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Bone growth assessed by cephalometric radiographs correlates with impacted canine diagnosis

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The number of patients with impacted teeth is increasing. We investigated the relationship between impacted canines and jawbone growth and development. Panoramic and lateral cephalometric radiographs of 80 patients with malocclusion involving impacted maxillary canines were analysed and classified using sector and McSherry and Pitt *et al.*'s classifications. Sella turcica bridging and ponticulus posticus formation were studied to assess the relationship of growth and development with impacted maxillary canines. Bone age was assessed by Baccetti's cervical vertebral maturation stages. Classes I, II and III sella turcica bridging occurred in 48.7%, 47.5%, and 3.8% of the cases, while ponticulus posticus classifications occurred in 82.5%, 12.5%, and 5% of cases, respectively. Cervical vertebral maturation stages were one stage lower than chronological age. Although the chronological age and the positional assessment of the impacted canines were correlated positively with the sector classification and McSherry and Pitt *et al*.'s classification for Classes 1 and 3, they correlated negatively for Class 2. The trend in bone growth delay correlated negatively with the distribution in McSherry and Pitt *et al*.'s Class 2. Assessing cervical vertebral maturation stage, sella turcica bridging, and the ponticulus posticus formation may facilitate early diagnosis of impacted canines, and could facilitate future orthodontic treatment. (J Osaka Dent Univ 2020 ; 54 : 283-292)

Key words : Cervical vertebral maturation stage ; Impacted maxillary canines ; Orthodontic treatment ; Sella turcica bridging ; Ponticulus posticus

INTRODUCTION

Recently, the number of patients visiting dental offices complaining chiefly of impacted teeth has increased. Several reports have addressed impacted teeth, including diagnosis and therapeutic procedures with orthodontic treatments.[1-3] However, the aetiological details remain poorly understood, although narrowing of the jaw may be a factor. Impacted maxillary canines, a common form of abnormal tooth eruption,[2-5] occurs twice as frequently in women as in men.[6] As reported, 85% and 15% of impacted canines occur on the palatal or buccal sides, respectively.[7, 8] Causes of impacted maxillary canines are broadly classified into factors related to induction of eruption and genetics.[9] Factors related to induction of eruption involve the effects of local material factors on the path of canine eruption.[10] Eruption may be hindered by abnormal location of the impacted canines, insufficient space for eruption, or other obstacles. Genetic factors have been implicated in lower positioning of the molars, timing of enamel calcification, premolar malformation, and formation of peg lateral incisors.[3, 11, 12]

In orthodontic treatment, cephalometric radiographs are taken to assess growth and development, and the craniomaxillofacial structure. Sella turcica, cervical spine, and other craniomaxillofacial regions are particularly useful for early appraisal of jaw development.[13-15] The sella turcica, located in the base of the skull, undergoes calcification and may share a similar embryological origin as the jaw, making it a potential indicator of genetic factors affecting the development of the maxilla, palate, and anterior facial bones.[7, 16, 17] Calcification or abnormal bridging of the sella turcica has been implicated in abnormal development of the sphenoid bone[9] and in craniomaxillofacial or systemic developmental abnormalities, as well as local abnormalities, such as congenitally missing teeth or impacted teeth.[17, 18]

The cervical spine and the facial skull are also reportedly correlated.[19] Correlation was reported between the cervical spine incline relative to the base of the skull and the direction of the growth of the mandible.[20] Relationships also exist between the height of the posterior arch of the first cervical vertebra (the atlas), also known as the ponticulus posticus, and the direction of growth of the mandible, as well as between cervical spine morphology and bone age.[21] The third cervical vertebra and the calcification stage of the cervical spine are also used to assess bone age.[22, 23] Moreover, abnormal development of the cervical spine is associated with abnormal maxillofacial morphology, occlusion, and teeth.[24] Furthermore, the formation of the ponticulus posticus is closely related to growth and development, and is thought to be related to impacted teeth.[14]

Given the increase in the number of cases of impacted teeth compared to previous studies,[25] we here investigated the relationship between impacted canines and jawbone growth and development by using panoramic and lateral cephalometric radiographs that are taken when orthodontic treatment is initiated. We also focused on the process of formation of the cervical spine and the sella turcica, as indicative of genetic factors related to abnormal growth and development, to understand the relationship between bone age and impacted maxillary canines.

