

# Skeletal Maturity Indicators: A Review

Priyanka S. Narote<sup>1\*</sup>, Aditi Sarda<sup>2</sup>, Amit Handa<sup>1</sup>, Ranjeet Pawar<sup>1</sup>

<sup>1</sup>Department of Orthodontics and Dentofacial Orthopaedics, Aditya Dental College, Beed, Maharashtra, India.

<sup>2</sup>Department of Endodontics, Aditya Dental College, Beed, Maharashtra, India.

## Abstract

An understanding of growth events is of primary importance in the practice of clinical orthodontics. Maturation status can have considerable influence on diagnosis, treatment goals, treatment planning, and the eventual outcome of orthodontic treatment. Growth biologically and histologically is a composite of morphogenetic and histogenetic changes occurring continuously over a period in response to genetic coding and environmental influence. It is one of the most myriad variations and plays an important role in the etiology of malocclusion and also in the evaluation of diagnosis, treatment planning retention, and stability of any case. In this review, various methods currently used as skeletal maturity indicators have been discussed.

**Keywords:** Canine calcification, Cervical vertebrae maturation indicators, Hand and wrist radiographs, Middle phalanx of third finger, Skeletal maturity indicators.

## INTRODUCTION

Every individual matures according to his or her own biological clock. Different authors had reported different methods in an attempt to determine the best indicator of maturity. These include height<sup>[1-3]</sup> weight chronological age;<sup>[4-10]</sup> sexual maturation frontal sinus biological age or physiological age; hand-wrist maturity;<sup>[2,11-13]</sup> cervical vertebrae<sup>[14-17]</sup> dental eruption; dental calcification stages<sup>[17-19]</sup> and recently introduced biomarkers.

Prediction of both the times and the amount of active growth, especially in the craniofacial complex, would be useful to the orthodontist. Growth modulation procedures, which bring about changes in the skeletal base such as the use of extraoral orthopedic forces or functional appliances, are suggested to be initiated during active growth periods.<sup>[7]</sup> These active growth periods have to be objectively assessed for both the timing and the amount of active growth vector or direction of growth. Maturation status of an individual can be best evaluated relative to different stages of physiologic maturity rather than evaluating it with chronologic age because the latter is not a reliable indicator.<sup>[8]</sup> Physiologic maturity is best-estimated by the maturation of one or more tissue systems, such as somatic, sexual, skeletal, and dental maturity. Among the given indicators, chronological age is considered to be an easy parameter to assess expected amount of growth and development.<sup>[10]</sup>

## CHRONOLOGICAL AGE

Birthdate by calendar determines chronological age. Wide individual variation lies in timing of pubertal growth spurt with respect to chronological age. Therefore, thus, chronological age cannot be considered as a reliable indicator for the evaluation of maturity status of a child.<sup>[2]</sup> This has led to the concept of Biological age or physiological age.

## BIOLOGICAL AGE OR PHYSIOLOGICAL AGE

The physiological age of a person is determined by the degree of maturation of the different tissue systems.<sup>[18]</sup> Physiological age can be estimated by the maturational status of somatic, sexual, skeletal, and dental system.

## Somatic maturity

An annual growth increment in height or weight determines the somatic maturity.<sup>[2]</sup> Measurement of height represents general growth of the skeleton. Average age of onset of stature growth for females and males of approximately 10 and 12 years, respectively, with the peak coming later in both sexes.<sup>[5]</sup>

**Address for correspondence:** Dr. Priyanka S. Narote,  
Department of Orthodontics and Dentofacial Orthopaedics, Aditya Dental  
College, Beed, Maharashtra, India.  
Email: narotepriyanka7@gmail.com

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Height, therefore, might represent a skeletal measure that can be used to predict the timing of the facial growth spurt and needs further exploration.

