SKELETAL MATURITY INDICATORS - A REVIEW

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ABSTRACT: All individuals grow and mature at different time. As a person grows from fetal life to adulthood, the bones of the skeleton changes in size and shape. An understanding of this growth events or skeletal maturity is of primary importance in clinical orthodontics. In this review various methods like Hand wrist radiographs, Cervical vertebrae, tooth mineralization, mid palatal suture, frontal sinus, biomarkers as maturity indicators has been discussed.

KEYWORDS: skeletal maturity indicators, hand wrist radiograph, cervical vertebrae, middle phalange, canine calcification

I. INTRODUCTION

All individuals grow and mature at different time. Growth is the entire series of anatomic and physiologic changes taking place between the beginning of prenatal life and close to senility. As a person grows from fetal life through childhood, puberty, and finishes growth as a young adult, the bones of the skeleton changes in size and shape. An understanding of this growth event is of primary importance in the practise of clinical orthodontics.

GROWTH SPURT

Growth is a three dimensional phenomenon. Most important aspect of growth is timing of growth. Although growth is an orderly process, there are periods of sudden rapid increase in growth which are termed as growth spurs. This is due to physiological changes in hormonal secretion. The timing of growth spurt is different for males and females. Females are early matures. During growth, the order, rate, time of appearance and progress of ossification in occurs in a predictable sequence that can be seen radiologically. These stages of skeletal maturation of an individual are essential for formulation diagnosis and treatment planning. Certain treatment procedures like functional appliances therapy, orthopaedic traction, extraction – non extraction treatment, orthognathic surgeries are based on growth. Certain anatomic regions of bone are suitable of skeletal maturation assessment. The anatomical site for the determination of skeletal status should be

1. Easily accessible.
2. Should contain the bones or skeletal units that mature at different time and the timing can be standardized.

The following methods are used to evaluate the skeletal maturity:

2. Lateral cephalogram to evaluate cervical vertebrae.
3. Clinical and radiographic examination of different stages of tooth development.
5. Evaluation of frontal sinus.

II. REVIEW OF LITERATURE

After Roentgen demonstrated his new radiographic discovery in 1895, Roland, in 1896, introduced the idea of using the comparative size and shape of the radiographic shadows of growing bones as indicators of rate of growth and maturity. Pryor in 1907 did a study on difference in the timing of ossification of bones of hand wrist on both males and females and the union of epiphysis with diaphysis. Rotch, and Crampton began tabulating indicators of maturity on sequential radiographs of the growing hand and wrist. Hellman published his observations on the ossification of epiphysial cartilages of the hand in 1928. Todd compiled hand-wrist data that was further elaborated on by Greulich and Pyle in atlas form. Flory in 1936, indicated that the beginning of calcification of the carpal sesamoid (adductor sesamoid) was a good guide to determining the period immediately before puberty. Julian Singer in 1980 proposed a system of hand – wrist radio-graph assessment. Hagg and Taranger created a method using the hand-wrist radiograph to correlate certain maturity indicators to the pubertal growth spurt. Fishman developed in 1982 a system of hand-wrist skeletal maturation indicators (SMIs) using four stages of bone maturation at six anatomic sites on the hand and the wrist.

HAND WRIST RADIOGRAPH

The hand-wrist region is made up of numerous small bones. The appearance, ossification and fusion of these bones follow an orderly sequence of events which corresponds to an individual maturity.

RELATIVE ANATOMY OF HAND-WRIST

The hand-wrist region is made up of the following four groups of bones:
Distal ends of long bones of forearm
Carpals
Metacarpals
Phalanges

DISTAL ENDS OF LONG BONES OF FOREARM
This is formed by the distal end of long bones radius and ulna. The radius is towards the thumb and ulna is towards the little fingers

THE CARPALS
The carpal bones are eight in number which makes the wrist that connect the hand to the forearm. These are irregular in outline without any specific shape. The carpal bones are organised in to two rows namely proximal rows and distal rows. The proximal raw consist of scaphoid, lunate, triquetrum and pisiform. The distal raw consist of trapezium, trapezoid, capitates and hamate. Out of these eight bones the maturational status of pisiform and hamate are utilized in different methods.

