Assessment of skeletal maturation and pubertal growth spurt using cervical vertebrae maturation indicators

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ABSTRACT

Objective: To assess the skeletal maturation and pubertal growth spurt using cervical vertebrae maturation indicators.
Methods: Pre-treatment lateral cephalograms of 99 males and 110 females in the age range of 7 to 18 years 7 months were evaluated with cervical vertebrae maturation indicators (CVMI) of Hassel and Farman.
Results: Each CVMI stage appeared earlier in females as compared to males. There were highly significant differences in genders for each CVMI stage.
Conclusion: Females showed faster maturation than males. Pubertal growth spurt in males starts at the age of 11 years and lasts for the period of 29 months, while in females, it starts at the age of 9.9 years and lasts for a period of 24 months.

Keywords: Skeletal maturation - cervical vertebrae maturation indicators - pubertal growth - spurt

RESUME

Objectif: évaluer la maturation squelettique et le jaillissement de croissance pubertal en utilisant des indicateurs de maturation de vertèbres cervicaux.
Méthodes: le Pré-traitement cephalograms latéral de 99 mâles et de 110 femelles dans la gamme d'âge de 7 à 18 ans 7 mois a été évalué avec les indicateurs de maturation de vertèbres cervicaux (CVMI) de Hassel et Farman.
Résultats : Chaque stade CVMI a semblé plus premier dans les femelles en comparaison des mâles. Il y avait des différences extrêmement significatives dans les genres pour chaque stade CVMI.
Conclusion: les Femelles ont montré la maturation plus rapide que les mâles. Le jaillissement de croissance de Pubertal dans les mâles commence à l'âge de 11 années et dure pour la période de 29 mois, pendant que dans les femelles, il commence à l'âge de 9.9 années et dure pour la durée de 24 mois.

Mots-clés: : maturation squelettique - les indicateurs de maturation de vertèbres cervicaux - pubertal - jaillissement de croissance

INTRODUCTION

The pattern of somatic growth during the first two decades is categorized into 4 intervals [1, 2]. Infancy starting from birth to approximately 3 years of age; Childhood from 3 years to 12 years of age; Adolescence from 12 years to 18 years; and Adulthood from 18 years onwards (Figure 1). Knowledge of predicting the adolescent/pubertal growth spurt of a patient well in advance holds a very high importance for an orthodontist who is planning growth modulation for his patients. The pubertal growth spurt varies significantly in the initiation, duration and amount of growth among individuals and populations, which can be due to heredity, racial difference, nutrition, and socioeconomic status [3, 4]. The timing of growth events is far more important than the actual measurement. Tofani5 and Burstone [6] found that earlier the growth spurt, the greater is its magnitude and vice versa for the late growth spurts. Maturational status influences the diagnosis, treatment planning, goals, and the eventual outcome of orthodontic treatment, especially dentofacial orthopaedic & orthognathic surgical decisions. Thus the prediction of timing and amount of active growth is an important issue.
There are many methods to assess the level of skeletal maturation e.g. chronological age, onset of menarche, hand wrist x-rays, cervical vertebrae maturation, dental maturation etc.
The chronological age is not a reliable method to determine the maturation stage of a child due to considerable variations in development [7–9] which has led to the concept of assessing skeletal / biological / physiological maturity.

