Assessment of maturity in orthodontics: A review
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Abstract
Precise evaluation of maturational stage should be an integral part of both diagnosis and treatment. Different authors had reported different methods in an attempt to determine the best indicator of maturity. These include body height, body weight; sexual maturation; frontal sinus, chronological age, biological age or physiological age; hand-wrist maturity; cervical vertebrae; dental eruption; dental calcification stages and biomarkers. Ever the method has its own advantages, disadvantages and over the other method. However, still researches are being done to explore best method to assess the maturity of an individual. This article reviews the methods of assessment of skeletal maturation.

Keywords
Biomarkers, cervical vertebral maturational index, dental maturation, hand-wrist radiographs, skeletal maturation

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; weight; chronological age; sexual maturation; Frontal sinus; biological age or physiological age; Hand-wrist maturity; Cervical vertebrae; dental eruption; dental calcification stages and biomarkers. 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. 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. Physiological age can be estimated by maturational status of somatic, sexual, skeletal, and dental system.

Somatic maturity
Annual growth increments in height or weight determines the somatic maturity. 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. 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.\cite{16} Menarche is an important predictor of maturation in females.\cite{19} 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. Out of the above-mentioned bones, hand-wrist and cervical vertebrae methods has been explored extensively as indicators of maturity.

### Hand-wrist method

Hand and wrist region contains many bones that ossify at different times and with different rates. Two general approaches can be used to describe to assess hand-wrist radiograph. The first is “Atlas” approach as used by Todd.\cite{16} describe the progressive maturation of the bones of the hand and wrist. Greulich and Pyle\cite{16} method utilizes an atlas of the hand and wrist as a standard of comparison. Tanner et al. (1962; 1975; 1983; 2001)\cite{16} improved the previous work of Pyle, Waterhouse, and Greulich by individual bones, not the overall maturational status of the hand and wrist. They gave a scoring method to determine skeletal maturity from Hand wrist radiographs named it as TW1 method (1962). It assesses the maturity of twenty bones: Radius, ulna, carpals (with the exception of the pisiform and metacarpals and phalanges of the first, third, and fifth ray. Individual bones of the subject’s radiograph are matched with those given in the atlas along with written criteria each bone of the hand and wrist is assigned any of the eight or nine stages on its way to full maturity. These stages then converted into the scores. These scores then summed to obtain skeletal age of the subject. The sum of these scores is termed the skeletal maturity score. However, there were many difficulties in using TW1 method and also there was a single set of scores for both the sexes that was not justifiable. They revised TW1 and named it as TW2 (1975). Basics of the TW1 method were not changed only the scores of each stage the bone were reassigned, and some bones that posed difficulties in rating were excluded. Authors revised TW2 method (1983) and scores were separately for males and females. This TW2 method provides standards for British Children which are age and sex specific Tanner et al again revised the TW2 method and named it as TW3 method (2001). Fishman developed a system consisting of eleven adolescent skeletal maturation indicators which identify four stages of the hand-wrist bone ossification at six anatomical sites located on the thumb, third finger, fifth finger and radius. SMI can be arbitrarily divided into periods of accelerating velocity (SMI 1-3), high velocity (SMI 4-7), and (SMI 8-11).\cite{16} Main disadvantage of hand wrist X-rays is the additional radiograph in addition to the routine radiographic records such as lateral cephalogram and Orthopantomogram.

### Cervical vertebral maturation (CVM) methods

Skeletal maturation has been assessed using the shapes of the first 4 or 5 vertebrae, excluding the atlas, and distinguishing 5 or 6 maturational stages based on the change ratio of the vertebral bodies and the depth of the inferior concavity. These changes have been used to estimate skeletal age. Several workers have indicated this to be a superior alternative to the hand and wrist method.\cite{5,17,18,32-36} Lamparski first used cervical vertebrae to determine skeletal maturity by analyzing size and shape changes in the bodies of second to sixth cervical vertebrae. Initiation and development of concavities on the lower border of the vertebral body, and the increase in height of the vertebral body, from tapered to rectangular, to square, can be used as skeletal maturity indicators (SMIs).\cite{16} Hassel and Farman developed a cervical vertebral maturational index (CVMI) by using the lateral profiles of the second, third and fourth cervical vertebrae from lateral cephalogram radiographs. They also correlated their CVMI with the Fishman SMI system method.\cite{15} The Index included six stages of vertebral maturation namely initiation, acceleration, transition, deceleration, maturation, completion. Authors condensed Fishman’s 11 SMIs into six cervical vertebrae maturation categories. Baccetti et al. modified earlier six staged CVM method. They merged two former stages (Cvs 1 and Cvs 2) single stage and presented a new CVM method with five maturational stages from (CVMs) I through (CVMs) V.\cite{17} Latter on expanded back back to six stages from previously condensed version of five maturational stages.\cite{18} Main advantage with CVM method lies in the fact that it eliminates radiation exposure for orthodontic patients as lateral cephalogram is routinely used for diagnosis and treatment planning in orthodontic clinics. However, cervical vertebrae maturation method required longitudinal follow-up for accuracy.

### Dental maturation

Dental maturity can be estimated by the number of erupted and unerupted teeth, stages of dentition (deciduous, mixed or permanent);tooth calcification, degree of tooth structure, stages of crown formation of developing teeth and stages of root formation of all erupted teeth. Dental eruption may be influenced by local factors: Ankylosis, early or extraction of the deciduous tooth, impaction and crowding of the permanent teeth. Moreover, the method can only be used during relatively short periods because between the ages of 2.5-6, 8-10 and 13-18 years, no teeth will emerge. Tooth mineralization is a constant; mineralization was established as an alternative method to determine dental maturation. There are basically two types of techniques for evaluation of dental maturation and correlating it to skeletal maturation—one uses Atlas approach while the other uses Scoring systems. “Altas” approach requires comparison of radiographs of jaws where morphologically different stages of tooth mineralization are compared with standard tables, figures, charts or radiographs provided by the respective authors in the form of atlas.\cite{37-42} Method using Atlas approach are Schour and Massler, Nolla, Anderssen et al. and Moorrees et al.\cite{43,44}
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Technique using Scoring systems include Demirjian\(^{16,19}\) and Haavikko methods.\(^{46}\) These techniques also require jaw radiographs but they restrict the number of teeth included in the analysis. The teeth are assessed for crown and root formation, and the results are interpreted into the dental age by reference tables. Out of all above methods Demirjian method is easy and accurate so, most widely accepted method for dental maturation.

**Biomarkers**

Bone growth and remodeling is not only under the control of local factors but systemic factors also play a crucial role. Biomarkers represent agents that are involved directly in bone growth and remodeling. Biomarkers avoid radiographic exposure also. Research is being done to explore the role of biomarkers for determination of skeletal maturation. Alkaline phosphates in serum\(^{22}\) and gingival crevicular and proteins in gingival crevicular fluid are biomarkers. Serum Insulin-like growth factor-I, DHEAS had been used to explore their role in assessment maturation of an individual. Recently biomarkers have been correlated with the dentition phase also.\(^{26}\)

**Conclusion**

Precise evaluation of maturational stage should be an integral part of both diagnosis and treatment. Different authors had reported different methods in an attempt to determine the best indicator of maturity. These include body height, body weight; sexual maturation; Frontal sinus, chronological age, biological age or physiological age; Hand-wrist maturity; Cervical vertebrae; dental eruption; dental calcification stages and biomarkers. Every method has its own advantages, disadvantages and limitation over the other method. But still researches are being done to explore best method to assess the maturity of an individual.

**References**