THE METACARPALS
Metacarpal bone forms an intermediate part located between the phalanges of the fingers and the carpal bones. Each metacarpal consist of body or shaft and two extremities; the head at the distal end near fingers and the base at the proximal end close to the wrist bones. They are numbered 1-5 starting from the thumb to the little finger. Each metacarpal ossifies from one primary centre (in its shaft) and a secondary centre on the distal end except for the first metacarpal where secondary centre of ossification appears at the proximal end

THE PHALANGES
They are the small bones which form the fingers. Each finger except the thumb is made up of three phalanges – proximal, middle and the distal phalanges. The thumb has only two phalanges – proximal and distal. Phalanges ossify in 3 stages[Figure 1]:
(A) Epiphysis and diaphysis are equal
(B) The epiphysis caps the diaphysis
(C) Fusion of the epiphysis and the diaphysis

THE SESAMOID BONE
The sesamoid bone is a small nodular bone most often present embedded in tendons in the region of the thumb. Calcification of sesamoid bone is one of the important features of pubertal growth spurt. Absence of sesamoid bone indicates delay in reaching puberty.

METHODS OF SKELETAL MATURITY ESTIMATION BASED ON HAND-WRIST RADIOGRAPHS:
The hand-wrist radiograph is considered to be the most standardized method of skeletal assessment. The following are the most commonly used methods:
Gruelich and Pyle method
Bjork, Grave and Brown method
Singers method of assessment
Fishman’s skeletal maturity indicators
Hagg and Taranger method

**Gruelich and Pyle Atlas method**

This is a holistic method based on “The Radiographic Atlas of Skeletal Development of the Hand and Wrist”, by Dr William Walter Greulich and Dr Sarah Idell Pyle, its last edition published in 1959. This atlas was developed during the middle of 20th century from data of North American children belonging to affluent families of European descent. This atlas contains the pictures of standard hand-wrist radiographs of different skeletal ages. They have given ideal pictures of hand and wrist radiographs for different chronological ages and for each sex. Each photograph in the atlas is representative of a particular skeletal age. The patient’s radiograph is matched on an overall basis with one of the photographs in the atlas.

**Bjork, Grave and Brown analysis**

They have divided the entire maturational process of the bones of hand between ages 9 and 17 into 9 stages. Each of these stages represents a level of skeletal maturity. A total of 14 ossification points were utilized

**Stage 1:**
- It occurs around 10.6 years in males and 8.1 years in females
- Epiphysis and metaphysis of the proximal phalanx of index finger are equal
- It signifies 3 years before the peak of pubertal growth spurt

**Stage 2:**
- This occurs around 12 years in males, 8.1 years in females
- Epiphysis and diaphysis of the middle phalanx of middle finger are equal
- It signifies just before the beginning of pubertal growth spurt

**Stage 3:**
- It occurs around 12.6 years in males and 9.6 years in females
- Hamular process of hamate exhibit ossification
- Visible ossification of pisseform
Epiphysis and diaphysis of radius are equal

Stage 4:

It occurs around 13.6 years in males and 10.6 years in females

Initial mineralisation of ulnar sesamoid of thump

Increased ossification of hamular process of hamate bone

Stage 5:

It occurs around 14 years in males and 11 years in females

Capping of epiphysis and diaphysis is seen in middle phalanx of the third finger, proximal phalanx of the thumb and in the radius

It heralds the peak of pubertal growth spurt

Stage 6:

It occurs 15 years in males and 13 years in females

Union of the epiphysis and diaphysis of distal phalanx of middle finger

End of pubertal growth spurt

Stage 7:

It occurs 15.9 Years in males 13.3 years in females

Union of the epiphysis and diaphysis of the proximal phalanx of middle finger

It signifies 1 year after growth spurt with little growth potential remaining

Stage 8:

Occurs 15.9 years in males and 13.9 years in females

Fusion of the epiphysis and diaphysis of middle phalanx of middle finger

Stage 9:

