ORIGINAL ARTICLE POJ 2016:8(2) 72-79

Timing of adolescent growth spurt among children with different skeletal classes

Waqar Jeelani[a], Mubassar Fida[b], Attiya Shaikh[c]

Abstract

Introduction: Treatment with growth modification appliances is only successful if commenced at the right stage of the adolescent growth spurt. The aim of this study was to determine and compare the mean age of the adolescent growth spurt among children with three skeletal malocclusions.

Material and Methods: A retrospective cross-sectional study was conducted on the lateral cephalograms of 440 children (203 boys and 237 girls) aged 9-17 years. Subjects were categorized into three skeletal classes (Class I=187, Class II=169, Class III=84) according to the sagittal jaw relationship. The cervical vertebral maturation (CVM) stage of each subject was recorded using Baccetti's method. The mean age at each CVM stage was compared between males and females using Mann-Whitney U test and among the three malocclusion groups using Kruskal-Wallis test.

Results: Pubertal growth peak occurred on average 1.5 years earlier in girls than boys. The mean difference in the time of adolescent growth spurt between Class I and Class II girls was of 7.5 months (p = 0.026) and between Class I and Class III boys was of 10.5 months (p = 0.022). All boys >16.5 years and girls >16.0 years were found to be in cervical stage 6.

Conclusions: Girls experience adolescent growth spurts on average 1.5 years earlier than boys. Adolescent growth spurt in Class II girls occurs earlier than Class I girls, while Class III boys mature later than Class I boys. However, timing of completion of adolescent growth spurt was comparable among the three skeletal classes.

Keywords: Cervical vertebral maturation; cervical stage; orthognathic surgery; dentofacial orthopedics

Introduction

The orthodontists of the current era are more inclined towards treating the underlying skeletal malocclusion instead of camouflaging it with the dentoalveolar compensations.[1,2] Functional jaw orthopedics remain a popular method of treating different skeletal malocclusions in growing children.[3-5] Similarly, an increase in the number of the patients undergoing orthognathic surgery for the treatment of skeletal malocclusions has been reported.[2,6] Treatment of the skeletal malocclusions is desirable not only to achieve a greater improvement in the overall facial esthetics but also to have a more stable treatment outcome as compared to the bare dental compensations made during a typical camouflage treatment.[7,8]

Different periods of growth acceleration and deceleration are the key components of the human development.[9,10] Various forms of dentofacial orthopedics are routinely utilized for the growth inhibition or promotion at certain growth sites in the craniofacial skeleton.[11-13] The adolescent growth spurt, a period of rapid growth offers a wider range of therapeutic modifiability and thus is of particular interest to the orthodontists.[9] In this context, recommendations have been made about the appropriate timing for the use of different functional appliances.[9,12] Similarly, orthognathic surgery is generally warranted in patients in which the adolescent growth spurt is essentially over as continued growth remains an important factor resulting in

[a] BDS. Resident Orthodontics, Section of Dentistry, Department of Surgery, The Aga Khan University Hospital, Karachi, Pakistan.

[b] Corresponding Author: BDS, MCPS, FCPS. Consultant Orthodontist/Associate Professor, Program Director Orthodontics Residency Program, Section of Dentistry, Department of Surgery, The Aga Khan University Hospital, Karachi, Pakistan. Email: mubassar.fida@aku.edu

[c] BDS, M.Orth, FCPS. Consultant Orthodontist/ Assistant Professor, Section of Dentistry, Department of Surgery, The Aga Khan University Hospital, Karachi, Pakistan.

relapse in these cases.[14,15] Since the success or failure of functional jaw orthopedics and orthognathic surgery is closely related to the maturational status of the patient, the diagnosis of the developmental stage of the patient has critical importance in orthodontic treatment planning.

