Available online at www.sciencedirect.com
SciVerse ScienceDirect
British Journal of Oral and Maxillofacial Surgery 51 (2013) 63–68
BRITISH Journal of Oral and Maxillofacial Surgery
www.bjoms.com

Condylar subchondral formation of cortical bone in adolescents and young adults

Jie Lei[a,b], Mu-Qing Liu[a,b], Adrian U. Jin Yap[c,d,e], Kai-Yuan Fu[a,b,*]

[a] *Center for TMD & Orofacial Pain, Peking University School & Hospital of Stomatology, Beijing, PR China*
[b] *Department of Oral & Maxillofacial Radiology, Peking University School & Hospital of Stomatology, Beijing, PR China*
[c] *Raffles Dental, Raffles Hospital, Singapore, Singapore*
[d] *Department of Restorative Dentistry, Faculty of Dentistry, National University of Singapore, Singapore, Singapore*
[e] *School of Science and Technology, SIM University, Singapore, Singapore*

Accepted 13 February 2012
Available online 10 March 2012

Abstract

We investigated subchondral formation of cortical bone in the condyles of adolescents and young adults, and looked for age-related and sex-related differences in bony formation with the aid of cone-beam computed tomography data in 1438 subjects aged between 10 and 30 years. The scans were part of the hospital's clinical protocol for patients seeking orthodontic or orthognathic treatment. No patient had signs or symptoms of temporomandibular disorders. Central images of the coronal and sagittal planes of the condyle were acquired and scored. Subchondral formation of cortical bone was seen as a high-density compact linear image, and subjects were classified into complete, partial, and no formation. Subchondral formation of cortical bone was first seen at the ages of 13–14 in boys and 12–13 in girls. Complete cortical bony formation was seen after the age of 22 years for men and 21 for women. We conclude that cortical bone begins to form around the periphery of the condyles during adolescence (12–14 years). A continuous, homogeneous, and compact cortical bony layer is established in young adults by the age of 21–22, indicating full development of the mandibular condyle. The condylar bone developed gradually and was generally fully developed a year earlier in women than men.

Keywords: Temporomandibular joint; Mandibular condyle; Growth and development; Cone-beam computed tomography

Introduction

Development of the mandibular condyle is closely related to the growth and development of the mandible. In the foetal period condylar chondrogenesis begins, together with endochondral ossification, which leads to formation of the condyle. During the twelfth week of foetal development, secondary cartilage forms on the surface of the osseous condyle. As chondrogenesis and endochondral ossification progress, the condyle elongates and the mandibular ramus increases in height. The condylar cartilage is relatively thinner, as endochondral ossification occurs faster than chondrogenesis. The cartilage will not be replaced by osseous tissue until the age of 20–25 years.[1–3]

The three of parts of the temporomandibular joint (TMJ), the articular eminence, the articular fossa, and the mandibular condyle, generally develop concurrently. By measuring 90 skulls, Katsavrias and Dibbets deemed that the height and inclination of the articular eminence nearly acquired their ultimate morphology by the age of 20 during the postnatal craniofacial growth period.[4,5] A study of human remains from 49 people between birth and 20 years that used quantitative angular measurement of the degree of development of the eminence, showed that development velocity diminished to zero by the middle to late teens.[6]

* Corresponding author at: Center for TMD & Orofacial Pain and Department of Oral & Maxillofacial Radiology, Peking University School & Hospital of Stomatology, No. 22 Zhong Guan Cun South Ave, Beijing 100081, PR China. Tel.: +86 10 82195342; fax: +86 10 62173402.
E-mail address: kqkyfu@bjmu.edu.cn (K.-Y. Fu).

0266-4356/$ – see front matter © 2012 The British Association of Oral and Maxillofacial Surgeons. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.bjoms.2012.02.006

Once the condyle has matured, endochondral ossification gradually ceases and a continuous, compact subchondral bony plate develops. The bone plate is seen as lamellar bone under light microscopy.[7] Ingervall et al. made a microradiographic study of specimens of TMJ from 22 cadavers aged 1 month to 23 years, and reported that a continuous bony layer around the periphery of the condyle (cortical bone) did not develop fully before the age of 20.[8]

The studies cited all involved a small number of dead people. Compact subchondral cortical bone can be detected using radiography in living subjects, and may be useful for evaluating condylar development.[9,10] Publications that have reported this, however, are limited and warrant investigation, particularly with the increasing use of cone-beam computed tomography (CBCT) in dental practice. We have used CBCT imaging to investigate the subchondral formation of cortical bone in subjects 10–30 years old. Age-related and sex-related differences in the formation of cortical bone were also calculated to try to understand the stage of maturity of growth of the condylar head.

