ORIGINAL ARTICLE

Buccally impacted maxillary canines increase the likelihood of root separation in adjacent first premolars

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OBJECTIVE: To investigate the influence of maxillary impacted canines on the root morphology of adjacent premolars in a Chinese population.

SUBJECTS AND METHODS: A sample of 370 Chinese subjects with maxillary canine impaction and 370 control subjects were collected in this study. CBCT data of all subjects were collected and analyzed. The prevalence of separate-rooted maxillary premolars was compared between subjects with and without impacted canines. Then, the prevalence of separate-rooted maxillary premolars was compared between subjects with buccal canine impaction (BIC) and those with palatal impaction (PIC).

RESULTS: The prevalence of separate-rooted first premolars was significantly higher in the canine impaction group (P = 0.046), but the prevalence of separate-rooted second premolars was not different (P = 0.780). Furthermore, a significant higher prevalence of first premolar root separation was found on the impacted site in the BIC subgroup (P < 0.001), but not in the PIC subgroup (P = 0.508). Also, the prevalence of separate-rooted first premolars in the BIC subgroup was significantly higher than that of the control group (P = 0.008), but not so for the PIC subgroup (P = 0.097).

CONCLUSIONS: Buccally impacted maxillary canines are associated with an increased prevalence of root separation in the adjacent maxillary first premolars. This is likely because that buccally impacted canines encroach on the space needed for root development of the first premolars.

Keywords: tooth root morphology; impacted canine; premolar; cone-beam computed tomography

Introduction

Knowledge about the prevalence of root separation in maxillary premolars and its associated factors is important for clinical dentistry, including canal preparation for endodontic treatment, orthodontic temporary anchorage device placement near the premolar roots, and design of surgical approach for their extraction when needed (Li et al, 2013; Consolaro and Romano, 2014; Agarwal et al, 2015). Among all four types of permanent premolars, the maxillary first premolar shows the most distinctive variation (Vertucci, 1984; Aoki, 1990; Chaparro et al, 1999; Atieh, 2008; Awawdeh et al, 2008; Tian et al, 2012). In Caucasians, two-rooted maxillary first premolars are the most common form with a prevalence ranging from 55% to 80% (Vertucci, 1984; Chaparro et al, 1999; Atieh, 2008; Awawdeh et al, 2008), while in Asians, one-rooted form predominates with a prevalence of approximately 65% (Aoki, 1990; Tian et al, 2012). Regardless of ethnicity, three-rooted maxillary first premolars are relatively rare with a prevalence of 0.8–4% (Chaparro et al, 1999; Atieh, 2008; Awawdeh et al, 2008; Tian et al, 2012).

Several previous studies have attempted to identify factors contributing to the variation of root morphology in Caucasians. Although certain genes such as Msx1 and Wnt have been found to play a role (Garn et al, 1960; Pelsmaekers et al, 1997), most studies indicated that the variation of first premolar roots was associated with environmental conditions, especially the impaction of adjacent canines. In two early case reports (Kerrigan and Sandy, 1995; McNamara and McNamara, 2000), it was speculated that root dilacerations of first maxillary premolars were a possible cause for canine impaction. Then, Chate (2004; 2003) reported that the developing first premolar root may be more prone to dilacerations in response to an impacted canine. More recently, Bertl et al (2013) found that palatal maxillary canine impaction increased the prevalence of...
one-rooted premolars. They further explained that this was because canine impaction influences root development of the first premolars by increasing local space.

For Asians, to date, no studies have investigated the relationship between maxillary canine impaction and the variation of premolar root morphology. As Asians differ from Caucasians in the predominant type of maxillary canine impaction (buccal rather than palatal) (Yan et al., 2013) and in first premolar root morphology (predominantly single-rooted rather than two-rooted) (Atieh, 2008; Awawdeh et al., 2008; Tian et al., 2012), whether the findings obtained from Caucasians described above is applicable to Asians is currently unclear. To clarify this issue, this study investigated the relationship between maxillary canine impaction and premolar root morphology in a Chinese population using cone-beam computed tomography (CBCT) imaging technique. Specifically, we addressed whether and how maxillary canine impactions might change the prevalence of root separation in premolars, followed by discussion of the applicability of the space interference theory proposed by Bertl et al. (2013).