### Sexual maturation

Sexual maturation involves using secondary sex characteristics to predict the individual maturational status. Tanner had given separate sexual maturity ratings for boys and girls which consists of five stages of sexual maturity with stage 1 being the least mature (preadolescent) and stage 5 being the most mature (adult). In boys, Tanner Sexual Maturity Ratings assesses pubic hair (amount, coarseness, color, and location), penile length and breadth, scrotal development, and testicular size. In girls, tanner sexual maturation rating assesses breast development (size and morphology) and pubic hair (location, color, morphology, and quantity). Prediction of sexual maturity requires a physical examination, and hence use of sexual maturity as maturation marker is limited in the orthodontic setup. Serial recording of voice change in boys can be used as a measurement of maturity but as mentioned above it requires a serial recording, not practical in orthodontic clinics.<sup>[5]</sup> Menarche is an important predictor of maturation in females.<sup>[9]</sup> Once menstruation begins, the growth spurt is usually near completion.

### Skeletal maturation

Certain bones in the body demonstrate an organized event of ossification. Degree of ossification in these bones determines skeletal maturation. These changes can be seen radiologically. The hand, foot, knee, elbow, shoulder, and hip, cervical vertebrae can be used to assess skeletal age of an individual. Skeletal maturity assessment involves visual inspection of the developing bone and their initial appearance, sequential ossification, and related changes in shape and size. Thus, the skeletal maturity indicators provide an objective diagnostic evaluation of the stage of maturity in an individual.

### PUBERTAL/ADOLESCENT GROWTH SPURT

The timing of recognition of the last and important growth spurt that is, the pubertal growth spurt is important in the percept of orthodontics. It is during this growth phase, the somatic growth rate is at its maximum. Every growth spurt has definite onset, accelerating phase, peak of the growth spurt, decelerating phase, end of the growth spurt. The duration of this growth spurt is short in females around 3–4 years compared to males in which it extends 4–5 years. The girls have an earlier onset of puberty whereas in the boys, late-onset is seen. The accelerating phase may last for 2 years on average. After 3–4 years of the end of this growth spurt, the active growth ceases.<sup>[17,18]</sup>

### ASSESSMENT OF TIMING OF ADOLESCENT GROWTH SPURT

The timing of the growth spurt can be assessed by chronological age, skeletal age, physiologic age, and dental age. The chronological age is not reliable as variability is the rule of growth pattern. In most of the conditions, skeletal age is

assessed to pinpoint identify the different phases of the growth spurt. A number of methods are available to assess the skeletal maturity of an individual in orthodontic practice which are broadly classified as follows:

#### A. Radiological

1. Special radiographs:  
Use of hand-wrist radiographs: This is the most common method and widely accepted method.<sup>[16]</sup>
2. Lateral cephalograms:  
Use of cervical vertebrae on a lateral cephalogram.<sup>[14,16]</sup>  
Use of frontal sinus using lateral cephalogram.
3. Orthopantomogram (OPG)/intraoral periapical:  
Use of different stages of tooth development.<sup>[14,18,19]</sup>

#### B. Biochemical

Recent biochemical method in saliva and serum are the Insulin-like growth factor growth hormone, Creatinine, Alkaline phosphatase.

The review of the literature shows a vast ore on this topic. These studies or reviews are related to methods of assessment, correlation between different methods, correlation between skeletal age and dental age and chronological, etc.

### Radiological

#### Hand wrist radiographs

The hand wrist radiograph is considered to be the most standardized method of skeletal assessment. Assessment of skeletal maturation using hand wrist radiograph as an index based upon time and sequence of appearance of carpal bones and certain ossification events has been reported by many investigators. A number of methods have been described to assess the skeletal maturity using hand-wrist radiographs.<sup>[16]</sup> The following are the most commonly used methods:

- A. Atlas Method by Greulich and Pyle.
- B. Bjork, Grave, and Brown Method modified by Schopf in 1978.
- C. Fishman's skeletal maturity indicators.
- D. Hägg and Taranger Method.
- E. Singers Method.

Amongst all, Atlas Method by Greulich and Pyle is a comparative method whereas all the other methods are individualized methods. All of these methods rely on the stage of the development of the epiphysis over the diaphysis. Usually, all the methods depend on the assessment of the following stages in the ossification of phalanges:

- Stage 1: The epiphysis and diaphysis are equal (Sign convention “=”).
- Stage 2: The epiphysis caps the diaphysis by surrounding it like a cap (cap).
- Stage 3: Fusion occurs between the epiphysis and diaphysis (U-Union).