Common methods to identify different stages of adolescent growth spurt involve increase in body weight and height, skeletal maturation of the hand and wrist, dental development, sexual changes, and cervical vertebral maturation (CVM).[16-23] Different studies[24-26] and a systematic review[27] have shown that CVM method is reliable and has a moderate to high level of reproducibility. The validity of this method has also been affirmed in the Pakistani subjects.[28] In addition, the use of lateral cephalograms in the CVM method eliminates the need of an additional radiation exposure to the patient for the assessment of the skeletal maturity.[26]

Wide variations in the timing of onset and duration of the adolescent growth spurt have been reported in the literature.[29,30] These variations are primarily related to the genetic background, ethnicity, nutritional status and the overall health of a child.[31,32] In this situation, distinguishing children of the same chronological age but with different degrees of skeletal maturation becomes more critical. Orthodontic treatment strategies are generally based on the type of malocclusion, thus identification of skeletal malocclusion related variations in the timing of pubertal growth spurt is likely to be of greater practical significance to the orthodontists. Hence, this study was conducted with an aim to assess the timing of the adolescent growth spurt in children with different skeletal malocclusions.

Material and Methods

A retrospective cross-sectional study was conducted using the pretreatment lateral cephalograms of growing children presenting at the dental clinics, Aga Khan University Hospital, Karachi. The sample size for three skeletal classes was calculated using the findings of Garcia-Drago and Arriola-Guillen.[33] Alpha was set as 0.05 and power was kept at 80% for sample size calculation which showed that a sample size of 43 in each group was sufficient in order to detect a clinically significant difference of 0.43 ± 0.63 year in the mean age at Cervical Stage (CS) 4 between Class I and Class III subjects. Cephalometric data of maximum number of available subjects were included to enhance the power of the study. Thus a total sample of 440 subjects was achieved.

The following inclusion criteria was used: children of Pakistani origin, age 7 to 18 years, and normal vertical facial pattern (anterior cranial base to the mandibular plane (SNMP) angle = $32^o \pm 5^o$).[34] Lateral cephalograms of children with the history of any type of orthodontic treatment, trauma or surgery of facial structures, any syndrome or developmental anomaly, or any chronic systemic disorder were excluded.

Patient's age was recorded to the nearest month and was converted into decimal expression for further use in the statistical analyses. The skeletal class of each subject was determined from the ANB angle and the vertical facial pattern was assessed by the anterior cranial base to the mandibular plane angle (SNMP angle) (Figure 1).[35] Subjects were divided into three groups according to the following criteria:

- Skeletal Class I - subjects with ANB angle $\geq 1^0$ and $\leq 4^0$ (187 subjects)
- Skeletal Class II - subjects with ANB angle $> 5^0$ (169 subjects)
- Skeletal Class III - subjects with ANB angle $< 0^0$ (84 subjects)

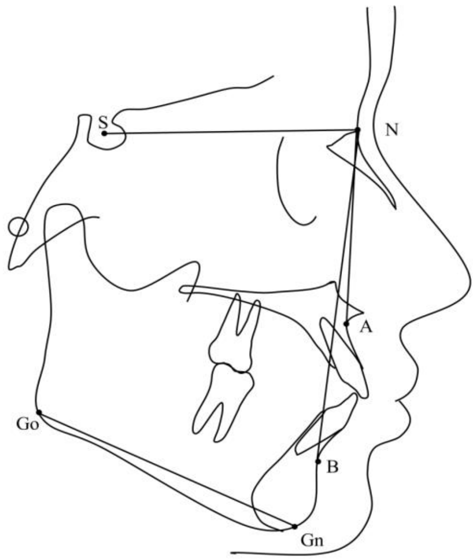

Figure 1

Point A: Deepest point between anterior nasal spine and prosthion

Point B: Deepest point between infra-dentale and pogonion

Nasion (N): Midline point at the fronto-nasal suture

Sella (S): Anatomic centre of sella turcica

Gonion (Go): Postero-inferior most point at the angle of mandible

Gnathion (Gn): Antero-inferior most point at mandibular symphysis

Cervical vertebral maturation stages were assessed on the lateral cephalograms by Baccetti's method[9]

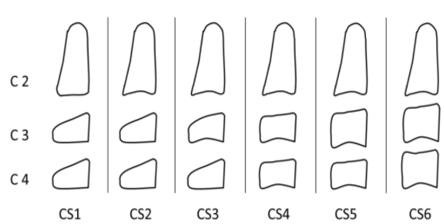

Figure 2: Cervical vertebral maturational stages according to the Bacceti's method

The Kolmogorov-Smirnov test was used to assess the normality of the measurements. The Mann-Whitney U test was used for comparison of mean ages of CVM between boys and girls. Comparison of age of CVM and SNMP angle among the three skeletal classes was made using the Kruskal-Wallis test. For paired comparisons between different skeletal classes the sample of children in CS1 and CS6 was discarded and post-hoc Dunnett's T3 and Scheffe's tests were used. A p-value of < 0.05 was taken as statistically significant. However, Bonferroni corrections were employed for p-value where necessary.

