mixed dentition phase. *Am J Orthod Dentofacial Orthop* 1996;110:417-22.
18. Baccetti T. A controlled study of associated dental anomalies. *Angle Orthod* 1998;68:267-74.
19. Baccetti T, Leonardi M, Giuntini V. Distally displaced premolars: a dental anomaly associated with palatally displaced canines. *Am J Orthod Dentofacial Orthop* 2010;138:18-22.
20. Wasserstein A, Brezniak N, Shalish M, Heller M, Rakocz M. Angular changes and their rates in concurrence to developmental stages of the mandibular second premolar. *Angle Orthod* 2004;74:332-6.
21. Shalish M, Chaushu S, Wasserstein A. Malposition of unerupted mandibular second premolar in children with palatally displaced canines. *Angle Orthod* 2009;79:796-9.
22. Baccetti T, Franchi L, De Lisa S, Giuntini V. Eruption of the maxillary canines in relation to skeletal maturity. *Am J Orthod Dentofacial Orthop* 2008;133:748-51.
23. Leonardi M, Armi P, Franchi L, Baccetti T. Two interceptive approaches to palatally displaced canines: a prospective longitudinal study. *Angle Orthod* 2004;74:581-6.
24. Dahlberg G. *Statistical methods for medical and biological students*. London, United Kingdom: Bradford and Dickens;1940.

25. Sacerdoti R, Baccetti T. Dentoskeletal features associated with unilateral or bilateral displacement of maxillary canines. *Angle Orthod* 2004;74:725-32.
26. Olive RJ. Orthodontic treatment of palatally impacted maxillary canines. *Aust Orthod J* 2002;18:64-70.
27. Olive RJ. Factors influencing the non-surgical eruption of palatally impacted canines. *Aust Orthod J* 2005;21:95-101.
28. Baccetti T, Crescini A, Nieri M, Rotundo R, Pini Prato GP. Orthodontic treatment of impacted maxillary canines: an appraisal of prognostic values. *Prog Orthod* 2007;8:6-15.
29. Kokich VG, Mathews DP. Surgical and orthodontic management of impacted teeth. *Dent Clin North Am* 1993;37:181-204.
30. Guest SS, McNamara JA Jr, Baccetti T, Franchi L. Improving Class II malocclusion as a side-effect of rapid maxillary expansion: a prospective clinical study. *Am J Orthod Dentofacial Orthop* 2010;138:582-91.
31. O'Grady PW, McNamara JA Jr, Baccetti T, Franchi L. A long-term evaluation of the mandibular Schwarz appliance and the acrylic splint expander in early mixed dentition patients. *Am J Orthod Dentofacial Orthop* 2006;130:202-13.