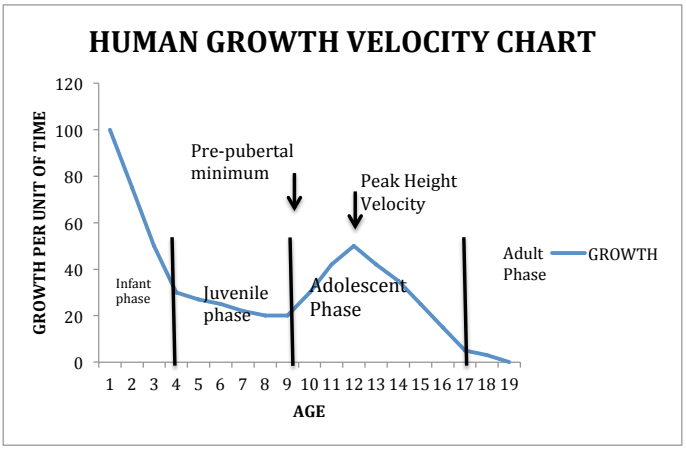

Figure 1: Human growth velocity chart for somatic tissues divided into 4 major phases of post-natal growth (Redrawn from Rasool G et al40. Pakistan Oral & Dental Journal Vol 31, No. 1 (June 2011) for illustration purpose only).

Skeletal maturation refers to the degree of development of ossification in bone and is a more reliable method for growth assessment. It can be done by a radiographic inspection of developing bones and subsequent ossification-related changes to predict timings of pubertal growth, to estimate growth velocity and the amount of growth remaining.
An assessment of skeletal development is commonly done using hand-wrist radiographs [10-16]. Skeletal-maturation

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evaluation using cervical vertebrae has gained popularity because the cervical vertebrae are easily seen on the lateral cephalograms routinely taken as pre-treatment diagnostic radiographs in orthodontics. Hassel and Farman17 in 1995 studied the bodies of cervical vertebrae (C2, C3, and C4) in lateral cephalograms to evaluate cervical vertebrae maturity indicators (CVMI) for assessing the skeletal maturity and correlated its 6 stages (Table 1) with Fishman's skeletal maturity indicators8, SMIs. Eleven SMIs (skeletal maturation indicators) were condensed into six CVMI categories showing various phases of adolescent growth spurt [17]. CVMI stage 2 represents the onset of pubertal growth spurt, CVMI stage 3 represents the peak of pubertal growth spurt, and CVMI stage 4 represents the deceleration part of pubertal growth spurt. Each stage also signifies the expected amount of active growth (Table 1).

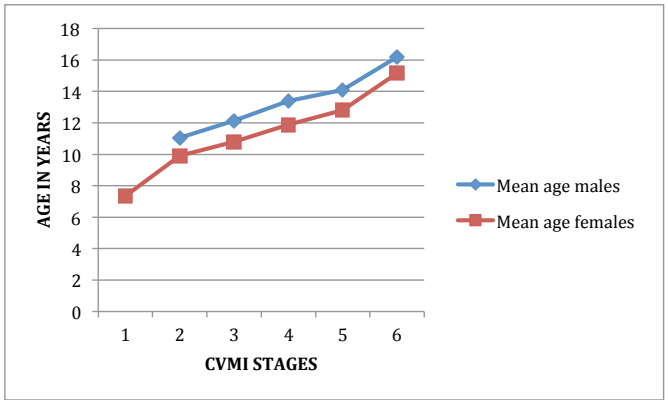

Figure 2: Mean age at each CVMI stage in both genders.

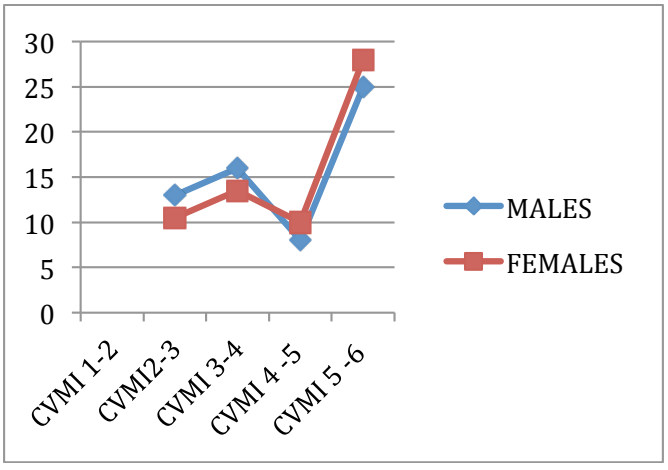

Figure 3: Duration between different CVMI stages in both genders.

