Review Article

Growth prediction methods: A review

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A B S T R A C T

Growth prediction is an estimation of the amount of growth to be expected. In orthodontics the term refers to the estimation of amount and direction of growth of the bones of the craniofacial skeletal and overlying soft tissues. Successful prediction requires specifying both the amount and the direction of growth, in relation to the reference point. Estimation of dentofacial growth must consider the increments, vectors, area, duration and timing of growth accessions. All these are subjected to the changes in growth pattern

1. Introduction

Growth prediction is an estimation of the amount of growth to be expected. In orthodontics the term refers to the estimation of amount and direction of growth of the bones of the craniofacial skeletal and overlying soft tissues. Successful prediction requires specifying both the amount and the direction of growth, in relation to the reference point.[1] Estimation of dentofacial growth must consider the increments, vectors, area, duration and timing of growth accessions. All these are subjected to the changes in growth pattern. The ability to predict the magnitude and direction of a patient's facial growth early in life would enable the clinician to identify those individual who requires interceptive growth modification and to ensure that the appropriate treatment can be rendered while growth is expected. Growth prediction helps the clinician to intercept and correct the malocclusion. It can be used as patient education aids. Growth prediction (VTO) is helpful in 'visualizing' the treatment objectives and prioritizes the objectives, keeping in mind the growth pattern of the patient. A tool for orthodontic treatment planning but without

forcing any particular treatment procedure.

2. Method of Predicting Craniofacial Growth

Method of predicting growth are given by various authors-
Bjork, in 1969, described three methods for predicting the craniofacial development

1. Longitudinal method
2. Metric method
3. Structural method

2.1. Longitudinal method

This is a commonly used method in which tracing periodic cephalometric radiographs follows the course of development.in the period of most rapid growth this may be established within a year or two

2.2. Limitations

1. Accurate only when performed retrospectively but not prospectively
2. Pattern and rate of growth is not constant and pattern recorded at a juvenile age may will be changed by

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adolescents.

3. Even as it permits the observation of the changes in the sagittal jaw relations with growth change occurring in the vertical relations are to a large extent.

For clinical purpose according to Bjork the analysis of the vertical development of the face may be improved by using natural reference structure in mandible by superimposing two radiographs taken at different ages and orienting them with references to this structures, growth pattern of the mandible can be estimated with fairly high degree of accuracy.[2]

2.3. Metric method

This aim at a prediction of the facial development on the basis of the facial morphology determined metrically from a single radiographic film.[3] However statistical studies of the possibility of the predicting the intensity of the directions of subsequent development from size and shape at childhood. Indicate that this method is not feasible at least from a clinical point of view no matter with system cephalometric analysis has been used.

2.4. Structural method

This is based on the information concerning of the remodelling process of the mandible during growth, gained from the implant studies by Bjork.[4] The principle is recognized specific structural features those results of the remodelling particular type of mandibular rotation.[5] A prediction of subsequent course is then made on the assumption that the trend will continue.

It easier now to classify growth prediction methods into:

1. Cephalometric methods.
2. Non-cephalometric methods.

Table 1: Classification of growthprediction methods

Growth prediction	
Cephalometric methods	Noncephalometric methods
1. Moorrees mesh	1. Moss's logarithmic spiral
2. Johnston's transformation grid.	2. Hirschfield and Moyers method
3. Jacobson's grid	3. Mckeown's allometric method
4. Broadbent's method	4. Todd's equation
5. Fishman's method	5. Finite element method
6. Sneath's transformation grid	
7. Bjork's implant growth rotation studies	
8. Rickett's arcial growth of mandible	
9. VTOs (Holdaway's, Rickett's and other methods)	

Cephalometric growth prediction methods can further be classified as:

• Template method: The commonly used templates are:

1. Unisex Bolton template from ages 1 to 18 years;
2. (Burlington template, three configurations;
3. Original Burlington or its Michigan modification;
4. Johnston's template analysis

3. Tweed's facial growth trends

Dr. Charles Tweed, in 1954, presented his work on diagnostic facial triangle. It is a clinical treatment planning tool that attempts to establish the prognosis of treatment.