To check the intra and inter-examiner reliability in assessing the CVM status, the lateral cephalograms of 30 subjects were assessed by the principal investigator and a second observer at two intervals. The Kappa value for intra and inter-examiner reproducibility in assessing cervical stages were found to be 0.90 and 0.81, respectively.

Results

The study sample comprised of 203 boys and 237 girls. The total sample (N = 440) was distributed according to different cervical stages: CS1 (n = 46), CS2 (n = 79), CS3 (n = 77), CS4 (n = 92), CS5 (n = 82) and C6 (n = 64). The mean SNMP angle of the total sample was $31.30^0 \pm 3.09^0$. The SNMP angle was compared among three skeletal classes that showed no significant difference (p = 0.155).

The mean age at different cervical stages was compared between boys and girls that showed significant differences (p < 0.05) at CS2 to CS5 (Table I). Based on these sex-based differences further analyses were carried out separately for boys and girls. The results of the Kruskal Wallis test showed significant variations in the timing of CVM among the three Classes at CS2, 3 and 4 across both genders (Table II).

Post-hoc analysis of children in CS 2 to CS5 showed that Class II girls undergo the adolescent growth spurt on average 0.63 year (p = 0.025) earlier than the Class I girls while Class II boys mature 0.23 years (p = 0.664) earlier than Class I boys. The Class III boys enter adolescent growth spurt on average 0.88 years later than the Class I boys (*p* = 0.022) while the same difference was found to be 0.58 years (p = 0.200) in girls (Table III).

The mean age at CS5 was 14.65 ± 0.80 years for boys and 13.71 ± 1.49 years for girls. The age of completion of adolescent growth spurt was assessed with respect to the maximum age at CS5 which was 16.5 years for boys and 16 years for girls after which all the subjects were found to be in CS6.

Table II: Mean age of CVM among three skeletal Classes

Gender	Cervical Stage	Mean Age (years ± SD)			*p*	Post hoc Dunnett's T3		
		Class I	Class II	Class III		Class I vs II (*p*)	Class I vs III (*p*)	Class II vs III (*p*)
Boys	CS 1	9.76 ± 1.65	9.65 ± 0.91	10.33 ± 0.50	0.737	0.996	0.538	0.400
	CS 2	11.05 ± 1.06	10.89 ± 0.91	12.37 ± 0.55	0.005*	0.037	0.004*	0.325
	CS 3	12.51 ± 0.88	12.02 ± 0.99	13.47 ± 0.62	<0.001**	0.412	0.011*	<0.001**
	CS 4	13.86 ± 0.42	12.95 ± 0.91	13.95 ± 0.70	0.009*	0.021*	0.988	0.067
	CS 5	14.58 ± 0.99	14.72 ± 0.54	14.79 ± 0.82	0.840	0.957	0.936	0.997
	CS 6	15.86 ± 0.73	15.33 ± 0.44	16.46 ± 0.87	0.091	0.109	0.478	0.104
Girls	CS 1	9.95 ± 0.98	10.28 ± 1.46	9.20 ± 0.93	0.285	0.954	0.573	0.301
	CS 2	11.19 ± 0.90	10.19 ± 0.76	11.46 ± 0.78	0.003*	0.014*	0.891	0.044
	CS 3	11.87 ± 1.03	11.61 ± 0.74	12.90 ± 0.22	0.019*	0.811	0.006*	<0.001**
	CS 4	12.93 ± 1.03	12.57 ± 0.69	13.59 ± 0.55	0.013*	0.332	0.051	<0.001**
	CS 5	13.75 ± 1.21	13.37 ± 1.93	14.40 ± 1.10	0.269	0.835	0.431	0.260
	CS 6	15.83 ± 0.95	15.30 ± 1.17	16.17 ± 0.67	0.106	0.519	0.714	0.089

N = 203; SD - Standard Deviation; Kruskal-Wallis test with Bonferroni correction

After applying Bonferrni correction for multiple testing a *p*-value of <0.025 was taken as statistically significant.