Table 1
Age and sex distribution of the 1438 subjects.

Age (years)	Male ($n = 480$)	Female ($n = 4958$)	Total ($n = 1438$)
10	0	8	8
11	7	19	26
12	11	45	56
13	27	50	77
14	31	38	69
15	19	35	54
16	27	33	70
17	15	30	45
18	34	57	91
19	40	54	94
20	36	68	104
21	40	53	93
22	28	75	103
23	24	75	99
24	24	64	88
25	21	50	71
26	20	54	74
27	18	38	56
28	22	39	61
29	23	37	60
30	13	26	39
Total	480	958	1438

Subjects and methods

CBCT imaging data of patients aged between 10 and 30 years old who attended our hospital from 2006 to 2011 for orthodontic or orthognathic treatment were used. The images of the TMJ were taken as part of the hospital's routine clinical protocol for patients who required orthodontic or orthognathic treatment, functional appliances, surgical orthodontics, and for patients with complaints of pain in the jaw or functional disability. The patients were screened for signs and symptoms of temporomandibular disorders (TMDs) using a history questionnaire and clinical examination as part of their initial orthodontic and orthognathic assessment. Because the study was retrospective it was exempt from the need for ethics committee approval. Data files from a total of 1438 subjects with no signs or symptoms of TMD, including radiographic osteoarthrosis, were extracted. The age and sex distribution of the subjects is shown in Table 1. Bilateral CBCT images of the TMJ were obtained using a three dimensional multi-image micro-CT (J. Morita Corp, Kyoto, Japan) at 76–80 kV and 4.2–6 mA. The scanned data were reconstructed, and multiple images of axial, coronal, and sagittal planes of the joints at 1.0 mm slice intervals were obtained.

The image of the central sagittal plane that was perpendicular to the condylar transverse axis was acquired through the middle point of the condyle on the axial plane. The image of the central coronal plane was acquired through the apex of the condyle on the sagittal plane. Photographic copies of the representative central images of the sagittal and coronal planes were produced (Figs. 1–3). The images were then independently evaluated by two assessors who had no knowledge of the identity of the subjects, or their age and sex. When there was disagreement, a final classification was derived from discussion.

The cortical formation of bone on condyles was classified as follows:

Complete formation of cortical bone. Continuous, homogeneous, and compact cortical bony layer around the peripheral of the condyle. A continuous, high-density, compact linear image was seen on the condyle (Fig. 1).
Partial formation of cortical bone. Partial compact cortical bony layer around the peripheral of the condyle. A discrete, high-density, compact, linear image was observed on the condyle (Fig. 2).
No cortical bone. Absence of a compact cortical bony layer around the periphery of the condyle (Fig. 3).

Percentages of the three classifications of stages of the formation of cortical bone for the different sex and ages were computed and analysed. The differences between individual bilateral condyles were assessed with the help of the chi square test, and probabilities of less than 0.05 were accepted as significant.

Results

Subchondral formation of cortical bone on the condyles was usually seen first when boys were 13–14 years old and girls 12–13. More than 90% of younger subjects before the age evaluated had none. Complete formation of cortical bone was recorded after the ages of 22 for men and 21 for women (Figs. 4 and 5). The percentage of condyles on which formation of cortical bone had been completed generally increased

