CRANIO®
The Journal of Craniomandibular & Sleep Practice

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ycra20

Posteroanterior cephalometric analysis of White-American and Chinese adolescents: a cross-sectional study

ShiYao Liu DDS , LinHui Shen DDS , RuoPing Jiang DDS , JiuXiang Lin DDS & TianMin Xu DDS

To cite this article: ShiYao Liu DDS , LinHui Shen DDS , RuoPing Jiang DDS , JiuXiang Lin DDS & TianMin Xu DDS (2020) Posteroanterior cephalometric analysis of White-American and Chinese adolescents: a cross-sectional study, CRANIO®, 38:6, 402-411, DOI: 10.1080/08869634.2018.1554343

To link to this article: https://doi.org/10.1080/08869634.2018.1554343

Published online: 20 Dec 2018.

CRANIO®: THE JOURNAL OF CRANIOMANDIBULAR & SLEEP PRACTICE
2020, VOL. 38, NO. 6, 402–411
https://doi.org/10.1080/08869634.2018.1554343

Taylor & Francis
Taylor & Francis Group

ORTHODONTICS

Posteroanterior cephalometric analysis of White-American and Chinese adolescents: a cross-sectional study

ShiYao Liu DDS, LinHui Shen DDS, RuoPing Jiang DDS, PhD, JiuXiang Lin DDS, PhD and TianMin Xu DDS, PhD

Department of Orthodontics, Peking University School and Hospital of Stomatology, Beijing, China; National Engineering Laboratory for Digital and Material Technology of Stomatology, Beijing, China; Beijing Key Laboratory of Digital Stomatology, Beijing, China

ABSTRACT

Objective: To characterize ethnic differences between Chinese and White-Americans between 8.5 and 17.5 years of age, with respect to transverse cephalometric characteristics and to establish transverse craniofacial normative values for Chinese adolescents.
Methods: Two-hundred fifty-seven and 547 posteroanterior cephalograms were selected from 35 White-Americans and 157 Chinese with individual normal occlusions. Transverse measurements were obtained and compared between ethnicities to guide determination of normative values for Chinese adolescents. Student's *t*-test or one-way analysis of variance was used, as appropriate.
Results: Chinese girls demonstrated significantly larger measurements than White-American girls at all ages, with the exception of nasal width. Chinese boys exhibited larger measurements than White-American boys at different ages. Chinese boys had larger measurements than girls for most measurements. These data established normative values for Chinese adolescents.
Discussion: Ethnic differences existed between Chinese and White-American adolescents with respect to transverse craniofacial measurements. Transverse normative values were established for Chinese adolescents.

KEYWORDS
Posteroanterior cephalogram; transverse craniofacial measurements; ethnic difference; normative value

Introduction

In orthodontic practice, orthodontists use lateral cephalograms to obtain clinical information, and numerous lateral cephalometric radiography studies have determined the sagittal and vertical dimensions of craniofacial structures [1–4]. In contrast, studies of the transverse dimensions of craniofacial structures are limited [5,6]. Transverse dimensions of craniofacial structures, which include important information needed for orthodontists to establish treatment plans, should also be well-explored.

Establishment of transverse craniofacial normative values can provide a foundation for the diagnosis and treatment of orthodontic diseases. Al-Azemi et al. [7] evaluated digital posteroanterior cephalograms (PACs) of 159 13–14-year-old Kuwaiti subjects with untreated ideal occlusions and established norms for these adolescents. PAC norms for American Children [8], Pakistani adults [9], and Turkish adults [10] have also been established. However, normative values established from other ethnicities may not be suitable for Chinese people, because people of different ethnicities exhibit distinct genotypes and biological characteristics [2,11]. Gender influence should also be considered when establishing normative values, because gender differences have been noticed in the transverse development of the craniofacial skeleton. For instance, Lux et al. [12] used PACs from a longitudinal study and found that most craniofacial widths were wider in males than in females.

The purpose of this study was to compare Chinese and White-American adolescents with individual normal occlusions to characterize ethnic differences with respect to transverse cephalometric characteristics. Additionally, the present study aimed to establish sex-related transverse craniofacial normative values for Chinese adolescents.

Materials and methods

Selection of subjects and PACs

The PACs used in this study were selected from two cohorts. The White-American cohort, described previously in a series of growth studies, was recruited from the original group at University of California School of

CONTACT TianMin Xu MD tmxuortho@126.com; tmxuortho@163.com Department of Orthodontics, Peking University School and Hospital of Stomatology; National Engineering Laboratory for Digital and Material Technology of Stomatology; Beijing Key Laboratory of Digital Stomatology, 22 South Zhong guan cun Avenue Haidian District, Beijing 100081, China

Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/ycra.

Dentistry (San Francisco, CA, USA), from 1967 to 1978, where all White-American children were of Northern European descent [13–16]. The Chinese cohort was recruited from the Peking University School and Hospital of Stomatology, Beijing, from 1990 to 1997, where all these children were from the northern part of China. Among these subjects, cases were further selected based on the following inclusion criteria: (1) adolescents <18 years old who had a normal occlusion; (2) those who underwent PAC radiography at least once in their childhood during the study period; (3) those who did not undergo orthodontic treatment or other treatments that influence the normal growth and development of cephalometric measurements before or during the observation period; and (4) those who had no history of syndromes of other systems.

Because the youngest subjects were 8.5 years old in both groups and PACs were taken annually, measurements were analyzed at 1-year intervals (i.e., 8.5, 9.5, 10.5 … 17.5 years of age). Note that each subject meeting the inclusion criteria might have undergone one or multiple PACs (i.e., at different ages), depending on how long he or she stayed in the original group during the study period (8.5–17.5 years of age). Hence, in this paper, the collected PACs were further divided into several groups according to age, each of which was composed of PACs taken at the same age so as to facilitate the experiment based on the cross-sectional model. Exemption from ethical approval for this study was granted by the institutional review board of the medical school of Peking University (PKUSSIRB-201735070) because it used pre-existing data.