CVMI has been proved independently effective in assessing the adolescent growth peak, and its effectiveness has also been proved by studies showing a high correlation between CVMI and skeletal maturation assessed by hand wrist radiographs [18-20]. So hand wrist radiographs can be reliably replaced with lateral cephalograms for growth prediction by assessing CVMI. Racial variations have also been found to exist in the skeletal maturation due to multiple factors [21-23].

Table 1: Cervical vertebra maturation indicators (CVMI, Hassel and Farman17, 1995)

CVMI Stage	Stage	Amount of growth expected	Characteristics
1	Initiation	85% - 100%	C2, C3, and C4 inferior vertebral body borders are flat. Vertebrae are wedge-shaped. Superior vertebral borders are tapered posterior to anterior.
2	Acceleration	65% - 85%	Concavities are developing in the inferior borders of C2 and C3. The inferior border of C4 is flat. The bodies of C3 and C4 are nearly rectangular in shape.
3	Transition	25% - 65%	Distinct concavities are seen in the inferior borders of C2 and C3. A concavity is beginning to develop in the inferior border of C4. The bodies of C3 and C4 are rectangular in shape.
4	Deceleration	10% - 25%	Deceleration of adolescent growth spurt. Small amount of adolescent growth expected. Distinct concavities in the inferior borders of C2, C3, and C4. C3 and C4 are nearly square in shape.
5	Maturation	5% - 10%	Final maturation of the vertebrae takes place during this stage. Insignificant amount of adolescent growth expected. Accentuated concavities of inferior vertebral body borders of C2, C3, and C4. C3 and C4 are square in shape.
6	Completion	Little or no growth	Adolescent growth is completed. Deep concavities are seen in inferior border of C2, C3, and C4. C3 and C4 heights are greater than widths.

Since the lateral cephalogram is a routine diagnostic radiograph taken for orthodontic treatment, the ability to assess skeletal maturity from CVMI on a lateral cephalogram offers an advantage as it avoids additional radiation exposure to obtain hand - wrist radiograph.
This study was done to evaluate the skeletal maturation and pubertal growth spurt using CVMI in Rwandese children. Rwanda is a land – locked country with highest population density in African continent. According to Demographic Health Survey 2010, there is about 43% population in 0 – 14 years age category. Rwandese children have better physique than their Asian, American and African counterparts, achieving good body height at an early age. But till date, there is no published details on the assessment of skeletal maturity and pubertal growth spurt timings of Rwandese children.
Broad objective: Assessment of skeletal maturation and pubertal growth spurt using cervical vertebrae maturation indicators.

Specific objectives:

1. To assess the level of skeletal maturation by using CVMI
2. To investigate the timing of occurrence and the duration of pubertal growth spurt in females and males.

METHODS

This study was designed as a descriptive, cross-sectional and quantitative research project.
Pre-treatment lateral cephalograms of 209 subjects (99 male and 110 female) were randomly selected from the records of orthodontic patients at King Faisal Hospital,

Rwanda. Most of the patients were urban residents.
Selection criteria: The inclusion criteria were as follows:
- Chronological age ranging from 7 to 19 years
- Normal overall growth and development
- Absence of previous history of trauma or disease to the face and neck
- No gross skeletal deformities e.g. clefts, hemiatrophy, hypertrophy etc, and not any congenital deformity, scoliosis, lordosis etc.
- Absence of previous orthodontic treatment

All radiographic assessments were performed on a back-illuminated radiographic view box in a darkened room. Any poor quality radiograph showing motion dullness or poor contrast was discarded.
Evaluation of cervical vertebrae maturity indicators (CVMI) on lateral cephalogram: CVMI was evaluated by using the method proposed by Hassel and Farman [17] (Table 1). Randomly selected records of 15 patients were re-evaluated to test the reproducibility of assessments, and data was evaluated in terms of the weighted kappa statistics. The kappa statistics for intra-observer agreement were 0.84. It is clear that there was acceptable intra-observer agreement for assessments [24].