**p* < 0.025; ** *p* <0.001

Discussion

In orthodontic practice, a significant degree of speculation is involved in determining the growth status of a patient.[36] Inaccurate diagnosis of skeletal maturity of a patient may result in failure to achieve significant skeletal improvement through dentofacial orthopedics and compromised stability of the corrective jaw surgery. The use of functional appliances in the preadolescent years is associated with a high risk of relapse with original malocclusion returning in the forthcoming years.[37] On the other hand, a great deal of unwanted dentoalveolar changes are the usual outcome of long functional appliance therapy carried out in the terminal stages of the adolescent growth spurt.[38]

The variations in the onset and duration of the adolescent growth spurt may also play a role in determining the final facial form of an individual.[29,30] Different craniofacial structures respond differently to the altered hormonal state during the adolescent growth spurt with studies showing mandibular growth being accelerated to a greater extent than the maxilla.[39-42]

Table I. Comparison of mean age of CVM between males and females

Cervical Stage	Boys (n=203) (years ± SD)	Girls (n=237) (years ± SD)	Mean Difference (years)	*p*
CS 1	9.81 ± 1.40	9.84 ± 1.24	0.03	0.941
CS 2	11.95 ± 1.03	10.69 ± 0.97	1.25	<0.001**
CS 3	12.61 ± 1.03	11.20 ± 0.92	1.41	0.002*
CS 4	13.69 ± 0.85	12.19 ± 0.91	1.50	0.003*
CS 5	14.68 ± 0.81	13.22 ± 1.50	1.45	<0.001**
CS 6	15.80 ± 0.76	15.21 ± 1.02	0.58	0.200

N = 440; SD - Standard Deviation; Mann Whitney U t-test

*$p < 0.05$; ** $p < 0.001$

During the adolescent growth spurt the growth potential of the patient is rapidly utilized. This depletes the population of progenitor cells and gives a more stable adult form to different body structures.[42] A late start of the adolescent growth spurt invokes rapid growth of jaw bones when they have already achieved a larger size; while an early start of the adolescent growth spurt is likely to result in a small final size of different body structures.[7,42] These theories are endorsed by the results of current study showing that the adolescent growth spurt occurs earlier in children with Class II malocclusion and later in those with Class III malocclusion. Same concept has been used by various authors trying to relate and early onset of puberty to a small sized mandible in girls as compared to the boys.[42]

Table III. Mean differences in the timing of adolescent growth spurt among three skeletal classes

		Boys	Girls
Class I vs II	**Mean Difference**	0.23 (~ 2⅔ months)	0.63 (~ 7½ months)
	Std. Error Difference	0 .26	0.23
	P	0.664	0.025*
Class I vs III	**Mean Difference**	- 0.88 (~ 10½ months)	- 0.58 (~ 6⅔ months)
	Std. Error Difference	0.31	0.32
	P	0.022*	0.200
Class II vs III	**Mean Difference**	1.12 (~ 13½ months)	1.21 (~ 14½ months)
	Std. Error Difference	0.30	0.32
	P	0.002*	<0.001**

N = 440; Post Hoc Scheffe test , After applying Bonferroni correction for multiple testing a *p*-value of <0.025 was taken as *statistically significant.*$p < 0.025$; ** $p < 0.001$*

Sexual maturity has been used as a reliable indicator of different stages of adolescent growth spurt.[20] Literature shows the girls reach the skeletal maturity on average 2 years earlier than the boys.[42] As judged from the timing of CVM, we found this difference to be of about 1.5 years in our sample. There is evidence that the secular trend in the age at menarche has reached a plateau, however, newer studies continue to highlight secular trends in the age of sexual maturation in boys.[43,44] Concurrently, the ethnic variations in the timing of adolescent growth spurt are also reported in the literature.[32] These factors, along with familial trends, nutritional status and systemic diseases necessitate for the orthodontist to have a keen look at the probable time of the adolescent growth spurt in a specific patient.[31,32]