MATERIALS AND METHODS

Subjects

Among the patients who visited our institution between January 2009 and December 2018 (aged 7 to 14 years), we assessed lateral cephalometric and panoramic radiographs of 80 children (36 boys and 44 girls) whose Hellman's dental age was IIIB and who had impacted maxillary canines. The positional relationships of the impacted canines were studied and assessed two-dimensionally from panoramic radiographs. The lateral cephalometric radiographs were used to assess the relationship of impacted canines with growth and development. No individuals with major diseases, cleft lip and palate, or craniofacial syndromes were included in the study. A period of operator training was commenced prior to data collection and evaluation. All patients were allocated subject numbers, so that the operator was blind to the subgrouping of the patients to minimise bias. No more than 10 radiographs were traced in one session to avoid fatigue of the operator.

As a retrospective study, this study has no identifiable patient information and is therefore exempt from individual informed consent. This study was conducted with the approval of the Ethics Committee of Osaka Dental University (Approval No. 110961).

Methods

In the present study, skeletal classifications were determined based on cephalometric analysis, with the bones classified according to previous methods,[26, 27] where skeletal 1, 2 and 3 represent ANB angles of 1.0−4.0° ; > 4.0° ; and < 1.0°, respectively. The panoramic radiographs were used for sector classification as previously described.[28] Sector classification is an assessment of the state of overlap between the crown of an impacted maxillary canine and the root of the lateral incisor, with classifications ranging from sectors I to IV.[25, 28] McSherry and Pitt *et al*.'s classifications 1 to 4 were used for two-dimensional examination and assessment of the positional relationships of the impacted maxillary canines.[8, 25, 29, 30] Classification 1 represents horizontal overlap between the crown of the canine and the root of the lateral incisor. Classification 2 represents vertical overlap of the crown of the canine to the lateral incisor. Classification 3 represents the angle of the canine relative to the midline. Classification 4 represents the location of the apex of the canine. Each of these classifications is subdivided into 3 subgroups (e.g., 1-1, 1-2 and 1-3). Previous studies have used these classifications to investigate prognosis indicators.[29-31]

Next, the relationship of abnormal eruption of the impacted canines with growth and development was studied. We focused particularly on the maturity of the sella turcica and the cervical spine. For the sella turcica, we employed a previous scoring scale,[14, 18] that has been used to investigate bridges formed by calcification between clinoid processes. The maximum anteroposterior distance (distance from the tip of the tuberculum sellae to the tip of the posterior wall of the sella) of the sella turcica was assessed, as was the maximum anteroposterior diameter (greatest distance between the tip of the tuberculum sellae and the posterior counter of the sella) (Fig. 1). The degree of bridging calcification was studied with regard to the relationship between sella turcica bridging and the impacted maxillary canines, using the previous scoring scale as follows : Class I is no calcification or bridging (normal appearance of the sella turcica) ; for Class II the interclinoidal distance (sella length) was either equal to or greater than 3/4 of the greatest anteroposterior diameter (i.e., partial calcification) ; and for Class III the interclinoidal distance was equal to or less than 3/4 of the greatest anteroposterior diameter (i.e., complete calcification) (Fig. 2).[14, 18]

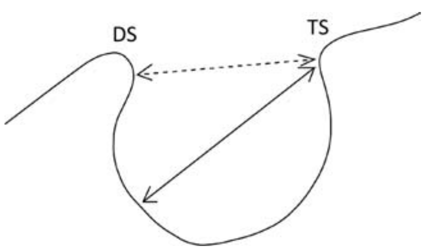
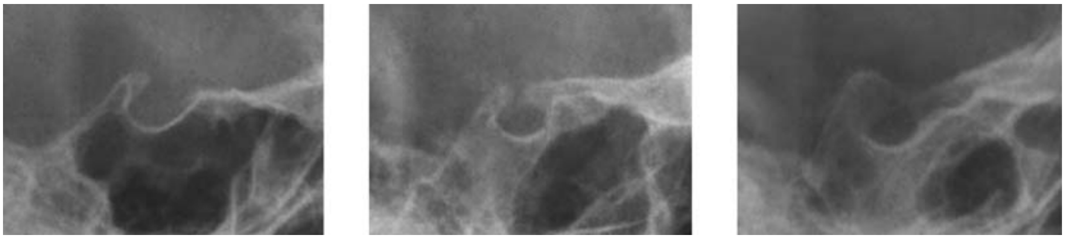