Statistical analysis:

Statistical analyses were performed with Epi Info 3.4.3 (CDC, Illinois). Descriptive statistics were calculated to determine the distribution of sample, means and standard deviations of the chronological ages for all the stages of CVMI stratified by the gender & total sample. Mann Whitney / Wilcoxon Two-sample test (Kruskal Wallis test for 2 groups) were done to evaluate inter-group differences. A p-value of < 0.01 was considered as statistically significant. Age of all the subjects was converted in months to calculate exact age for statistical purpose and then reconverted in years by dividing with a factor of 12, wherever necessary.

RESULTS

The study involved records of 47.4% (n=99) males and 52.6% (n=110) females. The age range of the study sample was from 7 years to 18 years 7 months. The mean age of males was 13.27 years (SD = 2.1 years), of females was 12.9 years (SD = 2.26 years), and that of total sample as 13.08 years (SD = 2.18 years).

Table 2: Percentage distribution and the mean chronological ages of all the subjects grouped by various CVMI stages

CVMI stages	Females n	Females %	Males n	Males %	Mean age males	Mean age females	Gend diffe
					Yrs ± SD	Yrs ± SD	Yrs
1	2	1.8	0	0	-	7.33±0.47	-
2	8	7.3	10	10.1	11.05±1.7	9.9±1.17	1.1
3	13	11.8	38	38.4	12.13±1.28	10.8±1.05	1.33
4	23	20.9	19	19.2	13.4±1.37	11.9±1.75	1.5
5	25	22.7	15	15.2	14.1±1.06	12.8±0.9	1.3
6	39	35.5	17	17.2	16.2±1.45	15.15±1.45	1.05
Total	110	100	99	100			

Mann Whitney / Wilcoxon Two-sample test (Kruskal Wallis test for 2 groups): (For females, Chi square = 81.57, DF = 5, ***p <0.001, Highly significant; For males, Chi square = 59.08, DF = 4, ***p <0.001, Highly significant)

Table 2 shows the percentage distribution and mean chronological ages of the sample grouped by various CVMI stages and gender. Each stage appeared significantly earlier in females than in males (Figure2). Mann Whitney / Wilcoxon Two-sample test (Kruskal Wallis test for 2 groups) showed highly significant differences among various CVMI stages in both the genders (For females, Chi square = 81.57, DF = 5, p <0.001; For males, Chi square = 59.08, DF = 4, p <0.001). Interval in months was also calculated between different CVMI stages (Table 3). Duration between CVMI stages 2 & 4 (i.e. pubertal growth spurt) was 29 months in males and 24 months in females.

Table 3: Duration in months between different stages of CVMI in males and females

CVMI INTERVAL	MALES	FEMALES
CVMI 1-2		
CVMI2-3	13	10.5
CVMI 3-4	16	13.5
CVMI 4 -5	8	10
CVMI 5 -6	25	28

Table 4a: showing comparison of mean age in years of all CVMI stages in different populations