Subjects and methods

Subjects

A retrospective sample of 370 Han Chinese subjects with maxillary canine impaction (experimental group) and 370 age- and sex-matched control subjects consecutively selected from a pool of patients referred for orthodontic treatment at the Affiliated Stomatological Hospital of Nanjing Medical University (Nanjing, China) from June 2010 to August 2014 were used in this study. All subjects in the experimental group met two inclusion criteria: clinically diagnosed maxillary canine impaction and in permanent dentition and three exclusion criteria: previous orthodontic treatments, dental trauma, and history of anterior maxillary dental surgery. All subjects in the control group also met the same inclusion and exclusion criteria except for the presence of maxillary canine impaction.

Radiographic examination

All CBCT scans were acquired from the same CBCT machine (NewTom VG; QR srl, Verona, Italy) with a standard acquisition protocol (16-cm diameter field-of-view, 110 kV, 1–20 mA-pulsed mode, and 0.3-mm voxel size).

A single blinded rater (C.D.) removed patient identification information of all CBCT data (DICOM files) and renamed them with randomly generated codes. Then, the DICOM files were imported into SimPlant O&O (version 13.0, Materialise NV, Leuven, Belgium) and reconstructed for analysis. The images of each case were presented on a 15.6-in computer screen with a 1920 × 1080 pixel screen resolution and analyzed by the same rater (C.D.) based on the following standardized protocol. The 3-D surface rendering was displayed at default threshold value of teeth (1200-3071) in the program. Registration of the status of the canines, position of the impacted canines, and root separation of the first and second premolars were recorded on the same basis and confirmed in the volumetric and three orthogonal (sagittal, coronal, and axial) views. Root separation (two or more roots) was diagnosed if it was clearly present on two consecutive slices (Figure 1). The angles (the angle between the long axis of maxillary impacted canine and adjacent first premolars, Angle3_4) and distances (the distance between the cusp tip of maxillary impacted canine and the deepest points of the central fossae of adjacent first premolars, Distance3_4) between maxillary impacted canine and adjacent first premolars were subsequently measured and analyzed (Figure 2). To evaluate intra-examiner reliability, CBCT images from 150 randomly selected subjects of the whole sample were diagnosed by the same rater after a 1-month interval.

The study protocol was approved by the IRB of Affiliated Hospital of Stomatology, Nanjing Medical University (PJ2011-030-001) on June 01, 2011. At the time of imaging, all participants provided informed consent that their radiographic records (with all individually identifiable information concealed) may be used for future research projects on canine impaction.

Statistical analyses

Intrarater reliability was assessed using Cohen’s kappa test for prevalence of separate-rooted premolars. Descriptive statistics were applied for the distribution of sex, age, Angle’s classifications, and root separation. The prevalence of separate-rooted premolars (2- and 3-rooted teeth combined) between impacted sides and contralateral sides was compared using the McNemar test. Chi-square or Fisher’s exact tests (if incidence<5) were used to compare the prevalence of separate-rooted premolars between subjects with and without impacted canines. To further analyze the association of the position of the impacted canines with root separation of premolars, subjects with canine impactions were categorized into buccal and palatal impaction subgroups, and the prevalence of separate-rooted premolars between the subgroups was also compared using chi-square test. All statistical analyses were performed using SPSS (version 19.0, IBM, Chicago, IL, USA), and P < 0.05 was considered statistically significant.

Results

Characteristics of study subjects

A total of 740 subjects were consecutively included in this study. Characteristics of age, sex, and Angle’s classifications and status of canine eruption are summarized in Table 1. Gender, age, and Angle’s classifications distribution among the unilateral impacted, bilateral impacted,
and erupted canine groups was comparable. Among unilateral canine impaction subjects, 203 were buccally positioned and 124 were palatally positioned. The kappa values reflecting intrarater reliability for image assessment (diagnosis of maxillary premolar root numbers) were 0.97 for the first premolars and 1.00 for the second premolars.

Root morphology of maxillary premolars in relation to the status of canine eruption

Root morphology of maxillary premolars in the control group with normally erupted canines is summarized in Table 2. No significant differences in the prevalence of root separation were found between the right and left side. Thus, both sides were combined for subsequent analysis, which showed that the average prevalence of separate-rooted first premolars and second premolars was 21.3% and 1.6%, respectively.

To evaluate the association between premolar root morphology and canine impaction, subjects with canine impaction (including both unilateral and bilateral impactions) were compared with the control group. As shown in Figure 3, compared to the control group, the prevalence of separate-rooted first premolars and second premolars was significantly higher than that of the control group ($P = 0.046$), while the prevalence of separate-rooted second premolars was not different ($P = 0.780$, Figure 3).