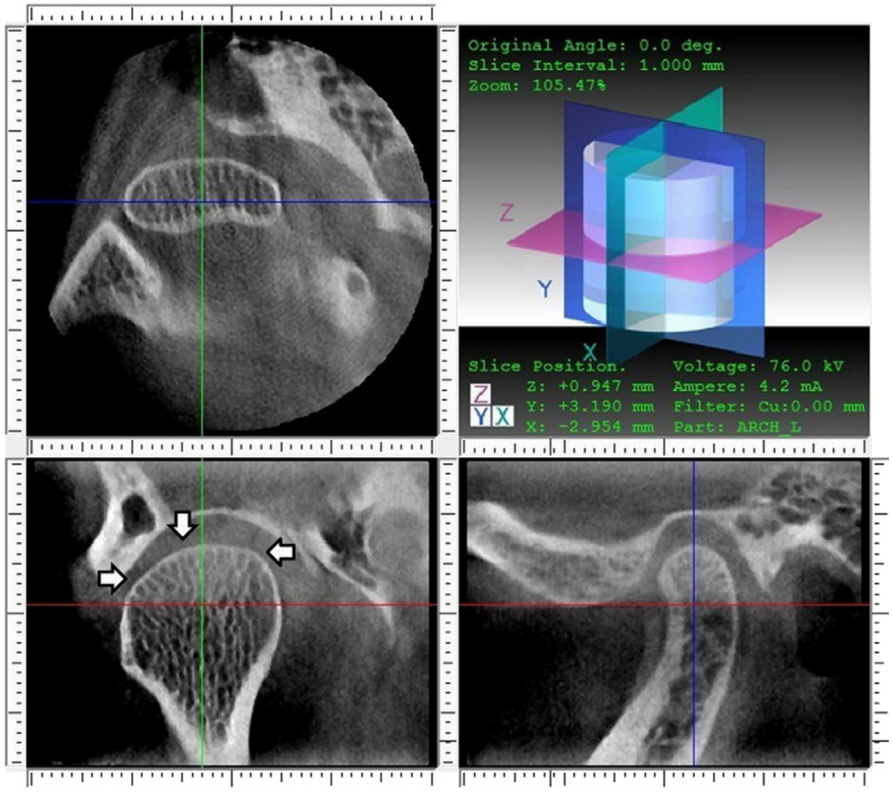

Fig. 1. Complete formation of cortical bone in a 23-year-old woman. There was a continuous high-density compact linear image on the condyle (arrows).

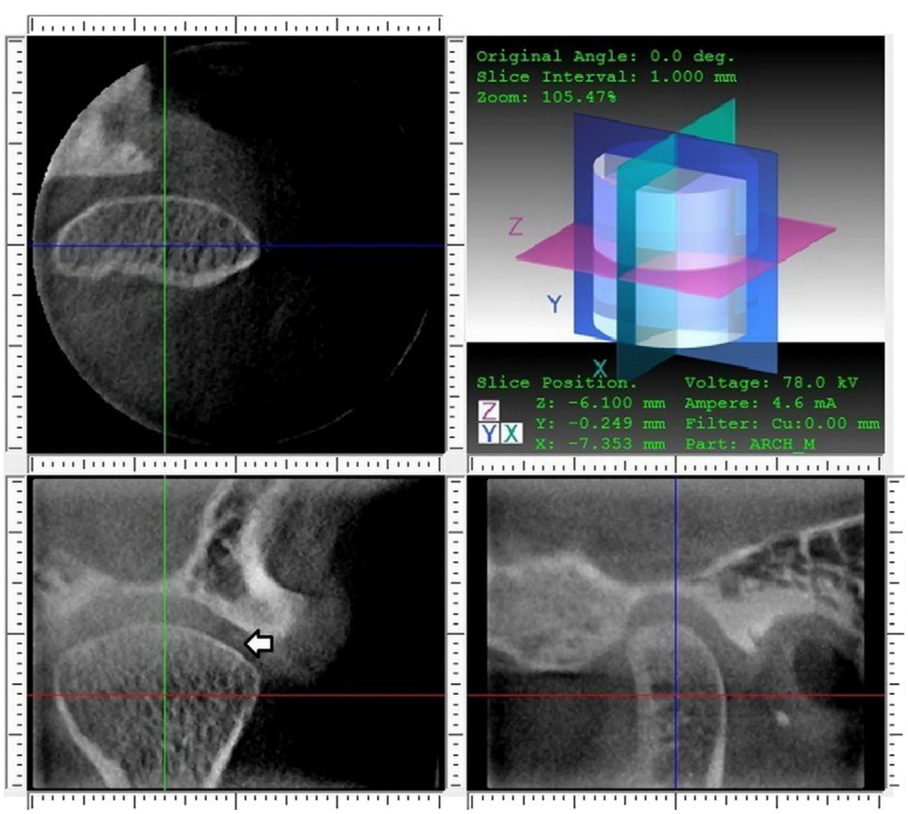

Fig. 2. Partial formation of cortical bone in a 19-year-old woman. There was a high-density compact linear image only on the lateral pole of the condyle (arrow).