It occurs in 18.5 years in males and 16 years in females

End of fusion of epiphysis and diaphysis of the radius

This is the last stage and end of active growth
Singer’s method of assessment

Julian Singer in 1980 proposed a system of hand – wrist radio-graph assessment. This helps the clinician to rapidly determine the maturational status of the adolescent patient. He divided the maturational status in to early, prepubertal, pubertal onset, pubertal, pubertal deceleration, growth completion

Stage 1[Early]:
Absence of the pisiform, absence of hook of the hamate. Epiphysis of proximal phalanx of second finger being narrower than its diaphysis

Stage 2[Prepubertal]:
Initial ossification of hook of the hamate, initial ossification of the pisiform. Epiphysis of proximal phalanx of second finger is equal to its diaphysis in width

Stage 3[Pubertal onset]:
Beginning of calcification of ulnar sesamoid, increased calcification of hook of hamate and pisiform. Increased width of epiphysis of proximal phalanx of the second finger

Stage 4 [Pubertal]:
Calcified ulnar sesamoid. Capping of the diaphysis of the middle phalanx of third finger by its epiphysis.

Stage 5 [Pubertal deceleration]:
Fully calcified ulnar sesamoid. Fusion of epiphysis of distal Phalanx of third finger with its shaft. Epiphyses of radius and ulna not fully fused with respective shafts.

Stage 6[Growth completion]:
No remaining growth sites seen. Fusion of epiphysis of radius and ulna with respective shaft

FISHMAN’S SKELETAL MATURITY INDICATORS

A system for evaluation of skeletal maturation was proposed by Leonard S Fishman in 1982. Fishman made use of four anatomical sites located on the thumb (adductor sesamoid), third finger, fifth finger and radius. (Figure 4 and 5)

Four ossification stages utilized are:

Epiphysis equal to diaphysis
Appearance of adductor sesamoid of thumb
Capping of epiphysis
Fusion of epiphysis

**EPHYYSIS EQUAL TO DIAPHYSIS**

1) Proximal phalanx of third finger (PP3)
2) Middle phalanx of third finger (MP3)
3) Middle phalanx of fifth finger (MP5)

It indicates the onset of the prepubertal growth velocity. Ossification
4) Adductor sesamoid of the thumb

It indicates a period of very rapid growth velocity

**CAPPING OF THE EPIPHYSIS OVER DIAPHYSIS**

5) Distal phalanx of third finger (DP3)
6) Middle phalanx of third finger (MP3)
7) Middle phalanx of fifth finger (MP5)

It indicates peak height velocity

**FUSION OF THE EPIPHYSIS OVER DIAPHYSIS IN**

8) Distal phalanx of third finger (DP3)
9) Proximal phalanx of third finger (PP3)
10) Middle phalanx of third finger (MP3)
11) Radius

It indicates growth completion

**MATURATION ASSESSMENT BY HAGG AND TARANGER**


Urban Haggand John Taranger investigated a prospective longitudinal study in 212 Swedish children. Data comprised of standing height, tooth emergence, pubertal development and hand-wrist radiographs. Skeletal development from hand and wrist radiographs is analyzed by taking annual radiographs between the ages of 6 and 18 years. The assessment was done for ossification of the ulnar sesamoid of the metacarpophalangeal joint of the first finger (S) and certain specified stages of three epiphyseal bones: The middle and distal phalanges of the third finger (MP3 and DP3) and the distal epiphysis of the radius (R).

**SESAMOID:**

Sesamoid is usually attained during the beginning of acceleration period of the pubertal growth spurt (onset of peak height velocity - PHV)

**THIRD FINGER MIDDLE PHALANX (MP3):**

MP3-F: The epiphysis is as wide as the metaphysis. This stage indicates that more than 80% of pubertal growth remaining.

MP3-FG: The epiphysis is as wide as the metaphysis and there is distinct medial and lateral border of the epiphysis forming a line of demarcation at right angles to the distal border. This stage indicates the accelerating slope of the pubertal growth spurt is attained 1 year before or after peak height.