Fig. 1 Sella turcica. DS : dorsum sellae, TS : tuberculum sellae, Continuous line : the interclinoidal distance, Dotted line : the greatest anteroposterior diameter of the sella.

For the cervical spine, we focussed on calcification of the posterior arch of the atlas (ponticulus posticus)[14, 18] to assess the relationship with impacted maxillary canines where Class I is no calcification (no bony emergence was observed) ; Class II is incomplete calcification (partial bony emergence) ; and Class III is complete calcification (complete bone bridge was observed) (Fig. 3). We also focused on bone age, by investigating differences between chronological and bone age in patients with impacted maxillary canines. Bone age was assessed by the cervical vertebral maturation stages (CS1-CS6)[32] (Fig. 4), where in CS1 the lower borders of C2-4 are all flat (or slightly convex) ; in CS2 concavity is present at the lower border of C2 (odontoid process) and C3 and C4 are wedge-shaped or trapezoidal ; in CS3 different concavities are present at the lower borders of C2 and C3 and the vertebral bodies of C3 and/or C4 are still trapezoidal ; in CS4 all vertebrae have concavity on the lower border, and C3 and C4 vertebral bodies are horizontal rectangles ; in CS5 the C3 and C4 vertebral bodies are square, and the

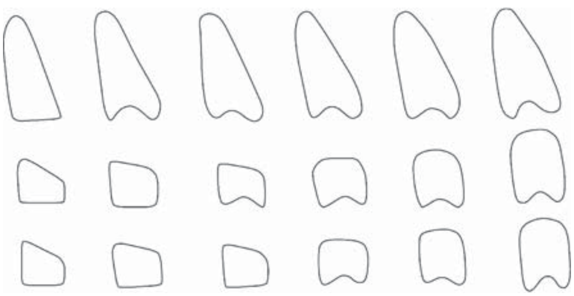


Class I Class II Class III

Fig. 2 Sella turcica bridging. Class I : No calcification or bridging (normal appearance of the sella turcica), Class II : The interclinoidal distance (sella length) was either equal to or greater than 3/4 of the greatest anteroposterior diameter (i.e., partial calcification), Class III : The interclinoidal distance was equal to or less than 3/4 of the greatest anteroposterior diameter (i.e., complete calcification).

Class I Class II Class III

Fig. 3 Extent of development of the ponticulus posticus on the atlas. Class I : No calcification (no bony emergence was observed), Class II : Incomplete calcification (partial bony emergence), Class III : Complete calcification (complete bone bridge was observed).