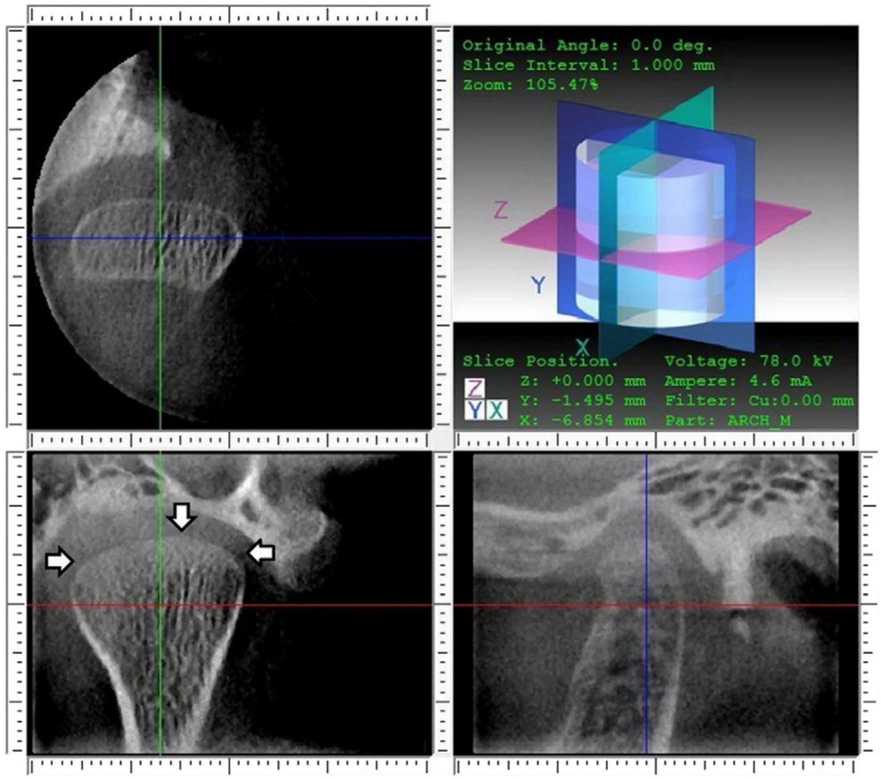

Fig. 3. No formation of cortical bone in a 14-year-old boy. There was no sign of a high-density compact linear image on the condyle (arrows).