#### Greulich and Pyle method

Greulich and Pyle published an atlas containing the pictures of standard hand wrist radiographs. In that, they had given ideal

pictures of hand wrist radiograph for different chronological age, and for each sex. Each photograph in atlas represents the particular skeletal age. Patient radiograph is matched with photographs in atlas. It involves comparing a hand wrist film with standard of same sex and nearest chronological age. The film then compared with adjacent standards. Both older and younger than the one which is of the nearest chronological age. Close one is chosen.

### ***Bjork Grave and Brown method***

- They divide maturation process of bone of hand between ages 9 and 17 years into nine stages.
- Each stage represent level of skeletal maturity.

Total 14 ossification points were used (Figure 1).

- Development stage assessed according to relation between epiphyses and diaphysis.

First stage: (Males 10.6 y, Females 8.1 y) (Figure 2).

PP2-stage: The epiphysis and diaphysis are equal. Occurs approximately 3 yrs before the peak of pubertal growth spurts.

Second stage: (Males 12 y, Females 8.1 y) (Figure 3).

MP3 stage: The epiphysis and diaphysis are equal. Just before the beginning of pubertal growth spurts.

Third stage: (Males 12.6 y, Females 9.6 y) (Figure 4).

Pisi-stage = Visible ossification of the pisiforme

H1-stage = Ossification of the hamular process of the hamatum

R-stage = The epiphysis and diaphysis are equal. Stage occurs 6 months before.

Fourth stage: (Males 13 y, Females 10.6 y) (Figure 5).

Fifth stage: (Males 14 y, Females 11 y) MP3 CAP (Figure 6). The diaphysis is covered by cap-shaped epiphysis this stage marks the peak of pubertal growth spurt

S = First mineralization of the ulnar sesamoid bone

H2: Progressive ossification of the hamular process of the hamatum marks the beginning of growth spurt

Sixth stage: (Males 15 y, Females 13 y) (Figure 7).

DP3u: Visible union of epiphysis and diaphysis. Indicates the end of pubertal growth spurt.

Seventh stage: (Males 15.9 y, Females 13.3 y) (Figure 8).

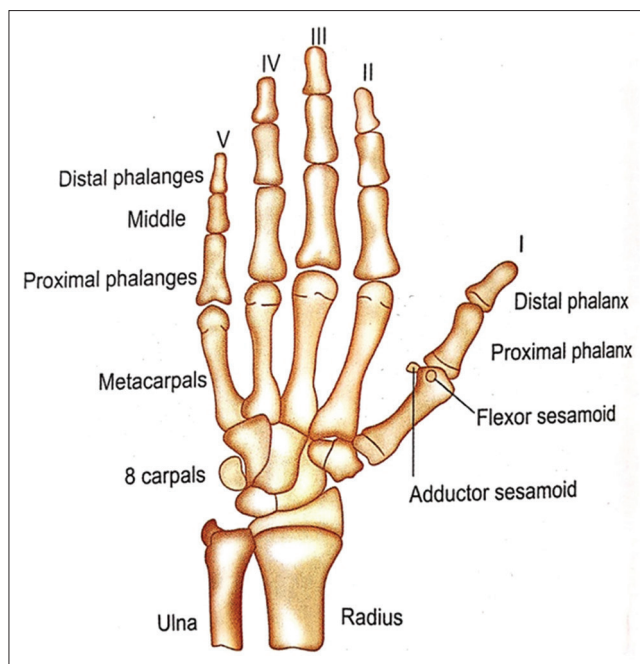
PP3u: Visible union of epiphysis and diaphysis. Occurs 1 year after growth spurt. Little growth potential is remaining.

Eighth stage: (Males 15.9 y, Females 13.9 y) (Figure 9).