CVMI stages	Rwanda	Chinese[34]	Indonesia[33]	Whites[33]	Chang[34]	India[36]	India[38]	India[37]	New zealand[39]
				Males					
1		10.3			9.32	8.83	11.18	10.43	10.39
2	11.05	11.18	11.73	11.38	10.98	11.21	11.73	12.41	10.83
3	12.13	12.61	12.82	12.44	12.42	13.40	12.77	13.38	12.61
4	13.4	13.93	14.76	14.07	14.21	13.75	14.58	15.13	13.36
5	14.1	16.02	15,8	15.54	15.18	15.83	15.96	15.67	14.28
6	16.2	16.58	17.03	16.84	16.29	16.67	17.5	16.45	14.69
				Females					
CVMI stages	Rwanda	Chinese[34]	Indonesia[33]	Whites[33]	Chang[34]	India[36]	India[38]	India[37]	New zealand[39]
1	7.33	9.22			8.45	8.73	9.45	9.02	9.52
2	9.9	10.27	9.69	9.55	9.44	10.44	10.6	10.05	9.62
3	10.8	10.8	11.2	11.11	10.6	13.00	11.7	11.36	11.05
4	11.9	12.6	12.83	12.58	11.76	12.5	13.45	12.49	12.05
5	12.8	14.8	14.15	14.26	13.95	14	15.1	13.16	13.48
6	15.15	15.8	14.7	15.33	15.85	16.30	16.6	14.45	13.43

Table 4b: showing comparison of mean age in years of whole sample for all CVMI stages

CVMI	Rwanda	Turks[21]
1	7.34	9.8
2	10.54	10.5
3	11.8	12.9
4	12.6	12.11
5	13.3	13.9
6	15.5	15.8

DISCUSSION

Knowledge of the concepts of facial growth is very important for effective dentofacial jaw orthodpedic interventions and orthognathic surgical planning. Treatment for growth modification should be started during active growth period to achieve maximum skeletal benefits, while surgical options are deferred till the active facial growth has finished to minimise future relapse. Timing of dentofacial orthopedic growth modification is typically linked to the period of maximum pubertal growth potential [25-27]. Therefore, estimating the peak of individual's growth potential, known as pubertal growth spurt, is an essential element of orthodontic diagnosis and treatment planning.

Staging of human skeletal development has been assessed using physiological parameters including peak growth velocity in standing height, pubertal markers (such as voice changes in males, menarche in females, breast development, appearance of pubic hair, and appearance of axillary hair), radiographic assessment of bone maturation, chronological age, and staging of dental development [28-31]. Peak growth velocity in standing height of an individual is the most objective valid representation of rate of overall skeletal growth but has little predictive value for future growth rate or percentage of the remaining growth as it holds only a retrospective significance. Similarly, other biologic markers such as secondary sexual characteristics cannot be used to predict the timing of maximum growth due to their retrospective nature.

Because there is wide variation among individuals in the timing of the pubertal growth spurt, chronologic age cannot also be used in the evaluation of adolescent growth. Hagg and Taranger [15] reported a two-year sex difference for the beginning, peak, and end of the pubertal growth spurt in standing height for males and females.

For these reasons, an indication of the maturation level of an individual is necessary to predict future growth [29] Direct evaluation of skeletal maturity level by observing certain bony maturation markers among different parts of the body is more valuable as a diagnostic tool in forecasting the prospective adolescent growth spurt and planning the growth modification therapy [30, 31].

Many methods have been suggested for prediction of skeletal maturity levels e.g. hand wrist x-rays, lateral cephalograms, dental maturation stages on panoramic radiographs etc [7-17]. Skeletal maturation staging from radiographic analysis is a widely used approach to predict timing of pubertal growth, and to estimate the proportion of the remaining growth. Skeletal maturity is influenced in each individual by a combination of genetic and environmental factors. An important consideration is that the same pattern of skeletal growth can be found in almost every individual, but the initiation, duration, and amount of growth varies considerably during the pubertal growth spurt [29].

Use of hand-wrist radiographs leads to unnecessary radiation exposure, thus making their use questionable. Lateral cephalograms are advantageous because unnecessary radiation exposure is avoided to obtain hand-wrist x-ray and are the mandatory pre-treatment records for every orthodontic patient.

Many studies have confirmed the validity of skeletal maturation evaluation using cervical vertebrae instead of hand and wrist bones [33]. The cervical vertebrae are easy to examine on the lateral cephalograms. Thus the hand wrist x-rays can be reliably replaced with CVMI observed on lateral cephalograms for growth assessment. Studies have proved that CVMI is a valid and reliable method for growth assessment and that is why it was used as a preferred method for the present study [17-21,26,32,33].