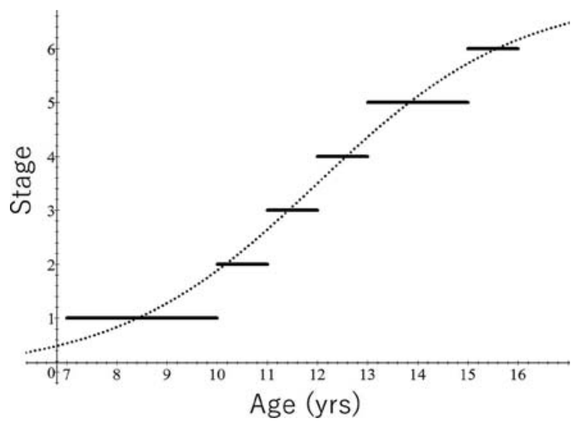


CS 1 CS 2 CS 3 CS 4 CS 5 CS 6

Fig. 4 Cervical vertebral maturation stages. CS1 : The lower borders of C2-4 are all flat (or slightly convex), CS2 : Concavity is present at the lower border of C2 (odontoid process) and C3 and C4 are wedge-shaped or trapezoidal, CS3 : Different concavities are present at the lower borders of C2 and C3, and the vertebral bodies of C3 and/or C4 are still trapezoidal, CS4 : All vertebrae have concavity on the lower border, and C3 and C4 vertebral bodies are horizontal rectangles, CS5 : The C3 and C4 vertebral bodies are square, and the posterior height is the same as its width, CS6 : The C3 and C4 vertebral bodies are vertical rectangles (i.e., the posterior height is greater than the width).

Table 1 Classes of chronological age corresponding with cervical vertebral maturation stages

Cervical vertebral maturation stage	Chronological age (class)
CS 1	7-10(A1)
CS 2	10-11(A2)
CS 3	11-12(A3)
CS 4	12-13(A4)
CS 5	13-15(A5)
CS 6	15-16(A6)



Dotted curve presents the stage, which is 7×logistic ((Age-12)/2), which is a rough continuous model of the stages.

posterior height is the same as the width ; and in CS6 the C3 and C4 vertebral bodies are vertical rectangles (i.e., the posterior height is greater than the width).

Stages of age distribution (A1-A6 ; patients' actual chronological age), with respect to the cervical vertebral maturation stages (CS1-CS6), pertaining to the cervical vertebral maturation stages and to bone age, as previously described,[32-36] were also investigated (Table 1). The age distribution in Table 1 was also used to establish bone growth delay, defined by subtracting the age stage (A1-A6) from the cervical vertebral maturation stage (CS1-CS6). With bone growth delay, the more negative the value, the lower the bone age (cervical vertebral maturation stage) compared to the chronological age.

Statistical analysis

The statistical processing software program EZR[37] version 1.38 based on R version 3.5.3, was used to study the correlation of impacted maxillary canines with growth and delay from various measured values obtained from the panoramic and lateral cephalometric radiographs. Correlations were evaluated using Pearson's correlation coefficient (r-value), and the hazard ratio p-value was calculated. p-values less than 0.05 were considered statistically significant.

RESULTS

There were 43 and 37 cases of unilaterally and bilaterally impacted maxillary canines for a total of 117 teeth (Fig. 5). In the sector classification, most were Class I, followed by Class IV (Table 2 A). Using McSherry and Pitt *et al*.'s classification, almost half were classified as Class 1-1 for Class 1 ; while for Class 2, slightly more than half were classified as Class 2-2 ; and for Class 3, about one-third each were classified as Class 3-1 and Class 3-2, excluding the 6.8% that exhibited negative angle values. For Class 4, most were classified as Classes 4-2 and 4-1 (Table 2 A). These findings were consistent with prior results.[25]

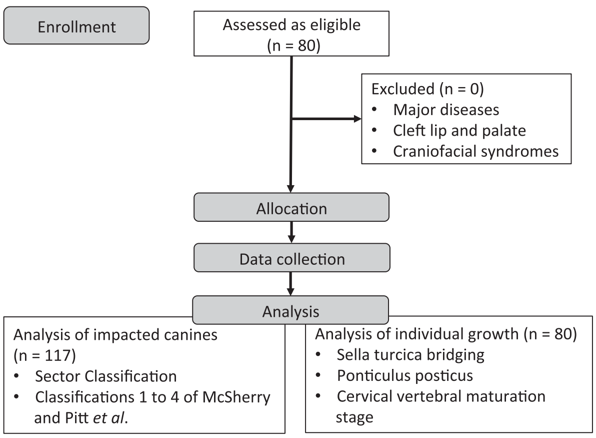


Fig. 5 Flowchart of this study.

In terms of sella turcica calcification, almost equal proportions were classified as Classes I and II, with a minority classified as Class III (Table 2 B). For the ponticulus posticus, the overwhelming majority were classified as Class I (Table 2 B). The distribution of bone growth delay in patients with impacted maxillary canines is shown in Table 3. The overall mean and standard deviation of growth delay were −0.97 and 0.13.