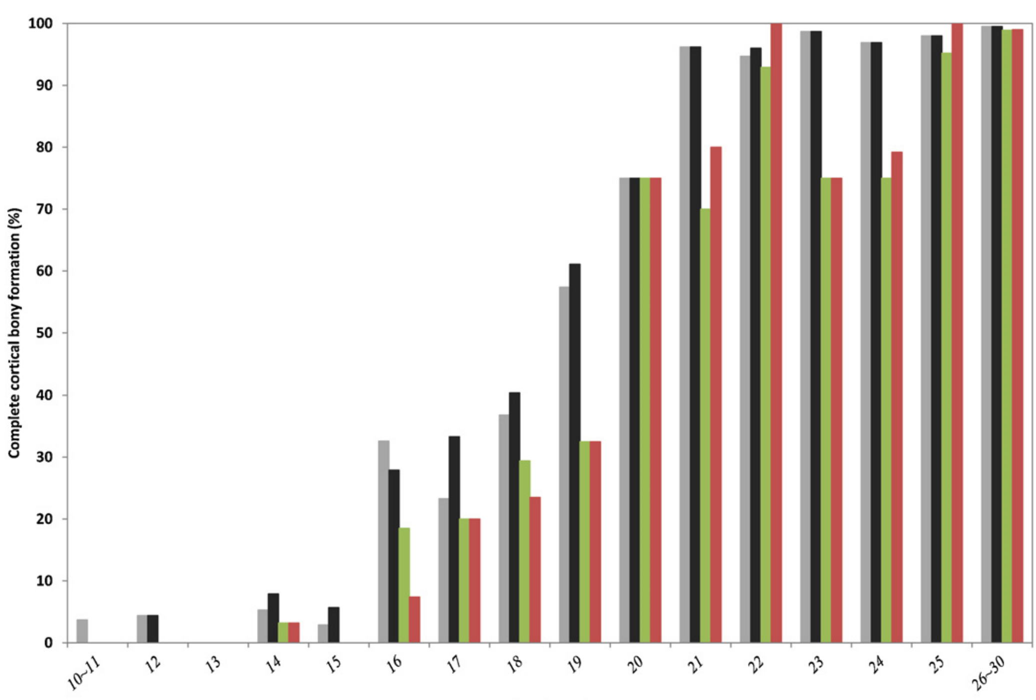

Fig. 4. Percentage in whom there is complete formation of cortical bone at every age from 10 to 30 years old. Grey column = female (left); black column = female (right); green column = male (left); and red column = male (right).

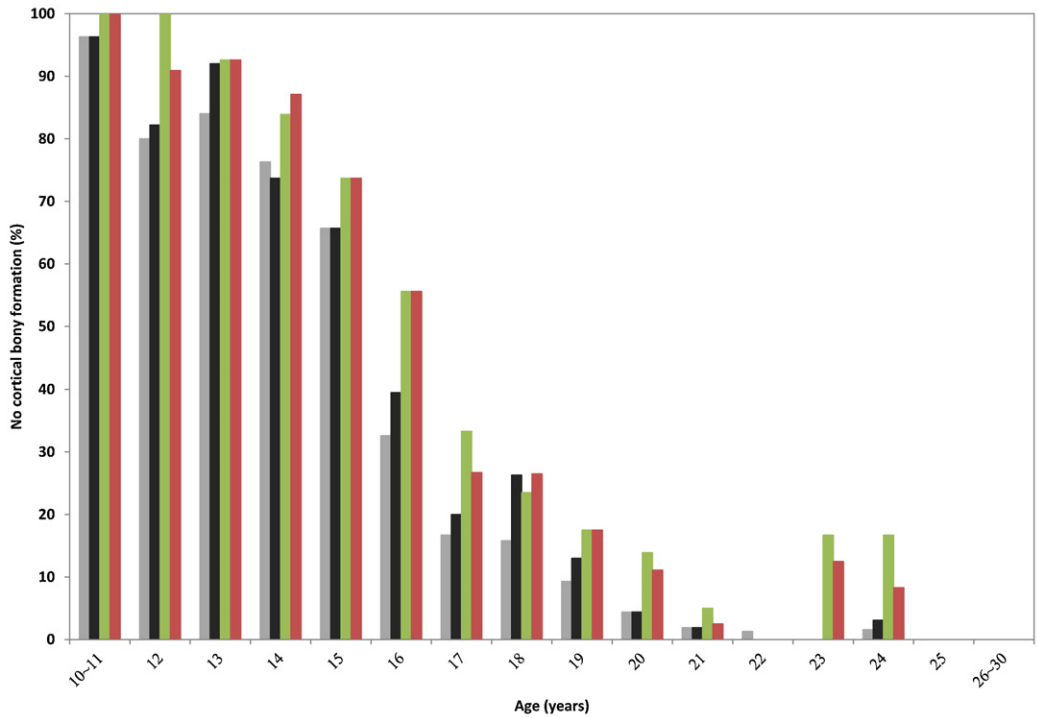

Fig. 5. Percentage in whom there is no formation of cortical bone at every age from 10 to 30 years old. Grey column = female (left); black column = female (right); green column = male (left); and red column = male (right).

in a year-dependent manner, and was a year earlier for women than for men. There was no significant difference in the formation of cortical bone between bilateral condyles in individual subjects; 90% of male and 93% of female subjects had similar stages of formation of cortical bone in their right and left condyles.