The selected PACs were scanned and stored as electronic data. The sources of magnification error in this study included the processes of taking cephalometric radiographs and digitization of the images. Magnification resulting from the process of taking cephalometric radiographs was calculated according to the following formula:

$$r = ((D/(D - d) - 1) \times 100),$$

where D is the distance between the X-ray tube and the film, d is the distance between the film and median plane of the object, and r is the magnification.

Cephalometric measurements

Cephalometric measurements on PACs of all subjects were assessed retrospectively. The landmarks used in this study were identical to those used in Ricketts's report [17]. To ensure the accuracy of point identification, a pilot experiment was performed. At the beginning, one PAC was taken from a complete dry skull without marking (Figure 1A); another PAC was then taken at the same head position after the dry skull was marked with skeletal bone landmarks (Figure 1B). By comparing these two cephalograms before and after marking, the authors (SYL and SLH) could identify the characteristics of craniofacial skeletal bones; this was helpful in identification of landmarks (Figure 1). The electronic PACs were imported into Matlab software (MathWorks, Natick, MA, USA) to digitize the landmarks. A horizontal plane (formed by connecting the bilateral points that intersected the lesser wing of the sphenoid with the medial rims of the orbits) was established to assess transverse measurements (Figure 2A), as described by Snodell et al. [11]. Measurements were determined as follows (Figure 2B):

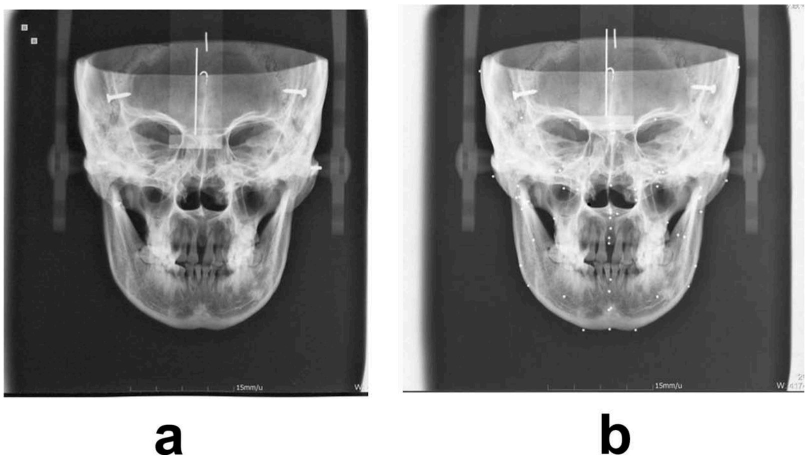

Figure 1. PACs of the pilot experiment. a: unmarked PAC; b: marked PAC. Comparison of the two cephalograms before and after marking to identify characteristics of the craniofacial skeletal bones, which helped to identify landmarks.

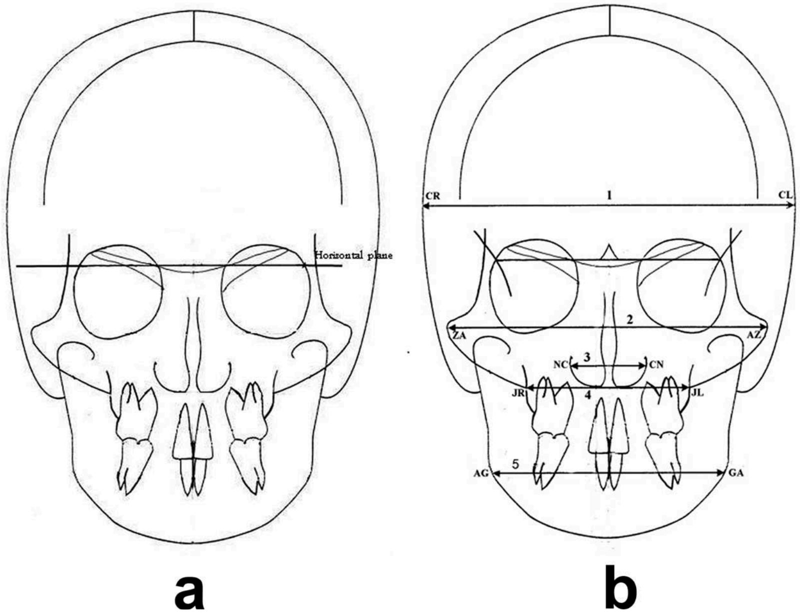

Figure 2. Reference plane, landmarks, and transverse measurements. a: Horizontal plane; b: Landmarks and transverse measurements. 1. Cranial width: the distance between the most left lateral points on the cranium; 2. Facial width: the distance between the most lateral aspect points on the zygomatic arch; 3. Nasal width: the distance between the most lateral points on the nasal aperture; 4. Maxillary width: the distance between the left and right jugal point at the intersection of the outline of the maxillary tuberosity and zygomatic buttress; 5. Mandibular width: the distance between points at the antegonial notch.

(1) Cranial width: the width of the cranium between the most lateral points on the cranium, parallel to the horizontal plane.
(2) Facial width: the width of the zygomatic arch between the most lateral points, parallel to the horizontal plane.
(3) Nasal width: the width of the nasal cavity between the most lateral points on the nasal aperture, parallel to the horizontal plane.
(4) Maxillary width: the width of the maxilla from bilateral points on the jugal process at the intersection of the outline of the maxillary tuberosity and zygomatic buttress, parallel to the horizontal plane.
(5) Mandibular width: the width of the mandible from points at the antegonial notch, parallel to the horizontal plane.
(6) Ratio of maxillary width to mandibular width: maxillary width divided by mandibular width.