Assessing the time of pubertal growth spurt in the different skeletal malocclusions may represent a reverse prediction model since a specific skeletal jaw relationship may result from the variations in the timing and duration of pubertal growth spurt. Armond et al.[45] has shown that the children with Class II malocclusion have a tendency to mature earlier than those with Class I jaw relationship. Similar results were given by Salazar-Lazo et al.[46] who showed a difference of about 6 months in the timing of pubertal growth peak between Class I and Class II children. On the other hand, studies show that the duration of pubertal growth peak in Class III children is on average 5 months longer as compared to the Class I children.[33,47] However, the increment in the jaw size during the pubertal growth spurt has been found to be comparable among the three skeletal classes.[48] Similarly, there is strong evidence that in the cases of mandibular prognathism the mandible generally continues to show significant growth even after the pubertal growth spurt is over.[49] Thus the variations in the timing of the adolescent growth spurt is less likely to significantly affect the final size of the mandible.

A controversy remains about the best method of assessing the developmental status of a child as some practitioners continue to give equal importance to dental and chronological age as compared to the skeletal age.[50,51] Santioago et al[26] showed a moderate to high level of reproducibility of CVM method in assessing the skeletal maturity of an individual using the Kappa statistics. Same method was used in the present study which showed a high level of reproducibility in assessing CVM stages. Altered patterns in the skeletal and dental maturation have been reported among various vertical facial patterns.[52,53] In this context, subjects with only normal vertical facial pattern were included in this study. The assessment of the craniofacial growth asks for a longitudinal study design as an essential method for reliable results. The longitudinal studies require repeated exposure to x-ray radiations that has certain ethical limitations.[24]

Conclusions

From the results of the current study following conclusions are derived:

- Girls enter the adolescent growth spurt around 1.5 years earlier than boys.
- The Class II girls enter the adolescent growth spurt 7.5 months earlier than the Class I girls.
- The Class III boys enter the adolescent growth spurt 10.5 months later than the Class I boys.
- Girls enter the final stage of the adolescent growth spurt (CS6) on average 1.3 years earlier than boys.
- No significant differences in the timing of completion of the adolescent growth spurt were present among children with different skeletal classes.

Orthodontists should consider these variations in the timing of the adolescent growth spurt while assessing the developmental status, so that an effective and efficient treatment plan may be formulated for each patient.

References

1. Proffit WR, White RP Jr. Combined surgical-orthodontic treatment: how did it evolve and what are the best practices now? Am J Orthod Dentofacial Orthop 2015;147:S205-15.
2. Proffit WR, Jackson TH, Turvey TA. Changes in the pattern of patients receiving surgical-orthodontic

