

Skeletal Maturity Indicators - Review Article

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Abstract: 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: Cervical vertebrae maturation indicators, hand and wrist radiographs, middle phalanx of third finger, skeletal maturity indicators, canine calcification

1. 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^{1,2,3} weight⁴ chronological age;^{4,5,6} sexual maturation⁵ frontal sinus⁷ biological age or physiological age; hand-wrist maturity;^{2,08,09,10,11-13} cervical vertebrae^{14,15,16,17} dental eruption; dental calcification stages^{18,19,20,21} and recently introduced biomarkers.²²⁻²⁹

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. Clinical decisions regarding the use of extra oral traction forces, functional appliances, extraction versus nonextraction treatment, or orthognathic surgeries are, at least partially, based on growth considerations. Prediction of both the times and the amount of active growth, especially in the craniofacial complex, would be useful to the orthodontist.³⁰ Growth modulation procedures, which bring about changes in the skeletal base such as the use of extra oral orthopedic forces or functional appliances, are suggested to be initiated during active growth periods. 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. Physiologic maturity is best- estimated by the maturation of one or more tissue systems, such as somatic, sexual, skeletal, and dental maturity. Amongst the given indicators, chronological age is considered to be an easy parameter to assess expected amount of growth and development.

Chronological age

Birth date 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.^{02,31,32} 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.¹⁸ Physiological age can be estimated by maturational status of somatic, sexual, skeletal, and dental system.

Somatic maturity

An annual growth increment in height or weight determines the somatic maturity.⁰² 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.⁰⁵ 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, quantity). Prediction of sexual maturity requires a physical examination, and hence use of sexual maturity as maturation marker is limited in the orthodontic set up. 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.⁰⁵ Menarche is an important predictor of maturation in females.⁰⁹ 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

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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 stage of maturity in an individual.

2. Pubertal/Adolescent Growth Spurt

The timing of recognition of the last and important growth spurt that is, the pubertal growth spurt is important in 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.³³⁻³⁶

3. 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.^{16,37,38-40}

2. Lateral cephalograms:

Use of cervical vertebrae on a lateral cephalogram.^{14,16}
Use of frontal sinus using lateral cephalogram.⁴¹

3. Orthopantomogram (OPG)/intraoral periapical:

Use of different stages of tooth development^{14,18,19,42-44}

B. Biochemical

Recent biochemical method in saliva and serum are the^{23,45-53}

- Insulin-like growth factor (IGF) growth hormone (GH),
- Creatinine,
- Alkaline phosphatase (ALP).

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.^{37,16,38-40} The following are the most commonly used methods:

- Atlas Method by Greulich and Pyle.
- Biork, Grave and Brown Method modified by Schopf in 1978.
- Fishman's skeletal maturity indicators.
- Hägg and Taranger Method.
- 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 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 [1959]⁵⁵ :

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 representative of 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 are chosen.

Bjork Grave and Brown [1976]⁵⁵

- They divide maturation process of bone of hand between ages 9 to 17 years into 9 stages,
- Each stage represent level of skeletal maturity.
- Total 14 ossification points were used
- Development stage assessed according to relation between epiphyses and diaphysis.

Stages-

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

PP2- stageThe 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) (Fig 3)

MP3 –stageThe epiphysis and diaphysis are equal. Just before beginning of pubertal growth spurts

Third stage: (Males 12.6 y , Females 9.6 y) (Fig 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 b4

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

S = First mineralization of the ulnar sesamoid bone

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

Fifth stage: (Males 14 y , Females 11 y)MP3 CAP (Fig 6)

The diaphysis is covered by cap shaped epiphysis This stage marks the peak of pubertal growth spurt

Sixth stage: (Males 15 y , Females 13 y) (Fig 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) (Fig 8)

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

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

MP3u : Visible union of epiphysis and diaphysis

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

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

FISHMAN SKELETAL MATURITY INDICATOR [1982]⁵⁵

He made use of anatomical site on 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 (Fig 11)

S.M.I. 1 PP3=

Third finger shows equal width of epiphysis with diaphysis

S.M.I.2 MP3=

Width of epiphysis equal to that of diaphysis in middle phalanx of third finger

Appears during onset of prepubertal growth velocity

S.M.I.3 MP5=

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

S.M.I. 4 S

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

S.M.I.5 DP3cap

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

S.M.I. 6 MP3cap

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

Stage 7 MP5cap

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

Stage 8 DP3U

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

Stage 9 PP3

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

Stage 10 MP3u

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

Stage 11 R U

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

Hagg and Taranger Method⁴²

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

- Girls: if menarche has occurred PHV has been attained and 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 boy is 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: (Fig 12)

The epiphysis is as wide as metaphysis.