Reliability assessment

To assess the reliability of the cephalometric measurements, intra-examiner and inter-examiner reliabilities were evaluated. Thus, both the same examiner and the another examiner repeated measurements on 150 randomly selected PACs (100 cephalograms from the Chinese cohort and 50 cephalograms from the American cohort) 2 weeks after the first examination. The numbers of cephalograms chosen for this analysis were based on the study by Springate [18], which showed that, while higher numbers of cases provided a more reliable estimation of error, repeating examinations on more than 50 cases does not provide any meaningful advantage.

Statistical analysis

The data exhibited a normal distribution. Data are presented as mean ± standard deviation (SD). Comparisons between the same age groups were analyzed by using Student's *t*-test, while comparisons between different age groups were analyzed by one-way analysis of variance (ANOVA). Intra/inter-examiner reliability was assessed by using the intra-class correlation coefficient. The $p < 0.05$ was considered a significant difference. All analyses were performed by using SPSS software (version 19.0, SPSS, Inc., Chicago, IL, USA).

Results

Basic information of the selected PACs

A total of 257 and 547 PACs were, respectively, selected from 35 White-American (13 boys and 22 girls) and 157 Chinese subjects (58 boys and 99 girls). The numbers of selected PACs for both genders of the two ethnicities are summarized in Table 1.

Table 1. Numbers of selected posteroanterior cephalograms (PACs) in both genders for each ethnicity.

	White-American			Chinese		
Age (years)	Boys	Girls	Total	Boys	Girls	Total
8.5	12	22	34	6	5	11
9.5	12	21	33	6	15	21
10.5	13	20	33	16	31	47
11.5	14	17	31	13	31	44
12.5	9	16	25	19	34	53
13.5	11	15	26	29	54	83
14.5	10	14	24	26	45	71
15.5	8	15	23	25	44	69
16.5	9	10	19	30	49	79
17.5	5	4	9	25	44	69
Total	103	154	257	195	352	547

Magnification correction

For the Chinese sample, D = 150.0 mm, d = 15.0 mm, and r = 11.1%. For the White-American sample, D = 63.6 inches, d = 3.6 inches, and r = 6%. To correct the magnification from the digitization of the images, the scales of the original medical image and the corresponding electronic version were unified. For the sample of Chinese subjects, the maximum distance of punch points on the right side of the medical film was 15.20–15.30 cm, while the corresponding distance of the electronic version was 15.83 cm. For the sample of White-American subjects, the maximum distance of the punch points on the right side of the medical film was 15.87 cm, while the corresponding distance of the electronic version was 15.92 cm. Therefore, both magnifications were corrected.

Reliability of measurements

The results of reliability assessment are shown in Table 2. All intraclass correlation coefficients (ICCs) were greater than 0.85, which indicated that the measurements were reliable.

Ethnic differences

As shown in Figure 3, Chinese girls demonstrated significantly larger measurements than White-American girls at all ages ($p < 0.05$), with the exception of nasal width, which solely showed significant differences at the ages of 11.5 ($p < 0.05$), 12.5 ($p < 0.01$), and 13.5 years ($p < 0.05$). Notably, Chinese boys showed wider cranial width (Figure 4A) and maxillary width (Figure 4D) than White-American boys at all ages ($p < 0.05$); similarly, Chinese boys showed wider facial width (Figure 4B) and mandibular width (Figure 4E) than White-Americans beginning at the age of 9.5 years ($p < 0.05$); they showed wider nasal width beginning at the age of 11.5 years (Figure 4C, $p < 0.05$). Chinese boys demonstrated a larger ratio of maxillary width to mandibular width than White-American boys; however, these differences were significant ($p < 0.05$) only at the ages of 9.5, 16.5, and 17.5 years.

Table 2. Measurements of inter-observer and intra-observer agreement.

Measurements	Inter-observer agreement	Intra-observer agreement
Cranial width	0.897	0.862
Facial width	0.915	0.900
Nasal width	0.944	0.928
Maxillary width	0.927	0.878
Mandibular width	0.942	0.923
Ratio of maxillary width to mandibular width	0.933	0.912

Gender differences in Chinese adolescents

As shown in Figure 5, Chinese boys exhibited larger mean values than Chinese girls at all ages for all measurements; however, significant inter-group differences occurred at different ages. For cranial width (Figure 5A), nasal width (Figure 5C), maxillary width (Figure 5D), and mandibular width (Figure 5E), significant inter-group differences were observed beginning at the ages of 12.5, 15.5, 10.5, and 12.5 years, respectively. For facial width (Figure 5B), Chinese boys demonstrated significantly larger values than Chinese girls beginning at the age of 12.5 years, with the exception of the age of 13.5 years. Chinese boys and girls demonstrated comparable ratios of maxillary width to mandibular width at all ages.

Normative values for Chinese adolescents

The authors compared the transverse craniofacial measurements between the group with PACs taken at 8.5 years old and groups with PACs taken at other ages. Specifically, regarding the nasal width, maxillary width, and mandibular width of boys, as well as the facial width of girls, the PACs taken at 11.5 years old exhibited significant differences, as compared to those taken at 8.5 years old; regarding cranial width of boys, maxillary width and mandibular width of girls, the significant differences occurred at 12.5 years old; and for facial width of boys and nasal width of girls, the significant differences occurred at 10.5 years old (Appendix). Therefore, for most examined measurements, it could be observed that the normative values were relatively stable for children who are no more than 11.5 years old (note that this is near the age that is used to distinguish the stages of mixed dentition and permanent dentition in clinical practice). The detailed transverse craniofacial normative values for Chinese adolescents are shown in Table 3.