treatment. Am J Orthod Dentofacial Orthop 2013;143:793-8.
3. Broadbent JM. Crossroads: acceptance or rejection of functional jaw orthopedics. Am J Orthod Dentofacial Orthop 1987;92:75-8.
4. DiBiase AT, Cobourne MT, Lee RT. The use of functional appliances in contemporary orthodontic practice. Br Dent J 2015;218:123-8.
5. Page DC. The orthodontic shift towards functional jaw orthopedics. Funct Orthod 2000;17:14-7.
6. Rivera SM, Hatch JP, Dolce C, Bays RA, Van Sickels JE, Rugh JD. Patients' own reasons and patient-perceived recommendations for orthognathic surgery. Am J Orthod Dentofacial Orthop 2000;118:134-41.
7. Profitt WR, White RP, Sarver DM. Contemporary treatment of dentofacial deformity. In: Mosby, St. Louis; 2003:689–709.
8. Proffit WR, Turvey TA, Phillips C. Orthognathic surgery: a hierarchy of stability. Int J Adult Orthodon Orthognath Surg 1996;11:191-204.
9. Baccetti T, Franchi L, McNamara JA. The cervical vertebral maturation (CVM) method for the assessment of optimal treatment timing in dentofacial orthopedics. Semin Orthod 2005;11:119-29.
10. Fishman L. Chronological versus skeletal age, an evaluation of craniofacial growth. Angle Orthod 1979;49:181–9.
11. Chen L, Liu J, Xu T, Lin J. Longitudinal study of relative growth rates of the maxilla and the mandible according to quantitative cervical vertebral maturation. Am J Orthod Dentofacial Orthop 2010;137:736.e1-e8.
12. Singer J. Physiologic timing of orthodontic treatment. Angle Orthod 1980;50:322–33.
13. Carlson DS, Goldstein SA. Bone biodynamics in orthodontic and orthopedic treatment. Monograph 27. University of Michigan: Center for Human Growth and Development, Ann Arbor; 1992:189-255.
14. Weaver N, Glover K, Major P, Varnhagen C, Grace M. Age limitation on provision of orthopedic therapy and orthognathic surgery. Am J Orthod Dentofacial Orthop 1998;113:156-64.
15. Capelli Jr J, Almeida RC. Ortho-surgical treatment of patients in the growth period: at what cost? Dental Press J Orthod 2012;17:159-77.
16. Hunter WS. The correlation of facial growth with body height and skeletal maturation at adolescence. Angle Orthod 1966;36:44–54.
17. Green LJ. The interrelationships among height, weight, and chronological, dental, and skeletal ages. Angle Orthod 1961;31:189–93.
18. Hägg U, Taranger J. Skeletal stages of the hand and wrist as indicators of the pubertal growth spurt. Acta Odontol Scand 1980;38:187-200.
19. Hägg U, Matsson L. Dental maturity as an indicator of chronological age: the accuracy and precision of three methods. Eur J Orthod 1985;7:25–35.
20. Hägg U, Taranger J. Menarche and voice changes as indicators of the pubertal growth spurt. Acta Odontol Scand 1980;38:179-86.
21. Lamparski DG. Skeletal age assessment utilizing cervical vertebrae [master's thesis]. Pittsburgh, Penn: Department of Orthodontics, The University of Pittsburgh; 1972.
22. Hassel B, Farman A. Skeletal maturation evaluation using cervical vertebrae. Am J Orthod Dentofacial Orthop 1995;107:58–66.
23. Baccetti T, Franchi L, McNamara JA. An improved version of the cervical vertebral maturation (CVM) method for the assessment of mandibular growth. Angle Orthod 2002;72:316-23.
24. Soegiharto BM, Moles DR, Cunningham SJ. Discriminatory ability of the skeletal maturation index and the cervical vertebrae maturation index in detecting peak pubertal growth in Indonesian and white subjects with receiver operating characteristics analysis. Am J Orthod Dentofacial Orthop 2008;134:227-37.
25. Gu Y, McNamara JA. Mandibular growth changes and cervical vertebral maturation. A cephalometric implant study. Angle Orthod 2007;77:947-53.
26. Santiago RC, de Miranda Costa LF, Vitral RW, Fraga MR, Bolognese AM, Maia LC. Cervical vertebral maturation as a biologic indicator of skeletal maturity. Angle Orthod 2012;82:1123-31.
27. Franchi L, Baccetti T, McNamara JA. Mandibular growth as related to cervical vertebral maturation and body height. Am J Orthod Dentofacial Orthop 2000;118:335-40.
28. Majeed O, Quadeer TA. Assessment of skeletal maturation and its correlation to chronological age using the cervical vertebral maturation method in a tertiary care hospital. J Pak Dent Assoc 2014;23:153-8.
29. Marshall WA, Tanner JM. Variations in pattern of pubertal changes in girls. Arch Dis Child. 1969;44:291–303.
30. Marshall WA, Tanner JM. Variations in pattern of pubertal changes in boys. Arch Dis Child. 1970;45:13–23.
31. Rogol AD, Clark PA, Roemmich JN. Growth and pubertal development in children and adolescents: effects of diet and physical activity. Am J Clin Nutr 2000;72:521S-8S.
32. Parent AS, Teilmann G, Juul A, Skakkebaek NE, Toppari J, Bourguignon JP. The timing of normal puberty and the age limits of sexual precocity:

variations around the world, secular trends, and changes after migration. Endocr Rev 2003;24:668-93.