Discussion

Subchondral formation of cortical bone on the mandibular condyles was evaluated using CBCT imaging of the TMJ. Cortical bone begins to form around the periphery of condyles during adolescence (12–14 years old). A continuous, homogeneous, and compact cortical bony layer around the periphery of the condyles is established in young adults after the ages of 21–22 years. Liu et al. looked at panoramic radiographs and Schüller's projection of the TMJ, and reported that cortical bone-like structures at the periphery of condyles were rare at the ages of 12–14 years, and the density and calcification of this bone was "immature".[9] Conventional radiographic imaging of the TMJ is, however, complicated by several anatomical and technical factors that hinder a clear and unobstructed view of the joints. Pure lateral views are obstructed by the structures of the midface, while transcranial (across the cranium to the condyle) and transpharyngeal (between the coronoid process and the neck of the condyle on the opposite side) show only the lateral and medial pole of the condyle, respectively. The superior subarticular surface of the condyle and its associated cortical bone cannot be seen using conventional radiographic techniques.

CT provides optimal imaging of the osseous components of the TMJ, and CBCT scanners were developed as an alternative to traditional CT for examination of pathological conditions, trauma, and for preoperative planning of treatment of the oral and maxillofacial region. CBCT results in images of CT quality, but the scanners are smaller and cheaper, the scanning time is shorter, and dose of radiation lower.[11–15] CBCT has been recommended for evaluation of the TMJ and is the preferred imaging method when bony conditions are involved.[14,15] CBCT images provide superior reliability and greater accuracy than tomography and panoramic projections in the detection of condylar cortical bone.[11]

Formation of condylar bone can also be evaluated by magnetic resonance imaging (MRI). Morimoto et al. suggested that alterations in structures with double contours on MRI should be used as the criteria for evaluating the maturity of mandibular condyles in children.[10] Possible examples include hypervascular loose fibrous tissue, and cartilaginous proliferation accompanied by active ossification on the superior surface of the mandibular condyles. The presence of structures with double contours indicates condylar growth, and their disappearance implies completion of growth and bony maturity.[10,16] They increase in condyles before the age of 13, decrease after the age of 13, and have almost disappeared by the age of 16.[10] On MRI, void signal lines indicate the presence of cortical bone in the mandibular condyle. The continuity of such signal lines on MRI, or cortical, bone-like, radiopaque lines on panoramic radiographs, were almost undetectable at the superior surface of condyles before the ages of 13 or 15, respectively.[17] The findings based on MRI and panoramic imaging confirmed those of the present study using CBCT.

The number of condyles on which formation of cortical bone had been completed generally increased in an age-dependent pattern. It was, however, relatively lower at the ages of 23 and 24 years in male subjects, which may be attributed in part to the small size of the sample (24 subjects/group) that arose from the higher female:male ratio of patients who sought orthodontic or orthognathic treatment. Findings from the larger female population (75 subjects were 23 years old and 64 were 24) may be more representative of this age group. We found completed formation of condylar cortical bone in over 96% of female subjects aged 23–24 years old. The fewer male subjects in this group could also be affected by anatomical issues, as many were seeking orthognathic treatment. It is conceivable that genetic, developmental, or iatrogenic factors that result in skeletal malformation, and interarch and intra-arch discrepancies, also influenced the subchondral formation of condylar cortical bone.

Cortical bone begins to form around the periphery of condyles at the age of 12–14 years. If there is sustained or repetitive adverse loading of the condyles from oral parafunctional habits or postural imbalances before the cortical bone has matured, dysfunctional remodelling of the condyles may occur leading to osteoarthritis or osteoarthrosis and idiopathic condylar resorption. This is most common in teenage girls (9:1 female:male ratio).[18] Although the specific aetiology of idiopathic condylar resorption is not known, its strong tendency to develop in adolescent girls supports the theory of hormonal mediation. Oestrogen is known to mediate cartilage and bony metabolism in female subjects, and an increase in oestrogen receptors may exaggerate the response to adverse loading of a joint, particularly in developing condyles.[19] It rarely occurs after the age of 20 years,[19] which is when we found that the condyle had fully developed.