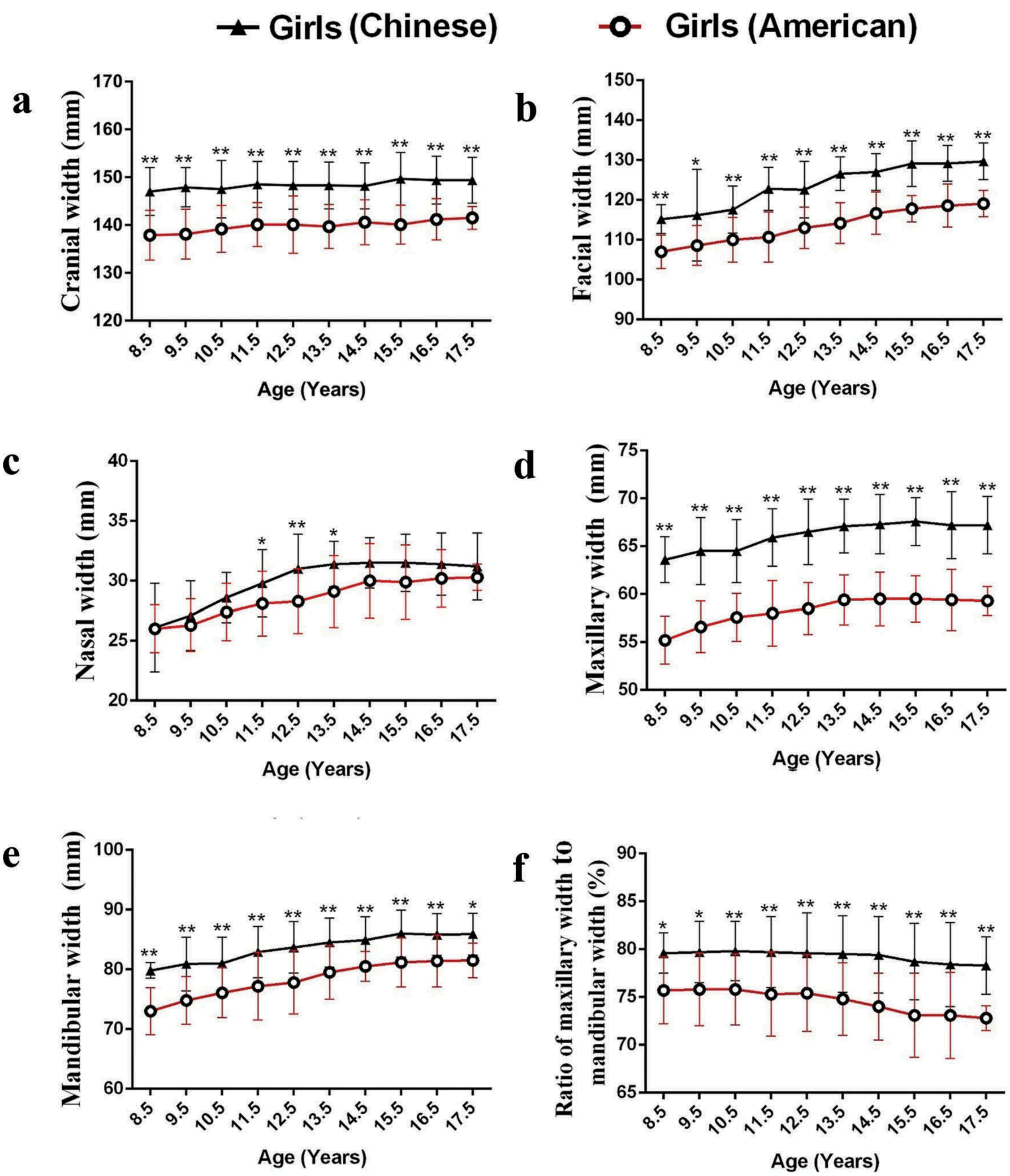

Figure 3. Measurements compared between Chinese girls and White-American girls. a. Cranial width; b. Facial width; c: Nasal width; d: Maxillary width; e: Mandibular width; f: Ratio of maxillary width to mandibular width. *$p < 0.05$, **$p < 0.01$ (Student's t-test).

Discussion

With the increasingly extensive use of three-dimensional (3D) radiographs, cone-beam computed tomography (CBCT) applications are becoming increasingly common in clinical practice; however, the inability to take annual or semiannual 3D radiographs for ethical reasons imposes its restrictions on research. PACs are relatively safe for subjects and can be used in research [19]. However, PACs also present certain technical issues, including magnification, superimposed structures, and inconsistent head position during imaging [20,21]. In the present study, the authors made the following modifications to ensure reliability:

(1) Subjects' heads were kept stable as much as possible during the period of cephalogram acquisition for both White-American and Chinese subjects.

(2) The magnification of PACs was corrected. Furthermore, the ICCs for all measurements were higher than 0.85, which indicated that the results were reliable.