Subsequently, to assess whether the lower prevalence of single-rooted maxillary first premolars was associated with a particular location of impacted canines, subjects with unilateral canine impaction were divided into buccally impacted canine (BIC) and palatally impacted canine (PIC) subgroups for the following comparisons. First, comparisons were conducted between the impacted and erupted side within each subgroup. A significant higher prevalence of maxillary first premolar root separation was found on the impacted side in the BIC subgroup ($P < 0.001$), but not in the PIC subgroup ($P = 0.508$) (Figure 4). Then, comparisons were made between the impaction subgroups and the control group. As shown in Figure 5, the prevalence of separate-rooted maxillary first premolars in the BIC subgroup was statistically significant higher than that of the control group ($P = 0.008$), but there was no statistical difference between the PIC subgroup and the control group ($P = 0.097$). Finally, in cases with bilateral impacted canines, buccally impacted canines were associated with a higher number of adjacent separate-rooted maxillary first premolars than were palatally impacted canines, but the difference was not statistically significant because of the small sample size ($P > 0.05$, Table 3). And, bilateral buccal impaction tended to be associated with a higher percentage of separate-rooted first premolars (33.3%, Table 3) than unilateral buccal impaction (30%, Figure 5), but the differences were insignificant ($P = 0.724$). This may be also due to a small sample size of the bilateral impaction group. To explain probable cause for this, further comparisons were made between the one-rooted and separate-rooted maxillary first premolars on the impacted side of the BIC and PIC subgroup. As shown in Table 4, the Angle3_4 and Distance3_4 were measured and analyzed. The results of analysis of variance (ANOVA) showed significant differences among the BIC one-rooted subgroup, the BIC separate-rooted subgroup, the PIC one-rooted subgroup, and the PIC separate-rooted

Table 1 The characteristic of the sample

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Impacted canine group</th>
<th>Erupted canine group</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unilateral (n = 327)</td>
<td>Bilateral (n = 43)</td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female (%)</td>
<td>181 (55.4)</td>
<td>19 (44.2)</td>
<td>200 (54.1)</td>
</tr>
<tr>
<td>Male (%)</td>
<td>146 (44.6)</td>
<td>24 (55.8)</td>
<td>170 (45.9)</td>
</tr>
<tr>
<td>Age</td>
<td>Mean ± s.d., y</td>
<td>15.2 ± 4.6</td>
<td>15.5 ± 4.7</td>
</tr>
<tr>
<td>Angle’s Classifications</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ClassI (%)</td>
<td>126 (38.5)</td>
<td>14 (32.6)</td>
<td>140 (37.8)</td>
</tr>
<tr>
<td>ClassII (%)</td>
<td>142 (43.4)</td>
<td>16 (37.2)</td>
<td>158 (42.7)</td>
</tr>
<tr>
<td>ClassIII (%)</td>
<td>59 (18.1)</td>
<td>13 (30.2)</td>
<td>72 (19.5)</td>
</tr>
</tbody>
</table>

*Comparison with chi-square tests among the three groups.

Table 2 Root morphology of the maxillary premolars in the control group (n = 370)

<table>
<thead>
<tr>
<th>Root morphology</th>
<th>Single root (%)</th>
<th>Two root (%)</th>
<th>Three root (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right first premolar</td>
<td>292 (78.9)</td>
<td>75 (20.3)</td>
<td>3 (0.8)</td>
</tr>
<tr>
<td>Left first premolar</td>
<td>298 (80.5)</td>
<td>69 (18.7)</td>
<td>3 (0.8)</td>
</tr>
<tr>
<td>Right second premolar</td>
<td>363 (98.1)</td>
<td>7 (1.9)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Left second premolar</td>
<td>365 (98.6)</td>
<td>5 (1.4)</td>
<td>0 (0)</td>
</tr>
</tbody>
</table>
subgroup. Further analysis revealed that the Angle3_4 and Distance3_4 of the BIC one-rooted subgroup were significantly higher than those of the BIC separate-rooted subgroup (Table 4).

Discussion

Consistent with previous reports on Asians (Aoki, 1990; Tian et al., 2012; Yang et al., 2014), our data showed that the majority of maxillary premolars in Chinese were single-rooted (Table 2). Also as expected, the prevalence of separate-rooted premolars in our subjects was lower than that in Caucasians (Vertucci, 1984; Chaparro et al., 1999; Atieh, 2008; Awawdeh et al., 2008). Surprisingly, however, we found maxillary canine impaction was associated with an increased prevalence of root separation in maxillary first premolars (Figure 3), which contradicts the findings in Caucasians, whose maxillary canine impaction was associated with a decreased prevalence of root separation (Bertl et al., 2013). While this difference is likely related to some ethnical variations, further analysis of these findings suggests that the specific locations (buccal or palatal) of the impacted canines may be playing a larger and more direct role.