The following three planes form this triangle;

1. Frankfort horizontal plane
2. Mandibular plane
3. Mandibular incisor plane

Three angles formed are named as;

1. Frankfort mandibular plane angle (FMA)
2. Incisor mandibular plane angle (IMPA)
3. Frankfort mandibular incisor plane angle (FMIA)

Tweed stated that the faces of all children grow downward and forward in one of the three ways. Therefore, facial growth trends may be classified as type A, Type B and Type C, each having subdivision.[6]

3.1. Type A growth trend

Growth is approximately equal in both vertical and horizontal directions. According to Tweed, approximately 25% of patients present this type of growth trend.

3.2. Type B growth trend

In this type, the growth is downward and forward with the middle face growing forward more rapidly than the lower, as designed by the increase in ANB angle. If ANB is less than 4°, prognosis is fair and reasonably acceptable facial changes and good occlusion can be attained with proper and determined treatment procedures.

3.3. Type C growth trend

In which type, the lower face is growing downward and forward more rapidly than the middle face, with a decrease in ANB reading. The prognosis is excellent for treatment of patient with Type C growth trend as far as facial esthetics is concerned. About 60% of the patients exhibit this type of growth trend, according to Tweed.

Table 2: Mandibular growth rotation prediction methods

condition	Bjork and skieller	Solow,houston	Profitt	Lavergne, Gasson	Enlow	Dibbets
Rotation of mandibular core related to cranial base	Total rotation	True rotation	Internal rotation			
	Matrix rotation	Apparent rotation	Total rotation	Positional rotation	Displacement rotation	
Rotation of mandibularplane related to core of mandible	intramatrix	Angular remodeling of lower border	External rotation	Morphogenetic rotation	Remodelling rotation	Counterbalancing rotation

4. Prediction of mandibular growth rotations

5. Arcial growth prediction (Ricketts, 1972)

Robert M. Ricketts, in 1972, using trial and error procedure with longitudinal cephalometric records and computers has developed a method to determine the arc of growth of mandible.

Considering arcial development as a basic explanation of mandibular growth is "A normal human mandible grows by superior anterior (vertical) apposition at the ramus or the curve or arc which is a segment formed from a circle.[7] The radius of this circle is determined by using the distance from mental protuberance (Pm) to a point at the forking of the stress lines at the terminus of the oblique ridge on the medial side of the ramus (point- eva)"

5.1. *Implication of growth principle have been summarized by Rickettsas*

1. Symphysis rotates during growth from a horizontal to a more vertical inclination, and the genial tubercles and the lingual plate drop downward in the process. this explains the characteristics "chin - button development" in the cephalometric film. Implant studies show that greatest apposition takes place at the inferior margin of the symphysis (and perhaps the posterior side) in preschool years. The apposition may appear lateral to the midline on the symphysis as bulk is needed for bracing.
2. This phenomenon explains the observation of reversal lines at the pogonion and supragonion.
3. It explains why mandibular plane changes extensively in some individuals
4. It shows why ankylosed teeth affect occlusal plane development
5. It explains how the early ankylosis of the lower molar terminal with the tooth located at the lower border of the mandible, the mandibular arc continues to grow and this tooth becomes trooped within the cortical bone and the lower border resorbs up to it

6. It suggests why mandibular anchorage is risky in retrognathic faces, because less space is available for molar eruption due to a more vertical eruption in that type than prognathic types.
7. It explains why the lower arches of brachyfacial (tight arc cases) can be expanded and brought and will remains stable.
8. It explains why good dentures may become progressively more crowded in long, tapered faces and sometimes in normal faces.
9. It explains how the third molar impaction can occur by bone growth around the molar rather than its submergence into ramus (however, it appears that both the processes are involved).
10. It offers a possibility that impaction of the third molars can be prevented by simple enucleation (at age 6-8) of the bud which lies on the surface, not within the bone.
11. It suggests that abnormal growth of mandible can be understood as a function of relative contribution of the coronoid and condyloid processes.
12. It shows why positioning of the roots of the lower first molar to the buccal, or locking them under cortical bone, will prevent upward and, therefore, forward eruption of the whole lower dental arch thereby enhancing of lower teeth.