On observing the Table 2 / Fig 2, it can be seen that each CVMI stage consistently appears earlier in girls than in boys, showing that the girls mature faster than boys. Many of the previous studies have also found the same, thus the observations of present study are in corroboration with earlier studies [22, 32-34].

The relationship between skeletal maturity and peak height velocity (PHV) is well established [9,14,15,35]. Studies [14,15, 35] have found that the appearance of adductor sesamoid of thumb indicates the beginning of pubertal growth spurt (i.e. onset of PHV), which corresponds to stage 2 of CVMI.17 In our study, the pubertal growth spurt according to the CVMI stage 2 (which signifies the pre–peak of pubertal growth spurt or onset of PHV) started at 9.9 years in females and 11.05 years in males, showing that the females are more advanced in maturation than males by nearly 1.15 years.

Bjork and Helm [35] found that the MP3cap stage heralds the peak (PHV) of pubertal growth spurt, which corresponds to stage 3 of the CVMI [17] In the present study, the CVMI stage 3 which signifies the peak of pubertal growth spurt (PHV), was seen at an approximate age of 10.8 years in females and 12 years in males, i.e. approximately 11 after months of the pre-peak stage in both genders.

The CVMI stage 4 which represents the deceleration phase of pubertal growth spurt was seen at an approximate age of 11.9 years in females and 13.4 years in males.

Fishman's skeletal maturity indicators 10 and 11 correspond to CVMI stages 5 and 6 and signify negligible growth [17]. In our study, the CVMI stage 5 was seen at an approximate age of 12.8 years in females and 14 years in males. It suggests that by that age, the children remain with negligible growth potential. Any dentofacial orthopaedic intervention should be started at least 6 – 8 months before the peak stage (PHV) for better skeletal response. Thus the functional orthopaedic treatment should be started

at 10 years in females and 11 years in males. Delaying the treatment will lead to loss of precious active growth period and thus compromising the treatment results.
It can be seen that duration of pubertal growth spurt i.e. duration between CVMI stages 2 - 4, which signifies acceleration part, attainment of PHV and deceleration parts of adolescent/pubertal growth spurt was 29 months long in males and 24 months long in females. Duration of peak pubertal growth i.e. during C3 and C4 in males is 16 months in females is 13.5 months (Table 3). It means that males grow for a longer period than females during the pubertal growth period. However, the complete end of growth is expected at 15 years in females and 16 years in males (CVMI stage 6), thus the decision of any orthognathic surgery should be deferred till that age.
When the mean ages of each CVMI stages of Rwandese sample were compared to that of other population [21, 33,34,36- 39], (Tables 4a,b), it was observed that each CVMI stage appeared earlier than other population in Rwandese children in both the genders. It suggests that Rwandese children a tendency of being early – maturers and grow faster.
Since this is the first study of its kind to assess the skeletal maturation of Rwandese children, it is recommended that further studies can be done to corroborate the findings by involving larger sample size and stratifying the sample based on nutrition, educational background, socio-economic status etc to see the effects of such variables on the status of growth of children.

CONCLUSION

The findings of this retrospective cross-sectional study demonstrate that the appearance of each CVMI stage was consistently earlier in female than in male subjects and thus the skeletal maturation is more advanced in females as compared to males. The pubertal growth spurt i.e. between CVMI stages 2 and 4 was 29 months long in males and 24 months long in females. The PHV i.e. CVMI 3 was observed at age 12 years in males and 10.8 years in females, which was approximately 11 months after the pre-peak stage of pubertal growth spurt. It can be concluded that the period of active pubertal growth in females is 9.9 – 11.9 years of age, and in males is 11 – 13.4 years age, and during this period, the growth modulation treatment should be done.

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