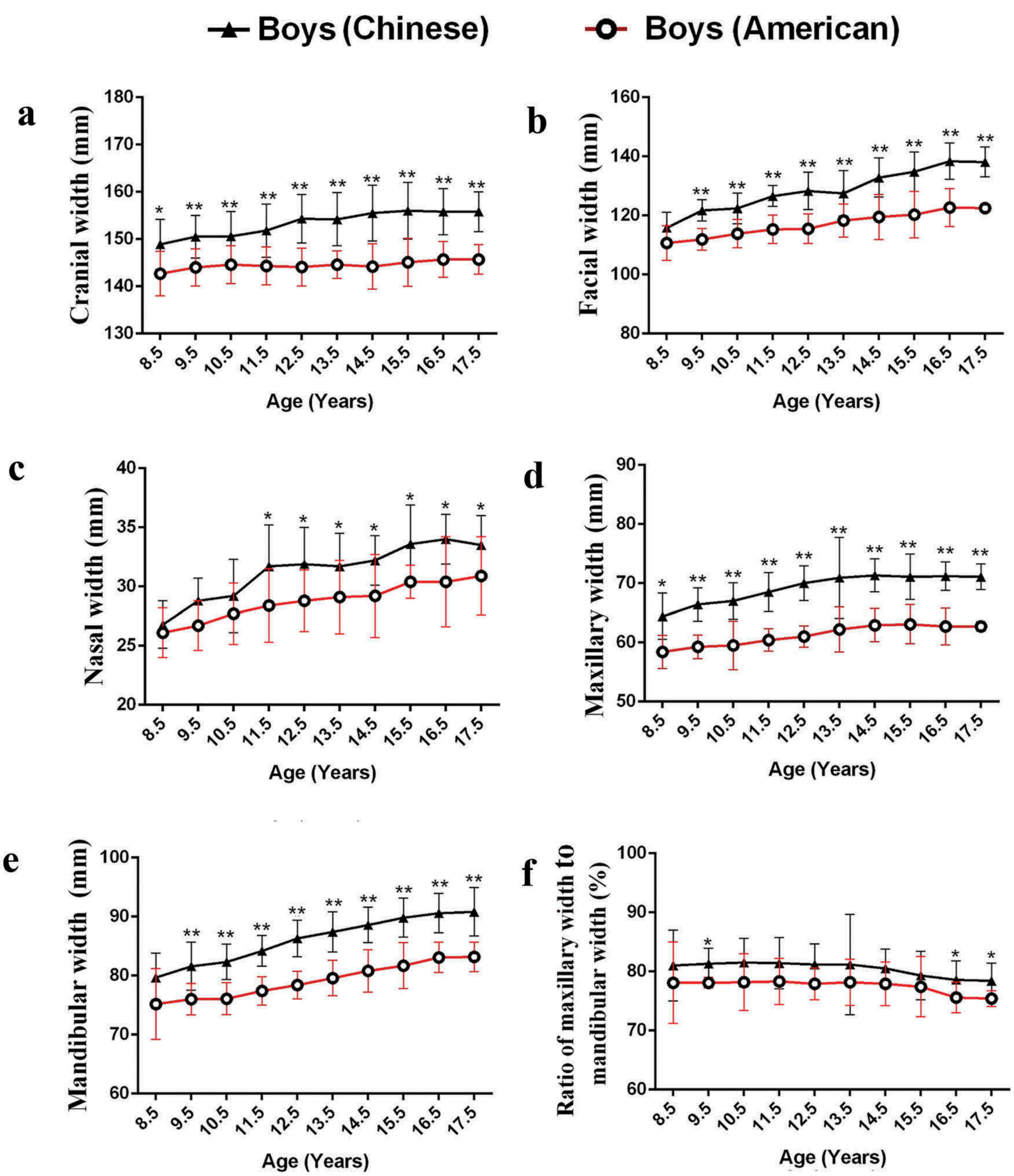

Figure 4. Measurements compared between Chinese boys and White-American boys. a. Cranial width; b. Facial width; c: Nasal width; d: Maxillary width; e: Mandibular width; f: Ratio of maxillary width to mandibular width. *$p < 0.05$, **$p < 0.01$ (Student's *t*-test).

People of different ethnicities may exhibit different transverse cephalometric characteristics. In a study performed by Wei et al. [22], adult Chinese subjects exhibited significantly greater facial width and bigonial mandibular width than 15-year-old White-Americans; however, the White-American subjects might continue to grow in the transverse dimension beyond 15-years of age. Aboul-Azm and Korayem [23] found that facial, maxillary, and bigonial mandibular widths in Egyptian adults exceeded those of adults of other ethnicities (Caucasian, Chinese, Japanese, and Danish), with the exception of maxillary width, in comparison with Chinese adults. Alazemi and Årtun [7] showed that Kuwaiti adolescents had wider maxillary measurements than those described as age-matched Ricketts' norms. In the present study, Chinese subjects exhibited wider transverse widths than White-American subjects at most ages, which indicated that Chinese and White-American adolescents exhibited different cephalometric transverse characteristics. It suggested that transverse craniofacial normative values should be established for them separately.