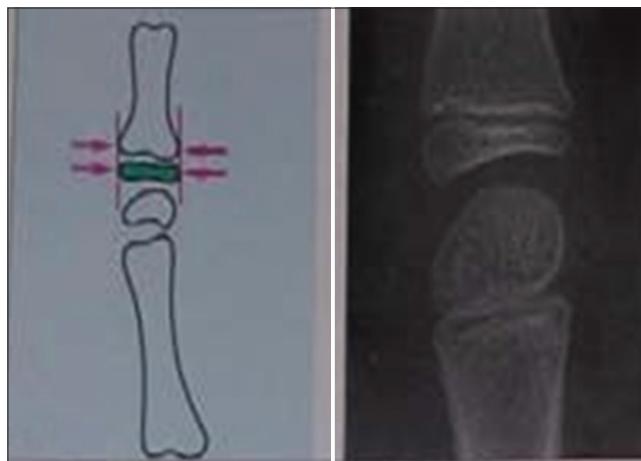
MP3u: Visible union of epiphysis and diaphysis.

Ninth stage: (Males 18.5 y, Females 16 y) (Figure 10).

R u: Visible union of epiphysis and diaphysis of radius. End of Active growth.



**Figure 1:** Bjork Grave and Brown Method



**Figure 2:** First stage: (Males 10.6 y, Females 8.1 y)

### **FISHMAN SKELETAL MATURITY INDICATOR (1982)**

He made use of anatomical site on the thumb, third finger, fifth finger, and radius. The system uses 11 anatomical sites, all of which exhibit consistency in time of onset of ossification covering entire period of adolescent growth period.

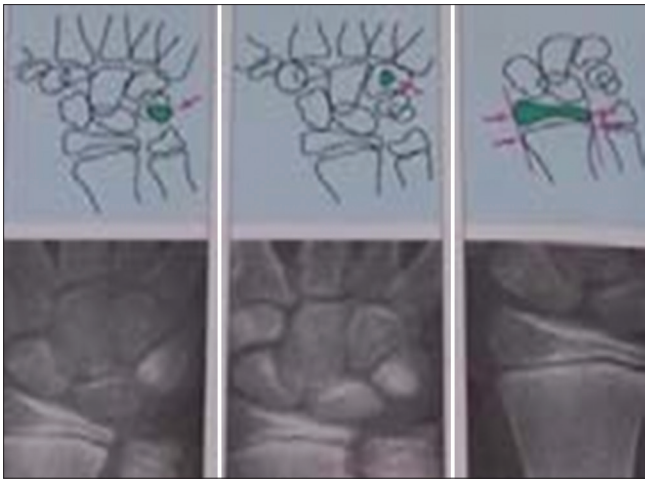
#### **Stages (Figure 11)**

##### **1 PP3**

The third finger shows equal width of the epiphysis with diaphysis.

##### **MP3**

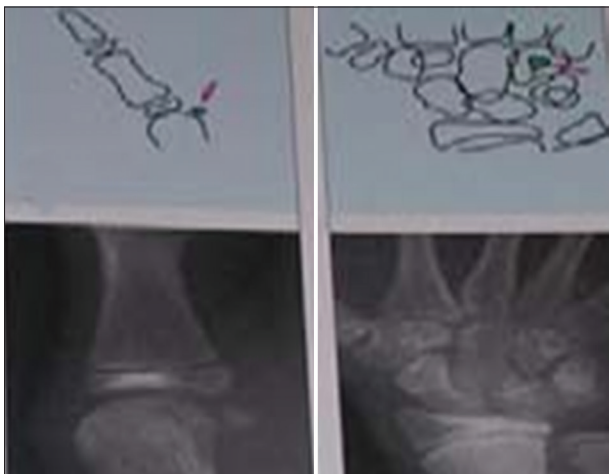
Width of epiphysis equal to that of diaphysis in the middle phalanx of the third finger. Appears during the onset of prepubertal growth velocity.



**Figure 3:** Second stage: (Males 12 y, Females 8.1 y)



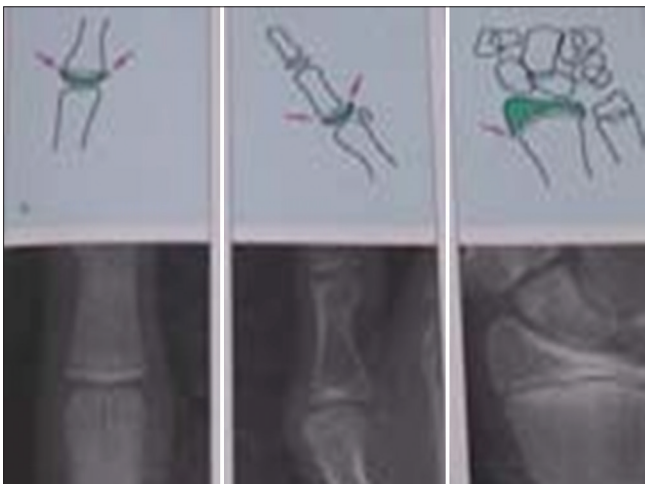
**Figure 6:** Fifth stage: (Males 14 y, Females 11 y)