In patients with impacted maxillary canines, chronological age and the positional assessment of

Table 2 (A) Distribution of impacted canines by sector classification and the classification by McSherry and Pitt *et al.,* and (B) Distribution of sella turcica bridging, ponticulus posticus and skeletal classification for patients with impacted canines

Classification	Number	%
Sector classification		
I	51	43.6
II	17	14.5
III	13	11.1
IV	36	30.8
Classification by McSherry and Pitt *et al.*		
Class 1-1	56	47.9
1-2	24	20.5
1-3	37	31.6
Class 2-1	40	34.2
2-2	60	51.3
2-3	17	14.5
Class 3-1	37	31.6
3-2	45	38.5
3-3	27	23.1
3-excluded	8	6.8
Class 4-1	52	44.4
4-2	54	46.2
4-3	11	9.4

A

Classification	Number	%
Sella turcica bridging		
Class I	39	48.7
Class II	38	47.5
Class III	3	3.8
Ponticulus posticus		
Class I	66	82.5
Class II	10	12.5
Class III	4	5.0
Skeletal classification		
1	44	55.0
2	31	38.8
3	5	6.2

B

Table 3 Distribution of bone growth delay in patients with impacted maxillary canines

Class	CS1	CS2	CS3	CS4	CS5	CS6
A1	0 (17)	1 (1)	2 (0)	3 (0)	4 (0)	5 (0)
A2	−1 (11)	0 (7)	1 (2)	2 (1)	3 (0)	4 (0)
A3	−2 (11)	−1 (3)	0 (7)	1 (0)	2 (0)	3 (0)
A4	−3 (7)	−2 (5)	−1 (2)	0 (1)	1 (0)	2 (0)
A5	−4 (2)	−3 (1)	−2 (1)	−1 (1)	0 (0)	1 (0)
A6	−5 (0)	−4 (0)	−3 (0)	−2 (0)	−1 (0)	0 (0)

Bone growth delay = y − x (CS = y, A = x), Mean ± SD : −0.97 ± 0.13.

Table 4 Correlation with positional evaluation of impacted maxillary canines

	Sector	McSherry and Pitt *et al.*			
		Class 1	Class 2	Class 3	Class 4
Chronological age	*$p=0.007$, $r=0.247$	*$p=0.004$, $r=0.261$	*$p=0.009$, $r=-0.240$	*$p=0.004$, $r=0.263$	$p=0.807$, $r=0.022$
Cervical vertebral maturation stages	*$p=0.020$, $r=0.214$	*$p=0.005$, $r=0.257$	$p=0.068$, $r=0.168$	*$p=0.011$, $r=0.231$	$p=0.409$, $r=-0.076$
Bone growth delay	$p=0.578$, $r=0.051$	$p=0.670$, $r=0.039$	*$p=0.0006$, $r=-0.312$	$p=0.385$, $r=0.081$	$p=0.496$, $r=0.063$

Correlation coefficient r and the risk ratio p were calculated from the obtained data. *$p<0.05$

the impacted maxillary canines correlated positively with the sector classification, and with McSherry and Pitt *et al*.'s Classes 1 and 3, and negatively with that of Class 2. Bone age positively correlated with sector classification, and with McSherry and Pitt *et al*.'s Classes 1 and 3. Bone growth delay correlated negatively with McSherry and Pitt *et al*.'s Class 2. Correlations are summarised in Table 4.

DISCUSSION

Impacted maxillary canines are a problem commonly encountered by orthodontists in daily practice. Our objective was to gain a better understanding of the causes of impacted maxillary canines, which may allow earlier and more accurate diagnosis in patients requiring orthodontic treatment. This may result in safer treatment and better outcomes. In this study, cervical vertebral maturation stages were one stage lower than the chronological age. Chronological age and the positional assessment of the impacted canines correlated positively with the sector classification, and with McSherry and Pitt *et al*.'s Classes 1 and 3, and correlated negatively with their Class 2. The trend in bone growth delay correlated negatively with the distribution in McSherry and Pitt *et al*.'s Class 2.