In Caucasians, it was suggested that canine impaction influences the root development of the first premolars by creating wider local space, which reduces the need for root separation or divergence (Bertl et al., 2013).

Table 3 The prevalence of maxillary premolars with separate roots in subjects with bilaterally impacted canines

<table>
<thead>
<tr>
<th>Prevalence of separate-rooted teeth (%)</th>
<th>Bilateral impaction (n = 43)</th>
<th>Buccally Bilateral impaction (n = 27)</th>
<th>Palatally Bilateral impaction (n = 16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First right premolar</td>
<td>12 (27.9)</td>
<td>9 (33.3)</td>
<td>3 (18.8)</td>
</tr>
<tr>
<td>First left premolar</td>
<td>10 (23.3)</td>
<td>8 (29.4)</td>
<td>2 (12.5)</td>
</tr>
<tr>
<td>Second right premolar</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Second left premolar</td>
<td>1 (2.3)</td>
<td>0 (0)</td>
<td>1 (6.3)</td>
</tr>
</tbody>
</table>
Table 4 The measurements of maxillary impacted canine and adjacent first premolars between the one-rooted maxillary first premolars group and separate-rooted group

<table>
<thead>
<tr>
<th>Measurements</th>
<th>BIC One root</th>
<th>BIC Separated root</th>
<th>PIC One root</th>
<th>PIC Separated root</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle3_4(°)</td>
<td>37.00</td>
<td>25.77</td>
<td>30.01</td>
<td>30.79</td>
<td>0.013</td>
</tr>
<tr>
<td>Distance3_4(mm)</td>
<td>14.57</td>
<td>11.78</td>
<td>13.51</td>
<td>14.16</td>
<td>0.011</td>
</tr>
</tbody>
</table>

*BIC, buccally impacted canine; PIC, palatally impacted canine; One root, one-rooted maxillary first premolars group; Separated root, separate-rooted maxillary first premolars group; Angle3_4, the acute angle between maxillary impacted canine and adjacent first premolars; Distance3_4, the distance between the cusp tip of maxillary impacted canine and the deepest points of the central fossae of adjacent first premolars.

Regardless of ethnicity, normally, the maxillary canine tooth buds reside on the distal–buccal of the primary canine. To create more space for the first premolar root development, the canines need to migrate substantially in the mesial and palatal directions. As we previously reported (Yan et al., 2013), such migration happens only to palatally impacted canines but not to buccally impacted canines. More specifically, due to the lack of normal guidance from the lateral incisor roots (missing or peg-shaped lateral incisors), the canines can take large and consistent mesial–palatal migrations before they reach the thick palatal cortical plate and become palatally impacted. Consistent with these data, the majority of subjects (75.6%) included in the Bertl et al.’s study had palatal canine impaction. Therefore, the explanation that canine impaction creates a wider space for first premolar root development as proposed by Bertl et al. (2013) is applicable to palatally impacted canines. And, no statistically significant difference was detected in subjects with buccally impacted canines because of limited sample number in the Bertl et al.’s study, but not so for our study.

For buccally impacted maxillary canines that are more common in Asians including Chinese, it is mainly due to narrow dental arch or skeletal (premaxilla) width; therefore, most likely narrower instead of wider spaces are created for first premolar root development (Jacoby, 1983; Yan et al., 2013). No study so far has longitudinally observed the migration path of buccally impacted canines, but our previous work has suggested that buccally impacted canines mostly migrate in a buccal or buccal–distal direction (Yan et al., 2013). This migration pattern, distinctly different from palatally impacted canines, is very likely to encroach on the space needed for first premolar development. Substantiating this notion, our current data strongly suggested that buccal canine impaction is associated with increased prevalence of first premolar root separation, a finding not commonly seen in palatally impacted canines. More specifically, although overall the impaction subjects had a higher prevalence of separate-rooted first premolars than the control subjects (Figure 3), further analysis revealed that this difference was mainly caused by buccally impacted canines rather than palatally impacted canines. After dividing the impaction subjects into buccal and palatal impaction subgroups, we found that only in patients with unilateral buccally impacted canines, the prevalence of separate-rooted first premolars was significantly higher on the impacted side than on the contralateral normal side (Figure 4). In addition, compared to the control group with normal canine eruption, only subjects with buccally impacted canines had significantly more prevalent separate-rooted first premolars than the control patients (Figure 5).