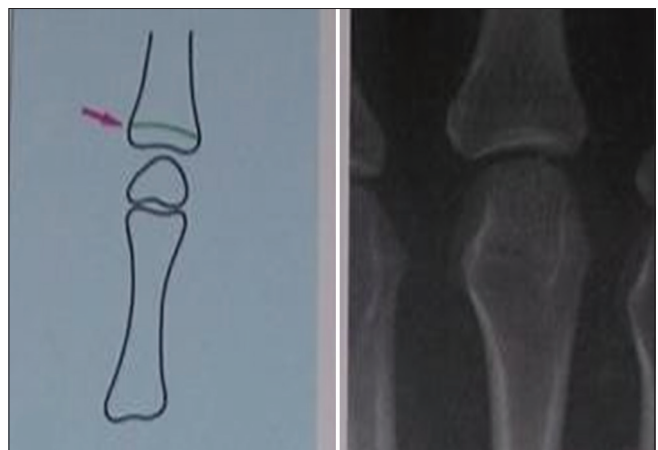
**Figure 4:** Third stage: (Males 12.6 y, Females 9.6 y)



**Figure 7:** Sixth stage: (Males 15 y, Females 13 y)



**Figure 5:** Fourth stage: (Males 13 y, Females 10.6 y)



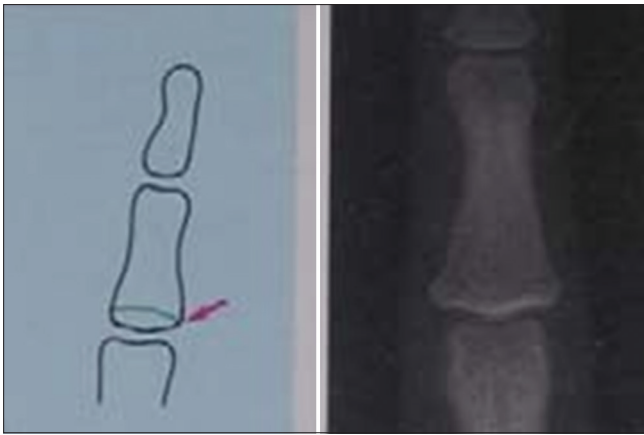
**Figure 8:** Seventh stage: (Males 15.9 y, Females 13.3 y)

#### **MP5**

Width of epiphysis equal to that of diaphysis in the middle phalanx of the fifth finger.

#### **S.M.I. 4 S**

Appearance of adductor sesamoid of thumb. Become visible during period of very rapid growth velocity.



**Figure 9:** Eighth stage: (Males 15.9 y, Females 13.9 y)



**Figure 10:** Ninth stage: (Males 18.5 y, Females 16y)

#### **S.M.I.5 DP3cap**

Capping of epiphysis over diaphysis is seen in the distal phalanx of the third finger. Peak height velocity.

#### **S.M.I. 6 MP3cap**

Capping of epiphysis over diaphysis is seen in the middle phalanx of the third finger. Become visible during period of very rapid growth.

#### **Stage 7 MP5cap**

Capping of epiphysis over diaphysis is seen in the middle phalanx of the fifth finger. Peak height velocity.

#### **Stage 8 DP3U**

Fusion of epiphysis over the diaphysis is seen in the distal phalanx of the third finger. Time interval of decelerating growth rate.

#### **Stage 9 PP3**

Fusion of epiphysis over the diaphysis is seen in the distal phalanx of the third finger

#### **Stage 10 MP3u**

Fusion of epiphysis and diaphysis is seen in the middle phalanx of the third finger. Time interval of decelerating growth rate.