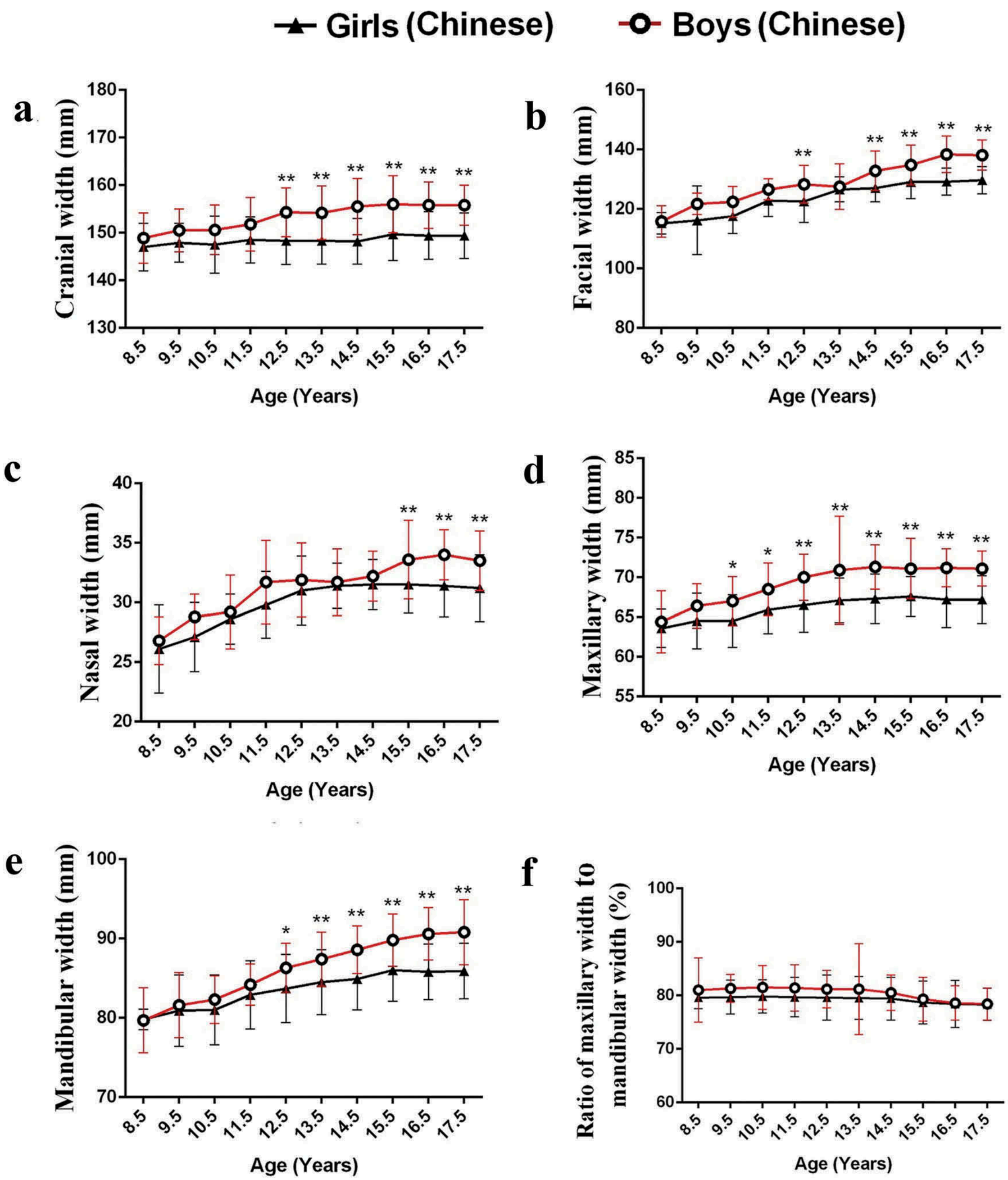

Figure 5. Gender differences were present in Chinese subjects. a. Cranial width; b. Facial width; c: Nasal width; d: Maxillary width; e: Mandibular width; f: Ratio of maxillary width to mandibular width. *$p < 0.05$, **$p < 0.01$ (Student's *t*-test).

Knowing the transverse craniofacial normative values is very important for orthodontists to diagnose and treat patients with transverse discrepancies. In the past, few studies have been performed to determine the posteroanterior cephalometric norms of different ethnic groups, such as Ataturk, American, Pakistani, and Turkish [7–10]; the primary conclusion has been that people of different ethnic backgrounds must be treated on the basis of their own characteristics because of significant interethnic differences. However, none of these studies focused on Chinese. The establishment of craniofacial transverse normative values for Chinese adolescents was another purpose of this study. From the results, it is clear that a gender difference was noted for most measurements. Furthermore, the majority of measurements were relatively stable before the age of 11.5 years; notably, this was near the age used to distinguish the stages of mixed dentition and permanent dentition in clinical practice; thus, the current study presented the normative values for all measurements using 11.5 years as a cutoff value. In summary, gender and age of 11.5 years were used as grouping criteria to describe normative values for all measurements. The mean values of

Table 3. Transverse craniofacial normative values for Chinese boys and girls (Mean ± SD, mm or %).

Measurements	Gender	Age	Normative values
Cranial width	Boys	7.5–11.5	150.7 ± 5.1
		12.5–17.5	155.3 ± 5.3
	Girls	7.5–11.5	147.9 ± 5.1
		12.5–17.5	148.9 ± 5.0
Facial width	Boys	7.5–11.5	122.7 ± 5.6
		12.5–17.5	133.5 ± 7.7
	Girls	7.5–11.5	119.2 ± 7.5
		12.5–17.5	127.6 ± 5.5
Nasal width	Boys	7.5–11.5	29.6 ± 3.3
		12.5–17.5	32.9 ± 2.8
	Girls	7.5–11.5	28.6 ± 2.8
		12.5–17.5	31.4 ± 2.4
Maxillary width	Boys	7.5–11.5	67.0 ± 3.4
		12.5–17.5	71.0 ± 3.9
	Girls	7.5–11.5	65.0 ± 3.4
		12.5–17.5	67.2 ± 3.0
Mandibular width	Boys	7.5–11.5	82.4 ± 3.4
		12.5–17.5	89.0 ± 3.7
	Girls	7.5–11.5	81.6 ± 4.3
		12.5–17.5	85.2 ± 3.9
Ratio of maxillary width to mandibular width	Boys	7.5–11.5	81.4 ± 4.2
		12.5–17.5	79.8 ± 4.9
	Girls	7.5–11.5	79.7 ± 3.2
		12.5–17.5	79.0 ± 3.9

SD = standard deviation.

cranial width, facial width, nasal width, maxillary width, mandibular width, and ratio of maxillary width to mandibular width in this study could be used for guidance as normal reference values. In the present study, boys showed higher values than girls for most measurements; similarly, adolescents with permanent dentition had higher values for most measurements, compared with adolescents with mixed dentition. Notably, these findings are similar to those reported by Hwang et al. [24].