5.2. *Drawbacks of arcial growth prediction*

1. It relies heavily on the operator's skill in tracing the cephalogram. Minor tracing errors could produce a grossly wrong prediction.
2. Ricketts uses patient's chronological age rather than skeletal age, since he requires no hand – wrist radiograph. Since average growth increments are added to the age, if the patient has completed growth or if he is in a growth spurt, or a lag phase, it will alter the results, particularly if the time interval is short and the patient is near maturity. Mitchell and Jordan, in their evaluation of arcial growth prediction method conclude that hand – wrist radiograph will improve the accuracy of the short range prediction of the amount of growth

expected.

3. Since the growth increment constants are derived from western population, the applicability of the same to any other population (e.g. Indian population) must be verified.

4. The method does not take into account the growth of the condyle and ramus laterally in the third dimension.

5. Method fails to predict the mandibular growth in cases of true prognathism, or in cases of environment disturbance in growth.

6. Tooth mineralization as an indicator of the pubertal growth spurt

The commencement of adolescent peak growth velocity in body height and facial growth is closely related in timing to certain ossification events which occur in the hand and wrist. An investigation into calcification patterns of the teeth revealed a high degree of correlation between the stage of mineralization of the lower canine and these events.[8]

The state of mineralization was related to degree of calcification of the hook of hamate, and the development of the epiphysis of the middle phalanx of third finger. He found that calcification stage G of the mandibular canine correlated the best with other maturational indicators.

Fig. 1: Diagrammatic appearance of stages C to H of tooth development for uni- and multiradicular teeth.

7. Frontal sinus as a predictor of mandibular growth

Rossouw, Lombard, and Harris, in 1991, attempted to assess the correlation between the frontal sinus and the mandibular growth.

The author concluded that although the frontal sinus is exposed to muscles attachment it and to influences from the external environment that play a part in the its size, "the frontal sinus as seen on a lateral cephalogram is a valuable indicator of excessive mandibular growth." Thus, patient having a large frontal sinus, according to the study, would most probably present an excessive mandibular growth.[9]

Fig. 2: Six specific cephalometric measurement to predict excessive mandibular growth

8. Visualized treatment Objective

It is a procedure based primarily on cephalometrics, the purpose of which is to establish a balanced profile and pleasing facial aesthetics and to evaluate the orthodontic correction necessary to achieve this goal. This is core of the few methods that emphasize the soft tissue profile balance of the patient's face. Guidelines are provided whereby the lips are graphically repositioned.[10] A template may be used to facilitate drawing the soft tissue of the lips. This is followed by location of the maxillary incisor teeth. Finally, the lower incisors are repositioned to be in harmony with the upper incisors. Following upon the repositioning of the mandibular incisor, the resultant arch length discrepancy may be calculated to determine whether or not teeth should be extracted prior to orthodontic correction. Should the computed information suggest that teeth be extracted, the V.T.O. will yield information based on anchorage requirements as to whether first or second bicuspids should be removed, or whether the proposed treatment plan is feasible or desirable.

8.1. The V.T.O. accomplishes the following:

1. Predicts growth over an estimated treatment time, based on the individual morphogenetic pattern.

2. Analyzes the soft tissue facial profile.

3. Graphically plans the best soft tissue facial profile for the particular patient.

4. Determines favourable incisor repositioning, based on an "ideal" projected soft tissue facial profile.

5. Assists in determining total arch length discrepancy when taking into account "cephalometric correction".

6. Aids in determining between extraction and nonextraction treatment.
7. Aids in deciding which teeth to extract, if extractions are indicated.
8. Assists in planning treatment mechanics.
9. Assists in deciding which cases are more suited to surgical and/or surgical-orthodontic correction.
10. It provides a visual goal or objective for which to strive during treatment.