**Figure 11:** Fishman Skelatal maturity indicator

#### **Stage 11 R U**

Fusion of epiphysis and diaphysis is seen in radius. Growth completed.

#### **Hagg and Taranger method**

In 1982 they carried out longitudinal study on 212 Swedish children. Skeletal development from hand wrist radiographs is analyzed by taking annual radiographs between the age of 6 and 18 years. The assessment is done for Ulnar Sesamoid of metacarpophalangeal (S) joint of the first finger and certain specified stages of the three epiphyseal bones: middle phalanges and distal phalanges of the third finger (MP3 and DP3) and distal epiphysis of radius (R). HAGG and TARANGER 1982 made the following findings concerning the relationship in time between the various pubertal events:-

- Girls: If menarche has occurred PHV has been attained and the growth rate is decelerating. If menarche has not occurred growth rate may be decreasing but has not yet reached the level of the end of pubertal growth spurts.
- Boys: If a boy has prepubertal voice most probably the PHV has not yet been reached.
- If the voice change has begun the boys are in pubertal growth spurts.
- If the boy has a male voice the growth rate has begun to decelerate.
- No boy will reach the end of pubertal spurt without having male voice.

#### **Middle phalanx**

##### **MP3-F**

The epiphysis is as wide as metaphysis. Stage attained before onset of PHV

Stage indicates >80% of pubertal growth remaining.

##### **MP3-FG**

The epiphysis is as wide as metaphysis

Distinct medial and/or lateral border of epiphysis forming a line of demarcation at right angle to the distal border.

Stage indicates the accelerating slope of pubertal growth spurt.

### MP3-G

Sides of epiphysis thickened and cap its metaphysis forming sharp edge at one or both sides.

Stage is attaining at about peak height of pubertal growth spurts.

### MP3-H

Stage is characterized by beginning of fusion epiphysis and metaphysis. This stage is indicated by decelerating slope of PHV but before the end of growth spurt.

### MP3-I

This stage is characterized by the completion of fusion of epiphysis and metaphysis. This is attained at end of the growth spurt.

### Third finger distal phalanx

#### DP3-I

Fusion of epiphysis and metaphysis completed. Indicates the decelerating period of pubertal growth spurts. Means end of peak height velocity.

### Distal epiphysis of radius (R)

#### R-I

Fusion of epiphysis and metaphysis on radius has begun. Stage R-i is attained one year before or at end of the pubertal growth spurt.

#### R-IJ

Fusion almost completed

R-J: complete fusion of epiphysis and metaphysis

R-IJ, R-J: are not attained before the end of pubertal growth spurts.

### Singers methode (1980)

Julian Singer in 1980 proposed system of hand wrist radiographic assessment. It helps the clinician to rapidly determine the maturational status of adolescent patient. This system has six stages.

## LATERAL CEPHALOGRAMS

### Skeletal maturation evaluation using cervical vertebrae

Cervical Vertebrae maturational indicator given by Lamparski<sup>[12]</sup> in 1965.

The primary objective of the author was to create a method of evaluating the skeletal maturation of the orthodontic patient with the cephalometric radiograph that is routinely taken with pretreatment records. Correlations were made between cervical vertebrae maturation and the skeletal maturation of the hand wrist.

Lamparski studied changes in size and shape of cervical vertebrae to create maturational standards for the cervical vertebrae. Six categories of cervical vertebrae skeletal maturation could be defined, and the following observations were made for each category.

## STAGES OF CERVICAL VERTEBRAE MATURATION

### INDICATOR

#### Stage 1/category 1

- All inferior borders of the bodies of C2, C3, and C4 are flat.
- The Superior borders are strongly tapered posterior to the anterior region.
- Very significant amount of adolescent growth expected.

#### Stage 2/category 2

- A concavity has developed in the inferior borders of C2 and C3.
- The anterior vertical height of the bodies has increased.
- C3 and C4 are more rectangular in shape.
- Significant amount of adolescent growth expected.