However, this study had limitations. As each subject might have had one or multiple PACs during the study period, all PACs in this study were divided into several groups, each of which consisted of PACs taken at the same age. In this case, similar to the experiment design of Hwang et al. [24], the authors employed a cross-sectional model to do the experiment. However, the cross-sectional design limited assessment of subjects to a single time frame, which inevitably included individual growth variations that should be considered during interpretation of the data. Additionally, huge differences in sample size among the various age, sex, ethnic groups, and the possible influence of secular trends on the differences between the two ethnic groups should also be considered during interpretation of the data. Further prospective studies involving longitudinal data with well-distributed sample size are needed.

Conclusion

Ethnic differences existed between Chinese and White-American adolescents in terms of transverse craniofacial sizes. Transverse craniofacial normative values of Chinese adolescents were established for the first time. Boys demonstrated higher values than girls for most measurements; similarly, adolescents with permanent dentition also had higher values than adolescents with mixed dentition for most measurements. Gender and age should be considered when establishing transverse craniofacial normative values for Chinese adolescents.

Acknowledgments

This paper was supported by the International Science & Technology Cooperation Program of China (2014DFA31800). This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflicts of interest

The authors report no conflicts of interest.

References

[1] Farronato G, Giannini L, Galbiati G, et al. Sagittal and vertical effects of rapid maxillary expansion in Class I, II, and III occlusions. Angle Orthod. 2011;81:298–303.

[2] Wu JY, Hagg U, Pancherz H, et al. Sagittal and vertical occlusal cephalometric analyses of Pancherz: norms for Chinese children. Am J Orthod Dentofacial Orthop. 2010;137:816–824.

[3] Franchi L, Pavoni C, Faltin K, et al. Long-term skeletal and dental effects and treatment timing for functional appliances in Class II malocclusion. Angle Orthod. 2013;83:334–340.

[4] Ishizaki K, Suzuki K, Mito T, et al. Morphologic, functional, and occlusal characterization of mandibular lateral displacement malocclusion. Am J Orthod Dentofacial Orthop. 2010;137:454.e451-459. discussion454-455
[5] Athanasiou AE, Droschl H, Bosch C. Data and patterns of transverse dentofacial structure of 6- to 15-year-old children: a posteroanterior cephalometric study. Am J Orthod Dentofacial Orthop. 1992;101:465–471.
[6] Yavuz I, Ikbal A, Baydas B, et al. Longitudinal posteroanterior changes in transverse and vertical craniofacial structures between 10 and 14 years of age. Angle Orthod. 2004;74:624–629.
[7] Al-Azemi R, Artun J. Posteroanterior cephalometric norms for an adolescent Kuwaiti population. Eur J Orthod. 2012;34:312–317.
[8] Huertas D, Ghafari J. New posteroanterior cephalometric norms: a comparison with craniofacial measures of children treated with palatal expansion. Angle Orthod. 2001;71:285–292.
[9] Ilyas M, Hamid W, Shaheen A. Posteroanterior cephalometric norms in Pakistani adults. Pak Ortho J. 2012;4:10–16.
[10] Uysal T, Sari Z. Posteroanterior cephalometric norms in Turkish adults. Am J Orthod Dentofacial Orthop. 2005;127:324–332.
[11] Snodell SF, Nanda RS, Currier GF. A longitudinal cephalometric study of transverse and vertical craniofacial growth. Am J Orthod Dentofacial Orthop. 1993;104:471–483.
[12] Lux CJ, Conradt C, Burden D, et al. Transverse development of the craniofacial skeleton and dentition between 7 and 15 years of age – a longitudinal postero-anterior cephalometric study. Eur J Orthod. 2004;26:31–42.
[13] Baumrind S, Korn EL, Ben-Bassat Y, et al. Quantitation of maxillary remodeling. 1. A description of osseous changes relative to superimposition on metallic implants. Am J Orthod Dentofacial Orthop. 1987;91:29–41.
[14] Baumrind S, Korn EL, Ben-Bassat Y, et al. Quantitation of maxillary remodeling. 2. Masking of remodeling effects when an "anatomical" method of superimposition is used in the absence of metallic implants. Am J Orthod Dentofacial Orthop. 1987;91:463–474.
[15] Baumrind S, Ben-Bassat Y, Korn EL, et al. Mandibular remodeling measured on cephalograms. 1. Osseous changes relative to superimposition on metallic implants. Am J Orthod Dentofacial Orthop. 1992;102:134–142.
[16] Baumrind S, Ben-Bassat Y, Korn EL, et al. Mandibular remodeling measured on cephalograms: 2. a comparison of information from implant and anatomic best-fit superimpositions. Am J Orthod Dentofacial Orthop. 1992;102:227–238.
[17] Ricketts RM. Perspectives in the clinical application of cephalometrics. The First Fifty Years Angle Orthod. 1981;51:115–150.
[18] Springate SD. The effect of sample size and bias on the reliability of estimates of error: a comparative study of Dahlberg's formula. Eur J Orthod. 2012;34:158–163.
[19] Kapila SD. Cone beam computed tomography in orthodontics: indications, insights, and innovations. New York (NY): Wiley; 2014. p. 387.
[20] Pirttiniemi P, Miettinen J, Kantomaa T. Combined effects of errors in frontal-view asymmetry diagnosis. Eur J Orthod. 1996;18:629–636.
[21] Malkoc S, Sari Z, Usumez S, et al. The effect of head rotation on cephalometric radiographs. Eur J Orthod. 2005;27:315–321.
[22] Wei SH. Craniofacial width dimensions. Angle Orthod. 1970;40:141–147.
[23] Aboul-Azm S, Korayem M. Craniofacial width dimensions in Egyptians. Egypt Orthod J. 1987;1:9–18.
[24] Hwang S, Noh Y, Choi YJ, et al. Dentofacial transverse development in Koreans according to skeletal maturation: a cross-sectional study. Korean J Orthod. 2018;48:39–47.