The V.T.O. procedure described is based on concepts of growth prediction which relate facial skeletal structural changes to the base of the craniofacial complex.
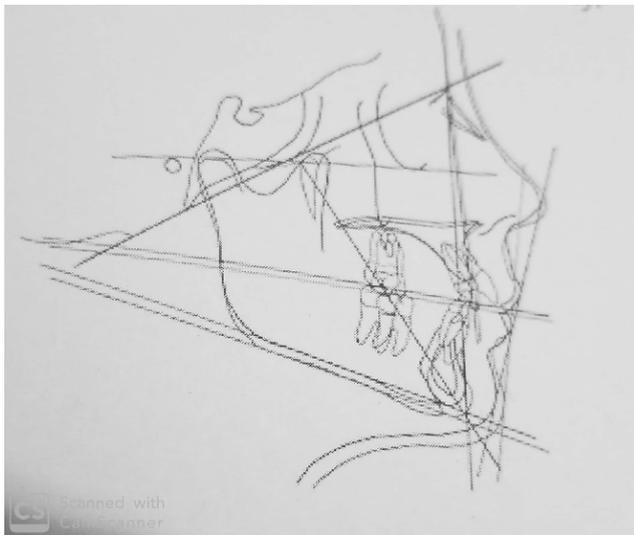

Fig. 3: The complete artwork

9. Hand wrist radiograph

Fishman developed 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.[11]

Also in 1982, Hagg and Tarangercreated a method using the hand-wrist radiograph to correlate certain maturity indicators to the pubertal growth spurt. Hand wrist radiograph is "the most standardized and studied method of skeletal age assessment", according to Smith in 1982, Fishman published a system for assessment of skeletal maturation on the basis of 11 discrete "skeletal maturity indicator" covering the entire period of adolescence development. The indicators provide identification of the progressive maturation events and are located on a six anatomic sites located on the thumb, third finger, fifth finger and radius.

10. Skeletal Maturity Indicators (SMI)

Width of epiphysis as wide as diaphysis
1. Third Finger-Proximal Phalanx

2. Third Finger-Middle Phalanx
3. Fifth Finger-Middle Phalanx
   Ossification 4. Adductor Sesamoid of Thumb
   Capping of Epiphysis 5. Third Finger-Distal Phalanx
6. Third Finger-Middle Phalanx
7. Fifth Finger-Middle Phalanx
   Fusion of Epiphysis and Diaphysis 8. Third Finger-Distal Phalanx
9. Third Finger-Proximal Phalanx
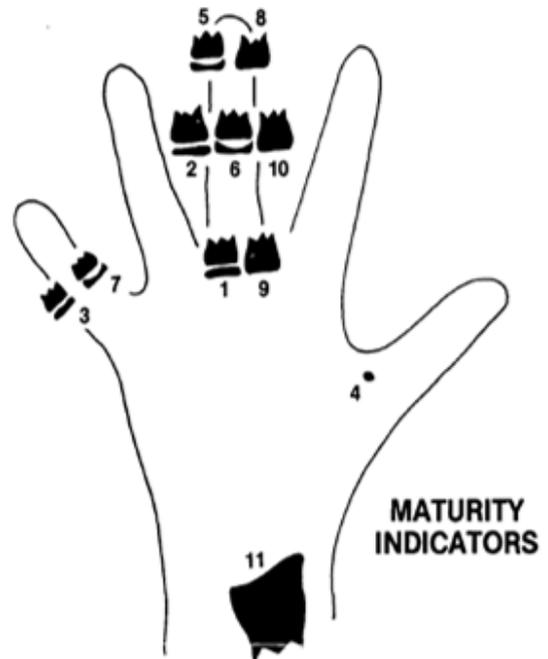10. Third Finger-Middle Phalanx
11. Radius

Fig. 4: Eleven skeletal maturity indicators (SMIs)