#### Stage 3/category 3

- Distinct concavities have developed in the inferior border of the C2 and C3.
- C4 starts developing concavity in lower border of body.
- Moderate amount of growth expected.

| Stage                           | Characteristic feature                                                                                       | Relation of epiphysis and diaphysis                                                  | Inference                                                                                                                    |
|---------------------------------|--------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|
| Stage 1 (early)                 | 1. Absence of pisiform<br>2. Absence of hook of hamate                                                       | Epiphysis of proximal phalanx of the second finger being narrower than its diaphysis | 1 year before the beginning of peak pubertal growth                                                                          |
| Stage 2 (prepubertal)           | 1. Initial ossification of hook of hamate<br>2. Initial ossification of pisiform                             | PP2                                                                                  | Just beginning of pubertal growth spurt. Mandibular growth potential is possible                                             |
| Stage 3 (pubertal onset)        | 1. Beginning of calcification of ulnar sesamoid<br>2. Increased calcification of hook of hamate and pisiform | Increased width of the epiphysis of proximal phalanx of the second finger            | Onset of pubertal growth spurt.                                                                                              |
| Stage 4 (pubertal)              | Calcified ulnar sesamoid                                                                                     | MP3 cap                                                                              | Accelerating phase of pubertal growth spurt                                                                                  |
| Stage 5 (pubertal deceleration) | Fully calcified ulnar sesamoid                                                                               | 1. DP3-U<br>2. Radius and ulna not fully fused with respect to shaft                 | This stage represent that period of growth when orthodontic treatment might be completed and patient is on retention therapy |
| Stage 6                         | No remaining growth sites                                                                                    | R-U                                                                                  | Growth completed                                                                                                             |

**Stage 4/category 4**

- C3 and C4 are nearly square in shape.
- Distinct concavities in lower borders of C2, C3, and C4.
- Small amount of growth expected.

**Stage 5/category 5**

- C3 and C4 are square in shape.
- Accentuated concavities are formed in C2, C3, and C4
- Insignificant amount of growth expected.

**Stage 6/category 6**

- C3 and C4 are increased in Vertical height and are higher than they are wide.
- All concavities have deepened.
- Adolescent growth is completed.
- Later, Hassel and Farman in 1995<sup>[13]</sup> used the cervical vertebrae and developed a system of skeletal maturation determination. Later, this was modified by Baccetti *et al.* 2005.<sup>[14]</sup> The shapes of the cervical vertebrae were seen to differ to teach level of skeletal development. This provided a means to determine the skeletal maturity of a person and thereby determine whether the possibility of potential growth existed. The shapes of the vertebral bodies of C3 and C4 changes from wedge shape to rectangle followed by square shape. In addition, they became taller as skeletal maturity progressed. The inferior vertebral borders were flat when immature and became concave with maturity. The curvatures of the inferior vertebral borders seem to appear sequentially from C2 to C4 as the skeleton matures. The concavities become more distinct as the person matures.<sup>[14,16]</sup>
- Hassel and Farman in 1995<sup>[16]</sup> found the correlation between skeletal maturity indicators seen in hand wrist radiograph and cervical maturity indicators in lateral cephalogram.

Category 1 was called INITIATION. This corresponded to a combination of SMI 1 and 2. At this stage, adolescent growth was just beginning and 80% to 100% of adolescent growth was expected. Inferior borders of C2, C3, and C4 were flat at this stage. The vertebrae were wedge-shaped, and the superior vertebral borders were tapered from posterior to anterior.

Category 2 was called ACCELERATION. This corresponded to a combination of SMI 3 and 4. Growth acceleration was beginning at this stage, with 65–85% of adolescent growth expected. Concavities were developing in the inferior borders of C2 and C3. The inferior border of C4 was flat. The bodies of C3 and C4 were nearly rectangular in shape.

Category 3 was called TRANSITION. This corresponded to a combination of SMI 5 and 6. Adolescent growth was still accelerating at this stage toward peak height velocity, with 25% to 65% of adolescent growth expected.<sup>[10]</sup> Distinct concavities were seen in the inferior borders of C2 and C3. A concavity was beginning to develop in the inferior border of C4. The bodies of C3 and C4 were rectangular in shape

Category 4 was called DECELERATION. This corresponded to a combination of SMI 7 and 8. Adolescent growth began to decelerate dramatically at this stage, with 10–25% of adolescent growth expected. Distinct concavities were seen in the inferior borders of C2, C3, and C4. The vertebral bodies of C3 and C4 were becoming squarer in shape.