MP3-G: The sides of epiphysis have thickened and cap its metaphysis, forming a sharp edge distally at one or both sides. This stage is attained at about peak height of pubertal growth spurt.

MP3-H: This stage is characterized by the beginning of fusion of the epiphysis and metaphysis. This stage is indicated by the decelerating slope of the PHV but before end of growth spurt.

MP3-I: This stage is characterized by the completion of fusion of the epiphysis and metaphysis. This is attained at the end of growth spurt in all subjects except a few girls.

**THIRD FINGER DISTAL PHALANX (DP3)**

DP3-I: Fusion of the epiphysis and metaphysis is completed in the distal phalanx of third finger. It indicates the decelerating period of the pubertal growth spurt (i.e., end of PHV) by all subject.

**RADIUS**

R-I: Fusion of the epiphysis and metaphysis on radius has begun. This stage is attained 1 year before or at the end of growth spurt by about 80% of the girls and about 90% of the boys.

R-IJ: Fusion is almost completed but there is still a gap between the margins.

R-J: is characterized by complete fusion of the epiphysis and metaphysis.

**CERVICAL VERTEBRAE AS MATURITY INDICATORS**
Cervical vertebrae are the vertebrae of the neck, immediately below the skull. The first 7 vertebrae of the spinal column constitutes the cervical spine. The first two i.e. the atlas and axis are quite unique. Third to seven has good similarity. The shape of cervical vertebrae changes according to each level of skeletal development. Vertebral changes takes place in the cartilaginous layer on the superior and inferior surface of each vertebrae.

The cervical vertebral maturation (CVM) method has become popular because the analysis of cervical vertebrae as it is performed on the lateral cephalogram, which is routinely available for orthodontic diagnosis. The use of cervical vertebrae as a skeletal maturity indicator was first described by Lamparski in an unpublished master’s thesis in 1972. Later on Hassel and Farman developed a system of skeletal maturation determination using the cervical vertebra. Three parts of the cervical vertebrae were traced. These entities were the dens (odontoid process), the body of the third cervical vertebra (C3), and the body of the fourth cervical vertebra (C4). They divided the cervical vertebral maturation into 6 categories:

**Category 1 - INITIATION**: 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. This corresponded to a combination of SMI 1 and 2 (Fig. 4).

**Category 2 – ACCELERATION**: 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. This corresponded to a combination of SMI 3 and 4. (Fig. 4).

**Category 3 – TRANSITION**: Adolescent growth was still accelerating at this stage toward peak height velocity, with 25% to 65% of adolescent growth expected. 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. This corresponded to a combination of SMI 5 and 6. (Fig. 4).

**Category 4 – DECELERATION**: 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. This corresponded to a combination of SMI 7 and 8. (Fig. 4).

**Category 5 – MATURATION**: 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. This corresponded to a combination of SMI 9 and 10. (Figure 4)
Category 6 – COMPLETION: Growth was considered to be completed 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. This corresponded to SMI 11 [Figure 4].

TOOTH MINERALIZATION AS AN INDICATOR OF SKELETAL MATURITY

Stages of root formation and mineralization have a close relationship with the skeletal maturation of an individual. Coutiaho et al\(^\text{25}\) in 1993 described the relation between eruption of mandibular canine and pubertal growth. The development of the mandibular canine was assessed according to Demirjian’s\(^\text{28}\) stages of dental calcification (figure 7). Canine stage F relates the beginning of puberty. The timing of stage G coincides with the capping of the third middle phalanges and the fifth proximal phalanges and the presence of the adductor sesamoid. It is indicative of peak height velocity. The intermediate stage between stages F and G can be used to predict the early stages of the pubertal growth spurt. Even though the findings show a close relationship between skeletal maturity and canine development but this cannot be used as the sole criterion to predict maturity of an individual.