33. García-Drago AG, Arriola-Guillén LE. Duration of the peak of growth in Class I and III subjects using the Baccetti's cervical vertebrae maturation analysis on lateral cephalometric radiographs. Oral Health Dent Manag 2014;13:963-6.
34. Reyes BC, Baccetti T, McNamara J Jr. An estimate of craniofacial growth in class III malocclusion. Angle Orthod 2006;76:577–84.
35. Steiner CC. Cephalometrics for you and me. Am J Orthod 1953;39:720-55.
36. Sadowsky, PL. Craniofacial growth and the timing of treatment. Am J Orthod Dentofacial Orthop 1998;113:19–23.
37. Hotz, R. Application and appliance manipulation of functional forces. Am J Orthod 1970;58:459–478.
38. Ruf S, Pancherz H. Dentoskeletal effects and facial profile changes in young adults treated with the Herbst appliance. Angle Orthod 1999;69:239-46.
39. Carlson DS, Buschang PH. Craniofacial growth and development: evidence-based perspectives. In: Graber TM, Vanarsdall, RL, editors. Orthodontics: Current principles and techniques. Mosby, St. Louis; 2000.
40. Nanda RS. The rates of growth of several facial components measured from serial cephalometric roentgenograms. Am J Orthod 1955;41:658–73.
41. Bambha JK. Longitudinal cephalometric roentgenographic study of face and cranium in relation to body height. J Am Dent Assoc 1961;63:776–99.
42. Proffit WR. Contemporary Orthodontics. St Louis, Calif: Mosby-Year Book Inc, 1999;296–325.
43. Tinggaard J, Mieritz MG, Sørensen K, Mouritsen A, Hagen CP, Aksglaede L, et al. The physiology and timing of male puberty. Curr Opin Endocrinol Diabetes Obes 2012;19:197–203.
44. Kryst L, Kowal M, Woronkowicz A, Sobiecki J, Cichocka BA. Secular changes in height, body weight, body mass index and pubertal development in male children and adolescents in Krakow, Poland. J Biosoc Sci 2012;44(4):495-507.
45. Armond MC, Generoso R, Falci SGM, Ramos-Jorge ML, Marques LS. Skeletal maturation of the cervical vertebrae: association with various types of malocclusion. Braz Oral Res 2012;26:145-50.
46. Salazar-Lazo R, Arriola-Guillén LE, Flores-Mir C. Duration of the peak of adolescent growth spurt in class i and ii malocclusion subjects using a cervical vertebrae maturation analysis. Acta Odontol Latinoam 2014;27:96-101.
47. Kuc-Michalska M, Baccetti T. Duration of the pubertal peak in skeletal Class I and Class III subjects. Angle Orthod 2010;80:54-7.
48. Nanda, R. Biomechanics and esthetic strategies in clinical orthodontics. St. Louis, MO: Elsevier Saunders; 2005.
49. Mitani H, Sato K, Sugawara J. Growth of mandibular prognathism after pubertal growth peak. Am J Orthod Dentofacial Orthop 1993;104:330–6.
50. King GJ, Keeling SD, Hocevar RA, Wheeler TT. The timing of treatment for Class II malocclusions in children: a literature review. Angle Orthod 1989;60:87-97.
51. Sinclair PM. The clinical application of orthopedic forces: current capabilities and limitations. In: Carlson DS, Goldstein SA, editors. Bone biodynamics in orthodontic and orthopedic treatment. Monograph 27. Craniofacial Growth Series. Ann Arbor: Center for Human Growth and Development, University of Michigan; 1992. p. 351-88.
52. Gottimukkala P, Gandikota CS, Challa PL, Perumalla K, Palla Y, Juvvadi SR. Assessment of skeletal and dental maturation of short and long-face children of South Indian population. J Ind Orthod Soc 2012;46:148-53.
53. Jamroz GM, Kuijpers-Jagtman AM, van't Hof MA, Katsaros C. Dental maturation in short and long facial types. Is there a difference? Angle Orthod 2006;76:768-72.