Category 5 was called MATURATION. This corresponded to a combination of SMI 9 and 10. Final maturation of the vertebrae took place during this stage, with 5–10% of adolescent growth expected. More accentuated concavities were seen in the inferior borders of C2, C3, and C4. The bodies of C3 and C4 were nearly square to square in shape.

Category 6 was called COMPLETION. This corresponded to SMI 11. Growth was considered to be complete at this stage. Little or no adolescent growth was expected. Deep concavities were seen in the inferior borders of C2, C3, and C4. The bodies of C3 and C4 were square or were greater in the vertical dimension than in the horizontal dimension. Baccetti *et al.* in 2005<sup>[14]</sup> modified the stages given by Hassel and Farman.<sup>[13]</sup>

**Cervical stage 1**

The lower borders of all the three vertebrae (C2–C4) are flat. The bodies of both C3 and C4 are trapezoid in shape (the superior border of the vertebral body is tapered from posterior to anterior). The peak in mandibular growth will occur on average 2 years after this stage.

**Cervical stage 2**

A concavity is present at the lower border of C2 (in four of five cases, with the remaining subjects still showing a cervical stage 1). The bodies of both C3 and C4 are still trapezoid in shape. The peak in mandibular growth will occur on average 1 year after this stage.

**Cervical stage 3**

Concavities at the lower borders of both C2 and C3 are present. The bodies of C3 and C4 may be either trapezoid or rectangular horizontal in shape. The peak in mandibular growth will occur during the year after this stage.

**Cervical stage 4**

Concavities at the lower borders of C2, C3, and C4 now are present. The bodies of both C3 and C4 are rectangular horizontal in shape. The peak in mandibular growth has occurred within 1 or 2 years before this stage.

**Cervical stage 5**

The concavities at the lower borders of C2, C3, and C4 still are present. At least one of the bodies of C3 and C4 is squared in shape. If not squared, the body of the other cervical vertebra still is rectangular horizontal. The peak in mandibular growth has ended at least 1 year before this stage.

**Cervical stage 6**

The concavities at the lower borders of C2, C3, and C4 still are evident. At least one of the bodies of C3 and C4 is rectangular vertical in shape. If not rectangular vertical, the body of the

other cervical vertebra is squared. The peak in mandibular growth has ended at least 2 years before this stage.

## INTRAORAL RADIOGRAPHS/OPG

### Tooth mineralization - An indicator of skeletal maturity

Dental maturity can be determined by the stage of tooth eruption or the stage of tooth formation. Tooth formation is proposed as more reliable criteria for determining dental maturation. The ease of recognition of dental development stages, together with the availability of periapical or panoramic radiographs in most orthodontic and dental practices are practical reasons for attempting to assess the physiologic maturity without resorting to hand wrist radiographs. Various researchers have carried out extensive work to correlate dental age and skeletal age. It is believed that stages of root formation and mineralization have a close relationship with the skeletal maturation of an individual. Relationships between the stages of tooth mineralization of the mandibular canine appear to correlate better with ossification stages than do the other teeth. Some of the dental indicators for skeletal maturity were put forward by Pyle SL<sup>[9]</sup> based on the mineralization of the lower canine. Nolla's<sup>[16]</sup> stage of calcification was utilized by some workers to correlate with skeletal maturity. Goldstein and Tanner have described a similar method based on the third molar. If a strong association exists between skeletal maturity and dental calcification stages, the stages of the dental calcification might be used as a first-level diagnostic tool to estimate the timing of the pubertal growth spurt. Relationships between the stages of tooth mineralization of the mandibular canine appear to correlate better with ossification stages than do the other teeth.

## CONCLUSION

Growth maturation stages are important for proper timing and treatment management. Various methods are present of which skeletal and physiologic/biochemical methods are reliable for the clinical references. The review also suggests that more simplified noninvasive methods can be considered as additional diagnostic tool to avoid exposure to radiation.

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