Six stages of hand-wrist development are the baseline for clinical reference:
STAGE I: Early stage: shows the absence of the pisiform; hook of hamate and epiphysis of proximal phalanx of 2nd digit is narrower than its shaft.
STAGE II: Prepubertal: proximal phalanx of 2nd digit and its epiphysis are equal in width. Initial ossification of pisiform seen.
STAGE III: Pubertal onset: initiation of calcification of hook of hamate/ pisiform. Epiphysis of PP2 broader than shaft.
STAGE IV: Pubertal: capping of the shaft of the middle phalanx of 3rd digit by its epiphysis.
STAGE V: Pubertal deceleration: calcified ulnar sesamoid. Calcification of epiphysis of distal phalanx of 3rd digit with its shaft. Epiphysis of radius and ulna not yet fully calcified with the respective shafts.
STAGE VI: Growth completion: epiphysis of radius and ulna fully calcified with the shafts.

11. Cervical vertebrae evaluation (Hassel and Farman, in 1995)

Cervical vertebrae maturation index or CVMI is stated as follows:

11.1. Initiation

1. Corresponded to a combination of SMI 1 and 2.
2. Very significant (80-100%)amount of adolescent growth expected
3. C2, C3, and C4 inferior vertebral body border flat. tapered from posterior
4. Superior vertebral borders are tapered posterior to anterior

11.2. Acceleration

1. Corresponded to a combination of SMI 3 and 4
2. Significant (65-85%) amount of adolescent growth expected
3. Concavities developing in lower borders of C2 and C3
4. Lower border of C4 vertebral body is flat
5. C3 and C4 are more rectangular in shape

11.3. Transition

1. Corresponded to a combination of SMI 5 and 6
2. Moderate (25-65%) amount of adolescent growth expected
3. Distinct concavities in lower borders of C2 and C3
4. C4 developing concavity in lower border of body
5. C3 and C4 are rectangular in shape

11.4. Deceleration

1. Corresponded to a combination of SMI 7 and 8
2. Small (10-20%) amount of adolescent growth expected
3. Distinct concavities in lower borders of C2, C3, and C4
4. C3 and C4 are nearly square in shape

11.5. Maturation

1. Corresponded to a combination of SMI 9 and 10
2. Insignificant (5-10%) amount of adolescent growth expected
3. Accentuated concavities of inferior vertebral body borders of C2, C3, and C4
4. C3 and C4 are square in shape

11.6. Completion

1. Corresponded to SMI 11
2. Adolescent growth is completed
3. Deep concavities are present for inferior vertebral body borders of C2, C3, and C4

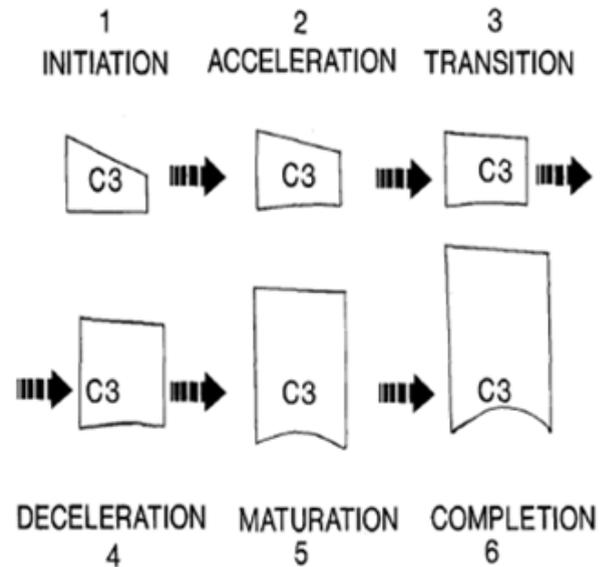4. C3 and C4 heights are greater than widths

Fig. 5: CVMI stages

12. Computerised growth prediction

The amount and direction of facial growth have long been regarded as vital factors in determining the success or failure of orthodontic treatment in a large percentage of patients. The ability to predict craniofacial growth accurately for individual cases will significantly reduce the difficulty of treatment planning in many instances. [12]

The computer was found to be accurate in predicting the effects of growth and treatment on

12.1. Maxillary development

The computer was accurate in predicting the increase in the length of the anterior cranial base

(sella-nasion) which develops anteroposteriorly.