Stage attained before onset of PHV

Stage indicates more than 80% of pubertal growth remaining.

MP3-FG: (Fig.13)

The epiphysis is as wide as metaphysis

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

Stage indicates the accelerating slope of pubertal growth spurt

MP3-G: (Fig.14)

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: (Fig 15)

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

MP3-I: (Fig. 16)

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

Third finger distal phalanx

DP3-I (Fig. 17)

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 pubertal growth spurt.

R-II:

Fusion almost completed

R-J: complete fusion of epiphysis and metaphysis

R-II, R-J:(Fig. 18) are not attained before the end of pubertal growth spurts

Rajgopal and Kansal in 2005⁵⁴ modified the stages of MP3

MP3-F stage: (Fig. 19)Start of the curve of pubertal growth spurt.

Epiphysis is as wide as metaphysis.

Ends of epiphysis are tapered and rounded.

Metaphysis shows no undulation.

Radiolucent gap (representing cartilageous epiphyseal growth plate) between epiphysis and metaphysis is wide.

MP3-FG stage: (Fig 20)Acceleration of the curve of pubertal growth spurt.

Epiphysis is as wide as metaphysis.

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

Metaphysis begins to show slight undulation.

Radiolucent gap

MP3-G stage: (Fig. 21)Maximum point of pubertal growth spurt.

Sides of epiphysis have thickened and cap its metaphysis, forming sharp distal edge on one or both sides.

Marked undulations in metaphysis give it “Cupid’s bow” appearance.

Radiolucent gap between epiphysis and metaphysis is moderate.

MP3-H stage: (Fig. 22)Deceleration of the curve of pubertal growth spurt.

Fusion of epiphysis and metaphysis begins.

One or both sides of epiphysis form obtuse angle to distal border.

Epiphysis is beginning to narrow.

Slight convexity is seen under central part of metaphysis.

Typical “Cupid’s bow” appearance of metaphysis is absent, but slight undulation is distinctly present.

Radiolucent gap between epiphysis and metaphysis is narrower.

MP3-HI stage: (Fig. 23)Maturation of the curve of pubertal growth spurt.

Superior surface of epiphysis shows smooth concavity.

Metaphysis shows smooth, convex surface, almost fitting into reciprocal concavity of epiphysis.

No undulation is present in metaphysis.

Radiolucent gap between epiphysis and metaphysis is insignificant.

MP3 I Stage(Fig.24)

End of pubertal growth spurt

1. Fusion of epiphysis and metaphysis complete.

2. No radiolucent gap exists between metaphysis and epiphysis.

3. Dense, radiopaque epiphyseal line forms integral part of proximal portion of middle phalanx.

Singers Methode [1980]⁵⁵

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

Stage	Characteristic feature	Relation of epiphysis and diaphysis	Inference
Stage 1 (early)	1.Absence of pisiform 2.absence of hook of hamate	Epiphysis of proximal phalanx of second finger being narrower than its diaphysis	1year before beginning of peak pubertal growth
Stage 2 (prepubertal)	1.Initial ossification of hook of hamate 2.Initial ossification of pisiform	PP2=	Just beginning of pubertal growth spurt. Mandibular growth potential is possible
Stage 3 (pubertal onset)	1.Begining of calcification of ulnar sesamoid 2.Increased calcification of hook of hamate and pisiform	Increased width of epiphysis of proximal phalanx of 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 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

4. Lateral Cephalograms

Skeletal Maturation Evaluation Using Cervical Vertebrae

Cervical Vertebrae maturational indicator(CVMI) given by Lamparski¹⁵in 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.

5. 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 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 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 1995¹⁶ used the cervical vertebrae and developed a system of skeletal maturation determination. Later, this was modified by Bacetti et al. 2005²⁸. 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 C3 to C4 as the skeleton matures. The concavities become more distinct as the person matures.^{14,16}
- Hassel and Farman in 1995¹⁶ 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% to 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 expected¹⁰. 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% to 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% to 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 vertical dimension than in horizontal dimension. Bacetti et al in 2005²⁸ modified the stages given by Hassel and Farman¹⁶(Fig. 25)

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.