In this study, we found 54% unilateral and 46% bilateral impacted canines, with unilateral impaction being more common than bilateral impaction. As previously explained, the eruption of impacted canines is hindered by abnormal positioning, insufficient space for eruption, or other obstacles. The maxillary canines, like the mandibular third molars, are very frequently impacted ; the incidence of ectopic canine eruption was reported as 1.7%, while another study showed that the majority (92%) of impacted maxillary canines are unilateral.[6, 38-40] Our subjects were aged 7 to 14 years, and the majority were classified as skeletal 1 (Table 2 B), similar to previous study findings.[25, 41]

In sector classification, the present study revealed sector I as the most frequent, followed by sector IV, with sector III being the least frequent. No resorption was observed in the roots of the adjacent lateral incisors for the 81 impacted canines in sectors I-III. Root resorption of the lateral incisors was seen, however, with 12 of the 36 teeth in sector IV. Our findings are similar to those of a previous study that classified most teeth (n=25) into sector I, with sector III being the least common.[42] In the present study, two-thirds of sector IV impactions caused root resorption of the adjacent teeth. A previous study, which reported that the most severely impacted canines were in sector IV, agreed with our findings.[28]

Based on McSherry and Pitt *et al*.'s classifications, Class 1-1 (no horizontal overlap) was the most frequent for Class 1, which corresponds to the most frequent result by sector classification (sector I, no horizontal overlap). For Classes 2 to 4, the most common subclasses were Class 2-2, 3-2, and 4-2, respectively. Among females older than 14 years, root resorption was exhibited at the lateral incisors in a group with an angle of at least 25° relative to the canine midline, as seen in Class 3.[43] Our study included two subjects 14 years of age, both of whom had an angle of incline that exceeded 25° relative to the midline. However, neither had root resorption. Consequently, our results supported that of a previous study.[25]

We studied the relationship between sella turcica bridging and impacted maxillary canines. Morphological changes in the anterior wall of the sella, the anterior clinoidal process, and sella length play extremely important roles in the formation of bridging.[3, 4] Bone fusion occurs early, and as a child matures, minute changes in the length and bridging of the sella turcica occur.[4] Additionally, the anterior part of the sella turcica, the pituitary gland, and the dental epithelial progenitor cells share a common origin (the predominant derivatives of the neural crest cells).[16] The sella turcica is a major area for the migration of neural crest cells and is an area of maxillary, palatal, and frontonasal growth and development.[17] Prenatal congenital abnormalities, including an abnormal cartilage primordium, reportedly have the potential to cause bridging of the sella turcica[44] and may be related to the pathway of the internal carotid artery.[45] Homeobox mutations and the sonic hedgehog gene are thought to have a negative impact on the development of the midface, teeth, and sella turcica.[46, 47] According to the above theory, the canines and the sella turcica have a common origin. With changes in developmental stages, sella turcica bridging could simultaneously bring about impacted canines.[3]

In our study, among patients with impacted maxillary canines, sella turcica calcification was 48.7% in Class I, 47.5% in Class II, and 3.8% in Class III, showing 51.3% had partial or complete bridging. When compared to three previous studies, we observed a lower rate of partial or complete bridging of the sella turcica.[3, 48, 49] In previous studies, partial or complete bridging was 52.6%,[14] 60%,[48] 70%[49] and 80%.[3] However, these differences may be due to varying sample sizes or ethnic and racial differences between the study populations. Although lower, our result at 51.3% was similar to the 52.6% in a previous study.[14] This suggests that sella turcica bridging is related to the occurrence of impacted maxillary canines. Thus, sella turcica bridging potentially affects impacted maxillary canines, and may be used to predict impacted canines.