12.2. Mandibular development

The computer was also accurate in assessing the absolute length of the mandible (basion-b point) but tended to under predict the degree of clockwise mandibular rotation as assessed by the mandibular plane angle (go-gn to sn).

12.3. Facial height

The computer significantly under predicted both the increase in lower anterior facial height (ANS to menton) and the increase in posterior face height (sella to gonion).
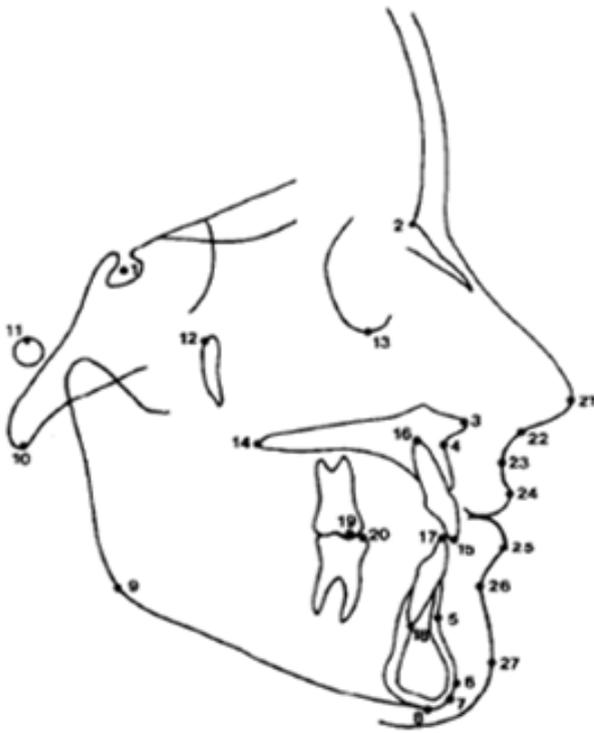
Fig. 6: Cephalometric points digitised

12.4. Incisor positions

The computer also proved to be inaccurate in measuring the anteroposterior changes in molar position. Both the maxillary and mandibular first molars were found to be more posterior (relative to the pterygovertical plane).

12.5. Soft tissues

The computer prediction of the soft-tissue profile was not very accurate

Conclusion of computerised growth prediction:

1. The computer was accurate in its prediction of the amount of growth in the anterior cranial base and the upper anterior facial height.
2. The computer underestimated the amount of increase in posterior facial height and lower anterior facial height.
3. The computer was accurate in predicting the effects of growth and orthodontic treatment on mandibular length but underestimated the amount of backward mandibular rotation.
4. The computer was accurate in predicting the effects of growth and orthodontic treatment on the degree of maxillary rotation but overestimated the increase in anteroposterior maxillary length.
5. The computer was accurate in predicting the effects of growth and orthodontic treatment on mandibular

incisor position but overestimated the amount of distal movement of the maxillary incisor.
6. The computer underestimated the amount of vertical eruption of the maxillary molars and overestimated the amount of vertical eruption of the mandibular molars.
7. The computer overestimated the amount of forward movement of the maxillary and mandibular Molars.
8. The computer was inaccurate in predicting the effects of growth and orthodontic treatment on the size of the nose and the relative anteroposterior positions of the upper lip, lower lip, and soft-tissue chin.

12.6. Disadvantage

Expensive and trained man power.

Recent computer software systems for growth prediction

1. QUICK CEPH for Apple Mackintosh
2. Rocky Mountain data systems for IBM mainframe systems.
3. Facial print for IBM personal computer.

13. Conflict of Interest

The authors declare that there is no conflict of interests

14. Source of Funding

None.

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