MID PALATAL SUTURE REGION AS AN INDICATOR OF SKELETAL MATURITY\(^\text{13}\)

Mid palatal suture is the region which provides maximum resistance to the expansion of maxilla. Reveko and Fishman\(^\text{13}\) evaluated the ossification pattern of mid palatal suture. Maturation evaluation was accomplished by examining the hand wrist radiographs with fishman’s system of SMI. From this study he conclude that before SMI 4, very little or no midpalatal approximation exists. The suture is only about 8% fused at SMI 3. At this stage of maturation, the anterior portion of the suture is widely open. Between SMI 4-7, an osseous interdigitation is very evident with approximation in some areas. After SMI 8, the suture demonstrates a marked increase in the rate of approximation. At SMI 11, approximately 50% of the total midpalatal suture is approximated. A higher percent of approximation occurs posteriorly. Therefore the best time to start an orthopaedic expansion is during the early maturational stage between SMI 1 to 4 as less orthopaedic force values would be required.

FRONTAL SINUS AS INDICATOR OF SKELETAL MATURITY[14]

The frontal sinus is part of the paranasal sinuses and originates from the anterior ethmoidal cells that start their migration into the frontal bone at the end of the first year of life. With increasing pneumatization the frontal sinus becomes radio graphically evident around the age of 8 years. Ruf and panchers\(^\text{14}\) did cephalometric roentgegraphic study to analyse frontal sinus enlargement during the pubertal growth period in relation to body height growth (somatic maturity) and to epiphysial development of the middle phalanx of the third finger and radius (skeletal maturity). Frontal sinus growth velocity at puberty is closely related to body height growth velocity at puberty. Even though this procedure for skeletal maturity cannot replace hand wrist radiograph but this provide important information about a person’s stage of somatic development when 2 lateral head films of approximately 1 -2 years are available.
BIOMARKERS

ALKALINE PHOSPHATASE (ALP)

Alkaline phosphatase (ALP) is a homodimeric protein enzyme of 86 kilodaltons. ALP has the physiological role of dephosphorylating compounds. Normally, in adults, 50% of total serum ALP is derived from liver and 50% from bone, where as in children and adolescents, 90% of the ALP activity is bone specific. Tarvade et al. found a significant correlation of salivary ALP and skeletal maturation stages. Perinetti et al. have reported two-fold peak increase in ALP levels in gingival crevicular fluid.

DEHYDRO EPIANDROSTERONE / DEHYDRO EPIANDROSTERONE SULFATE

DHEA also known as androstenolone, is an endogenous steroid hormone. Dehydroepiandrosterone (DHEA) and its sulphated conjugated dehydroepiandrosterone sulphate (DHEAS) are produced from adrenal gland during adrenarche, which is a period of 3 years before puberty. They stimulate gonadstat (pituitary and hypothalamus together) to initiate puberty. According to study by Apter et al. in girls, serum DHEA showed increase between 7.5 years to 12.5 years followed by a plateau up to 15.5 years of age, and then a continuous increase till 18.5 years while in boys, a progressive increase in DHEA was seen from 8.5 years to 12.5 years of age followed by rapid increase till 18.5 years.

OSTEOCALCIN

Osteocalcin, also known as bone carboxyglutamic acid (Gla) protein. It is produced mainly by osteoblasts. It plays a significant role in regulation of body metabolism. As osteocalcin is produced by osteoblasts, it is often used as a marker for the bone formation process. Its level is increased significantly with age, body weight, height, and bone age until age 12–13 years in girls and 14–15 years in boys. According to Kirmani et al. there was an increase in serum osteocalcin level at puberty and peaked at 14 years of age but declined after the age of 14 years. Therefore Osteocalcin is a potential biomarker, which can predict growth status of an individual.
III. CONCLUSION

Growth maturation stages are important for proper timing of orthodontic treatment. A thorough knowledge of various maturity indicators will help the clinician to provide accurate treatment for various stages of an individual growth.
FIGURE 3 (HAGG AND TARANGER METHOD – MP3 STAGES)

FIGURE 4 (HASSEL AND FARMEN METHOD OF CERVICAL VERTBRAL MATURITY INDICATORS)

FIGURE 5 (FISHMANS ELEVEN SKELETAL MATURITY INDICATORS)

FIGURE 6 (SEQUENCE OF OSSIFICATION)

FIGURE 7 Demirjian's stages of dental calcification
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