We also studied the relationship between ponticulus posticus development and impacted maxillary canines. A positive correlation has been reported between ponticulus posticus development and palatally impacted canines.[14, 48] Due to compression of the neurovascular structures passing through the arcuate foramen, this structure can cause neck pain, chronic tension headaches, vertigo, shoulder and arm pain, and neurosensory-type hearing loss. Vertebrobasilar insufficiency can also occur.[50-55] Formation of the ponticulus posticus also reportedly causes chronic cervical pain, headaches, Lhermitte's phenomenon (an electric sensation felt through the back), cervical myelopathy, and stenosis of the atlas and axis.[19, 50, 56, 57]

Our results suggested that formation of the ponticulus posticus may predict impacted maxillary canines. This is consistent with a previous study showing that ponticulus posticus formation was Class I, II or III in 57.1%, 20% and 22.9% of the cases, respectively.[48] Leonardi *et al*.[14] reported that subjects with palatally impacted canines more often had a ponticulus posticus (Class II and Class III: 15.8%) than subjects with no impacted teeth (control group) (4.3%). The results of our study were similar to those of Leonardi *et al*.,[14] with 82.5% in Class I, 12.5% in Class II, and 5% in Class III. As suggested, patients with impacted canines should be screened for ponticulus posticus in order to prevent latent clinical symptoms due to the abnormal formation of the ponticulus posticus.[48]

We studied the cervical vertebral maturation stages and the severity of impacted maxillary canines. We used the cervical vertebral maturation stages (CS1-CS6), as were used in a previous study,[32] to assess the second to fourth cervical vertebrae based on lateral cephalometric radiographs (Fig. 4). When we compared chronological age and bone age in patients with impacted maxillary canines, we found they had a cervical vertebral maturation stage that was one stage lower than their chronological age, with a mean of −0.97 and a standard deviation of 0.13. This shows that cervical vertebral maturation stages and bone growth delay could be a criterion for early diagnosis of impacted maxillary canines. This suggests that the age distribution used in this study (Table 1), based on those of previous reports,[32-36] is effective for assessing both chronological and bone age.

However, results may also be affected by ethnic and racial differences between study groups. A control group (patients with no impacted canines) should thus be used to verify whether the definition of the relationship between the cervical vertebral maturation stages (CS1-CS6) and chronological age (A1-A6) is valid. In previous studies,[58-61] cervical vertebral maturation stages were considered effective because of their high reliability, similar to carpal bone radiographs for assessing bone age. The morphological features of the cervical spine were assessed by three parameters : convexity, height, and morphology of the lower border of the vertebral body. The degree of convexity is a particularly useful parameter[59] for classifying cervical spine maturity.[35, 58]

Furthermore, we examined the correlation among chronological age, bone age (cervical vertebral maturation stage), and bone growth delay in the positional assessment of impacted maxillary canines. We found that chronological age and the positional assessment of the impacted maxillary canines positively correlated for sector classification and for McSherry and Pitt *et al*.'s classification in Classes 1 and 3, and negatively correlated for Class 2. These results imply that the severity of maxillary tooth impaction depends on age. In addition, the correlation between bone age (cervical vertebral maturation stage) and the positional assessment of the impacted maxillary canines was positive for the sector classification, and for Classes 1 and 3 by McSherry and Pitt *et al*.'s classification. However, the correlation between bone growth delay and the positional assessment of the impacted maxillary canines was negative only for Class 2 by McSherry and Pitt *et al*.'s classification. This shows that chronological age is split into bone age (cervical vertebral maturation stage) and bone growth delay (Table 4). Factors related to positional assessment of impacted maxillary canines involve not only chronological age, but also bone age and bone growth delay. Although the validity of the model definition in Table 1 should be studied, the above findings suggest that impacted maxillary canines and bone growth delay are indeed related. The results thus support the notion that patients with impacted maxillary canines have a cervical vertebral maturation stage (bone age) that is one stage lower than their chronological age.

CONCLUSION

There is a high likelihood that impacted canines cause root resorption of adjacent teeth, and thus warrant careful consideration. We found that patients with a lower bone age than chronological age tend to have impacted canines. Sella turcica bridging and ponticulus posticus formation were also shown to be related to impacted canines. Thus, assessing bone age (cervical vertebral maturation stage), sella turcica bridging, and the state of formation of the ponticulus posticus may aid in the early diagnosis of impacted canines, and may facilitate future orthodontic treatments for impacted teeth.

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CONFLICTS OF INTEREST
There are no conflicts of interest to declare.

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