Our explanation that buccally impacted canines reduce local space for first premolar root development was also supported by the finding that second premolar root development was not affected by the impacted canines. These data strongly suggest that premolar root development is sensitive to local spatial conditions, which can be interfered by canine impaction, instead of a general variation in space within the dental arch. This agrees with the finding of a previous case report that presented a developing root deviation of first premolar adjacent to a buccally impacted canine over the course of 1 year and the root deviation was considered as the result of close spatial relationship during tooth eruption and root development (Chate, 2004). This explanation is further supported by the measurements of the angles and distances between the impacted canines and adjacent first premolars. More specifically, as shown in Table 4, for separate-rooted first premolar, the average angle to the impacted canine was significantly more acute and the average distance to the impacted canine was smaller, than those of single-rooted premolars.

Taken together, our data were not contradictory to the findings and interpretations reported by Bertl et al. (2013), but did provide an important addition to refine the space influencing theory proposed by them. That is, maxillary canine impaction can significantly affect root morphology of the adjacent first premolar by interfering with local space, but depending on the specific location of the impacted canines, the outcomes vary. To be more specific, palatal canine impaction, the predominant type in Caucasians, increases the spaces for the first premolars and results in more single-rooted teeth; buccal canine impaction, the dominant type in Asians, decreases the space for the first premolars and results in more separate-rooted teeth.

As with many studies, this study has several limitations and certain cautions need to be exercised when generalizing our findings. First, a retrospective sample of Han Chinese patients was used in this study. The lack of previous similar studies for this population precluded us from conducting a power analysis for sample size determination before the study. Nevertheless, through a post hoc power analysis based on our data, we confirmed that the sample size (370/group) has a 94.7% power to detect the differences between the groups (calculated in G*Power 3.1.9.2, Universität Kiel, Germany). Next, all subjects in this study were patients seeking orthodontic treatments. It has been found that the prevalence of malocclusion in the general Chinese population was nearly 70% and there was a trend of increase in the last 40 years (Fu et al., 2002). Based on
this report, our sample represents the general population fairly well, but we cannot completely rule out the possibility that there may be differences between our sample and the general population. Finally, all subjects in this study received 16-cm field-of-view and 0.3-mm voxel-size CBCT scans. This may be considered by some investigators a higher radiation exposure than our research focus on the maxillary canine region in this project, especially according to the European guidelines (Isaacson, 2013). This potential limitation is largely associated with the use of a retrospective sample of orthodontic patients as mentioned above, whose imaging records were used for both treatment planning and research. On the other hand, inclusion of both jaws in the CBCT scan has allowed us to study dental anomalies in the mandible likely related to maxillary canine impaction based on a subsample of this study (Yan et al., 2013). More importantly, a single 16-cm field-of-view CBCT scan allowed us not to take additional panoramic and cephalometric images for clinical treatment planning. According to Loubelle et al. (2009), a 16-cm field-of-view 0.3-mm voxel-size CBCT using NewTom 3G has a 57 μSv effective dose. Had a maxilla-only field-of-view CBCT taken, together with the additional panoramic and cephalometric X-rays, the effective dose would be about 50 μSv, which is only slightly lower than the 16-cm field-of-view scan. Therefore, this limitation is relatively minor.

Conclusion

Based on the analysis of CBCT images from a large sample of Chinese patients with and without maxillary canine impaction, this study revealed that there was a significantly increased likelihood of root separation in first premolars when the adjacent canines were buccally impacted. This finding confirms that maxillary canine impaction can interfere with the space needed for first premolar root development, with buccal and palatal impactions resulting in opposite changes in local space and probability of root separation in the first premolars.

Acknowledgements

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Author contributions

Dan Cao and Linlin Zhu, the main researchers, contributed equally to this study. They have designed the study, performed the literature search, acquired the data, assessed the results, and drafted the manuscript. Yali Chen has acquired the data and assessed the results. Lizhe Xie has acquired the data. Zongyang Sun has designed the study and revised it critically for important intellectual content. Bin Yan has designed, supervised the study, revised it critically for important intellectual content, and finally approved the version to be published.

Conflicts of interest

None to declare.

References


Oral Diseases