Appendix 1. Transverse craniofacial measurements comparisons between different age groups and 8.5 years group for Chinese boys (mean ± SD; mm or %).

	8.5 years (n = 6)	9.5 years (n = 6)	10.5 years (n = 16)	11.5 years (n = 13)	12.5 years (n = 19)	13.5 years (n = 29)	14.5 years (n = 26)	15.5 years (n = 25)	16.5 years (n = 30)	17.5 years (n = 25)
CW	148.9 ± 5.3	150.5 ± 4.5	150.6 ± 5.2	151.8 ± 5.6	154.3 ± 5.1*	154.2 ± 5.6*	155.5 ± 5.9*	156.0 ± 4.9*	155.8 ± 4.2*	155.8 ± 1.1*
FW	115.8 ± 5.3	121.7 ± 3.6	122.4 ± 5.2*	126.6 ± 3.6*	128.3 ± 6.3*	127.5 ± 7.7*	132.8 ± 6.6*	134.8 ± 6.7*	138.4 ± 5.1*	138.1 ± 8.6*
NW	26.8 ± 2.0	28.8 ± 1.9	29.2 ± 3.1	31.7 ± 3.5*	31.9 ± 3.1*	31.7 ± 2.8*	32.2 ± 2.1*	33.6 ± 3.3*	34.0 ± 2.1*	33.9 ± 2.1*
MxW	64.4 ± 3.9	66.4 ± 2.8	67.0 ± 3.1	68.5 ± 3.3*	70.0 ± 2.9*	70.9 ± 6.8*	71.0 ± 2.8*	71.1 ± 3.8*	71.2 ± 2.4*	71.1 ± 2.2*
MaW	79.7 ± 4.1	81.6 ± 4.1	82.3 ± 3.0	84.2 ± 2.6*	86.3 ± 3.1*	87.4 ± 3.4*	88.6 ± 3.0*	89.8 ± 3.3*	90.6 ± 3.3*	90.8 ± 4.1*
R	81.0 ± 6.0	81.3 ± 2.6	81.5 ± 4.1	81.4 ± 4.3	81.2 ± 3.5	81.2 ± 8.5	80.5 ± 3.3	79.3 ± 4.1	78.6 ± 3.2	78.4 ± 3.0

CW = cranial width; FW = facial width; NW = nasal width; MxW = maxillary width; MaW = mandibular width; R = ratio of maxillary width to mandibular width vs. 8.5 years group, $^*p < 0.05$ (ANOVA); SD = standard deviation.

Appendix 2. Transverse craniofacial measurements comparisons between different age groups and 8.5 years group for Chinese girls (mean ± SD; mm or %).

	8.5 years (n = 5)	9.5 years (n = 15)	10.5 years (n = 31)	11.5 years (n = 31)	12.5 years (n = 34)	13.5 years (n = 54)	14.5 years (n = 45)	15.5 years (n = 44)	16.5 years (n = 49)	17.5 years (n = 44)
CW	147.0 ± 5.0	148.0 ± 4.1	147.5 ± 6.0	148.5 ± 4.8	148.2 ± 5.0	148.3 ± 4.9	148.2 ± 4.8	149.7 ± 5.5	149.4 ± 5.0	149.3 ± 4.8
FW	115.2 ± 3.6	116.2 ± 8.5	117.6 ± 5.9	122.8 ± 5.4*	122.6 ± 7.1*	126.6 ± 4.2*	127.0 ± 4.6*	129.1 ± 5.7*	129.2 ± 4.5*	129.7 ± 4.6*
NW	26.1 ± 3.7	27.1 ± 2.9	28.6 ± 2.1*	29.8 ± 2.8*	31.1 ± 2.9*	31.4 ± 1.9*	31.5 ± 2.1*	31.6 ± 2.4*	31.4 ± 2.6*	31.2 ± 2.8*
MxW	63.6 ± 2.4	64.5 ± 3.5	64.5 ± 3.3	65.9 ± 3.5	66.5 ± 3.4*	67.1 ± 2.8*	67.4 ± 3.1*	67.6 ± 2.5*	67.2 ± 3.5*	67.2 ± 3.0*
MaW	79.8 ± 1.3	80.9 ± 4.5	81.0 ± 4.4	82.9 ± 4.3	83.7 ± 4.3*	84.5 ± 4.1*	84.9 ± 3.9*	86.0 ± 3.9*	85.8 ± 3.5*	85.9 ± 3.5*
R,%	79.6 ± 2.1	79.7 ± 3.2	79.8 ± 3.1	79.7 ± 3.7	79.6 ± 4.2	79.5 ± 4.0	79.4 ± 4.0	78.7 ± 4.0	78.4 ± 4.4	78.3 ± 3.1

CW = cranial width; FW = facial width; NW = nasal width; MxW = maxillary width; MaW = mandibular width; R = ratio of maxillary width to mandibular width vs. 8.5 years group, $^*p < 0.05$ (ANOVA); SD = standard deviation.