Acknowledgement

The research was supported by a grant from Capital Medical Development Research Foundation (2009-3037).

References

1. Mérida-Velasco JR, Rodríguez-Vázquez JF, Mérida-Velasco JA, Sánchez-Montesinos I, Espín-Ferra J, Jiménez-Collado J. Development of the human temporomandibular joint. *Anat Rec* 1999;**255**:20–33.
2. Yuodelis RA. The morphogenesis of the human temporomandibular joint and its associated structures. *J Dent Res* 1966;**45**:182–91.
3. Avery JK. *Oral development and histology*. 3rd ed. Stuttgart: Thieme; 2002.
4. Katsavrias EG, Dibbets JM. The growth of articular eminence height during craniofacial growth period. *Cranio* 2001;**19**:13–20.
5. Katsavrias EG. Changes in articular eminence inclination during the craniofacial growth period. *Angle Orthod* 2002;**72**:258–64.
6. Nickel JC, McLachlan KR, Smith DM. Eminence development of the postnatal human temporomandibular joint. *J Dent Res* 1988;**67**:896–902.
7. Luder HU. Age changes in the articular tissue of human mandibular condyles from adolescence to old age: a semiquantitative light microscopic study. *Anat Rec* 1998;**251**:439–47.
8. Ingervall B, Carlsson GE, Thilander B. Postnatal development of the human temporomandibular joint. II. A microradiographic study. *Acta Odontol Scand* 1976;**34**:133–9.
9. Liu YY, Wang H, Yang ZY, Ba K, Li MX, Liu L. The correlation between temporomandibular joint maturity and second molar root development in adolescents. *Int J Stomatol* 2010;**37**:154–6 [in Chinese].
10. Morimoto Y, Konoo T, Tominaga K, Tanaka T, Yamaguchi K, Fukuda J, et al. Relationship between cortical bone formation on mandibular condyles and alternation of the magnetic resonance signals characteristic of growth. *Am J Orthod Dentofacial Orthop* 2007;**131**:473–80.
11. Honey OB, Scarfe WC, Hilgers MJ, Klueber K, Silveira AM, Haskell BS, et al. Accuracy of cone-beam computed tomography imaging of the temporomandibular joint: comparisons with panoramic radiology and linear tomography. *Am J Orthod Dentofacial Orthop* 2007;**132**:429–38.
12. Silva MA, Wolf U, Heinicke F, Bumann A, Visser H, Hirsch E. Cone-beam computed tomography for routine orthodontic treatment planning: a radiation dose evaluation. *Am J Orthod Dentofacial Orthop* 2008;**133**:640.e1–5.
13. Hashimoto K, Arai Y, Iwai K, Araki M, Kawashima S, Terakado M. A comparison of a new limited cone beam computed tomography machine for dental use with a multidetector row helical CT machine. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2003;**95**:371–7.
14. Honda K, Larheim TA, Matsumoto K, Iwai K. Osseous abnormalities of the mandibular condyle: diagnostic reliability of cone beam computed tomography compared with helical computed tomography based on an autopsy material. *Dentomaxillofac Radiol* 2006;**35**:152–7.
15. Tsilakis K, Syriopoulos K, Stamatakis HC. Radiographic examination of the temporomandibular joint using cone beam computed tomography. *Dentomaxillofac Radiol* 2004;**33**:196–201.
16. Morimoto Y, Tominaga K, Konoo T, Tanaka T, Yamaguchi K, Fukuda J, et al. Alternation of the magnetic resonance signals characteristic of mandibular condyles during growth. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2004;**98**:348–54.
17. Westesson PL, Katzberg RW, editors. *Imaging of the temporomandibular joint. Volume 1: Facial region and anterior skull base*. Baltimore: Williams & Wilkins; 1991.
18. Wolford LM. Idiopathic condylar resorption of the temporomandibular joint in teenage girls (cheerleader syndrome). *Proc (Bayl Univ Med Cent)* 2001;**14**:246–52.
19. Abubaker AO, Raslan WF, Sotereanos GC. Estrogen and progesterone receptors in temporomandibular joint discs of symptomatic and asymptomatic persons: a preliminary study. *J Oral Maxillofac Surg* 1993;**51**:1096–100.