6. 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 the 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 Chertkow and Fatti⁴³ based on the mineralization of the lower canine. Nolla's¹⁹ stage of calcification was utilized by some workers to correlate with skeletal maturity. Goldstein and Tanner have described a similar method based on 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.

Demirjian's Stages of Dental Calcification (1973)¹⁸

Demirjian developed a method for estimating dental maturity or dental age using radiological appearances of the

mandibular teeth i.e. from incisors to molars. Each tooth was rated according to the developmental criteria. (Amount of dentinal deposit, shape changes of pulpal chamber, etc) Rather than changes in size. Eight stages i.e. from A to H were defined from first appearance of calcified points to the closure of apex.^{18,19,42,43,45}

Panoramic radiographs were used because they are easier to make than intra oral radiographs in young and nervous children and they give less radiation for full mouth radiograph and picture of the mandible region produced is little distorted. Though there is 3% to 10% enlargement of the mandible (Sapoka and Demirjian 1971) this is not a serious drawback, because the rating system is based on shape criteria rather than on absolute lengths.

Canine calcification stages starts from stage D to H

Stage D (Fig. 26)

- The crown formation is completed down to the cemento-enamel junction.
- The superior border of the pulp chamber has a definite curved form, being concave towards the cervical region.
- The projection of the pulp horn, if present, gives an outline shaped like an umbrella top.
- Beginning of root formation is seen in the form of a Spicule.

Stage E (Fig. 27)

- The walls of pulp chamber now form straight lines, whose continuity is broken by the presence of the pulp horn, which is larger in the previous stage.
- The root length is less than the crown height.

Stage F (Fig. 28)

- The walls of the pulp chamber now form a more or less isosceles triangle. The apex ends is funnel shape.
- The root length is equal to or greater than the crown height.

Stage G (Fig. 29)

- The walls of the root canal are now parallel.
- Its apical end is still partially open.

Stage H (Fig. 30)

- The apical end of root canal is completely closed.
- The periodontal membrane has a uniform width around the root and the apex.

7. 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.



Figure 1: Stages in ossification of phalanges



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



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



Figure 11: Stages

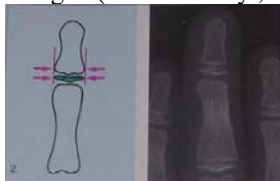


Figure 3: Second stage (Males 12y, Females 8.1 y)



Figure 12: MP3 F stage by Hagg and Taranger



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



Figure 13: MP3 FG stage by Hagg and Taranger



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



Figure 14: MP3 G stage by Hagg and Taranger

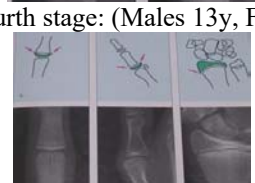


Figure 6: Fifth stage: (Males 14y, Females 11y)MP3 cap



Figure 15: MP3 H stage by Hagg and Taranger



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



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

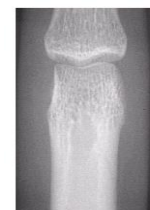


Figure 16: MP3 I stage by Hagg and Taranger



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



Figure 17: DP-3 I stage by Hagg and Taranger

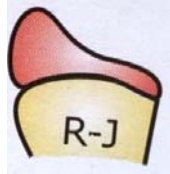


Figure 18: R-J stage by Hagg and Taranger

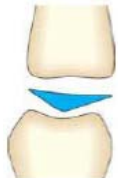


Figure 19: MP3-F stage modification by Hagg and Taranger



Figure 20: MP3-FG stage modification by Hagg and Taranger

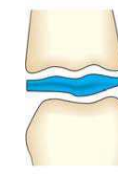


Figure 21: MP3-G stage modification by Hagg and Taranger



Figure 22: MP3-H stage modification by Hagg and Taranger



Figure 23: MP3-HI stage modification by Hagg and Taranger



Figure 24: MP3-I stage modification by Hagg and Taranger



Figure 25: CVMI Stages



Figure 26: Mandibular Canine calcification stages stage D



Figure 27: Mandibular Canine calcification stages stage E



Figure 28: Mandibular Canine calcification stages stage F



Figure 29: Mandibular Canine calcification stages stage G



Figure 30: Mandibular Canine calcification stages stage H

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