Cephalometry

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With the development of x-ray technology and its application to the craniofacial skeleton, numerous landmarks have been described and studied to better diagnose and plan treatment options for anomalies related to facial architecture. The following text serves to highlight the important landmarks and illustrate how they may be used to plan successful orthognathic reconstruction.

Key Words: Cephalometry, landmarks, analysis

HISTORICAL ASPECTS AND MODERN TECHNIQUES

After the discovery of x-rays by Roentgen in 1895, the earliest forms of visualizing the head were described by two separate investigators working simultaneously. In 1931, Broadbent in the United States and Hofrath in Germany presented a standardized method of imaging the skull and face that would later be called "cephalometry." Their technique involved placing the patient in a head-holding device and generating an image using a high-powered x-ray beam set at a distance of 5 feet from the film. The position of the head was gently fixed at both the nasion and the external ear canal to provide reproducibility. Modern techniques vary little from this early setup and today cephalometric analysis is an important component in the diagnosis of malocclusions and skeletal malformations (Fig 1). Standard settings for an adult include an electric potential of 70 kV, a current of 12 mA, and an exposure time of 0.8 seconds. For children, the voltage is slightly lower and the exposure time is halved.

Since its discovery, numerous authors have described points, lines, and angles on the cephalogram to analyze, diagnosis, and recommend treatment options. Before 1931, the diagnosis of craniofacial deformities was performed by clinical examination, dental models, and facial photography. The introduction of the Broadbent-Bolton cephalometer ushered in an era of intensive study of human craniofacial growth. In this article, the common landmarks are outlined and the major analyses are described.

RADIOGRAPHIC ANATOMY AND CEPHALOMETRIC LANDMARKS

Examination of the standard cephalogram involves highlighting important points, angles, and lines and relating them either to themselves over time or to each other at any given point in time. It is traditionally done by placing a hard copy of the radiographic image on a light board and taping a sheet of tracing paper on top (Fig 2). The important lines of the craniofacial skeleton are drawn and the important points marked with a pencil.

Computerized cephalometric systems were introduced in the 1970s and are currently used by orthodontists and craniofacial surgeons for diagnosis and treatment planning. The major benefit of a computerized system is the speed with which calculations may be performed. It also allows for easy storage and retrieval and seamless integration with paperless office charts. Computerized systems are still dependent on landmark identification, which may be flawed. The ideal system is constantly evolving. It should, however, be easy to perform, relatively inexpensive, able to process cephalometric images, capable of double digitations, and store all of the information generated.

CEPHALOGRAM TRACING

A standard lateral cephalogram in an adult contains many landmarks that serve as reference points and lines to measure and analyze the craniofacial skeleton (Fig 3). These landmarks are presented in no particular order and vary in importance depending on how one wants to analyze a given image.

A cephalogram in an infant is useful to diagnose premature closure of the cranial sutures. Open sutures of the skull appear as linear lucencies between the flatter surrounding bones. With age,
they fuse and become less noticeable. The paired coronal sutures may be seen as overlapping lines just posterior to the frontal bone on a standard lateral cephalogram. The paired lambdoidal sutures appear posteriorly behind the posterior fontanelle. The single sagittal suture is seen in the superior midline and better visualized on the anteroposterior image.

Tracing the cephalogram may begin at the cranial base, which is approximated by the pituitary fossa (or “sella turcica”) and the nasofrontal suture. As described subsequently, the cranial base serves as one of two commonly used horizontal reference lines for the positions of the maxilla and mandible. This line is considered stable because patients achieve most of their growth around the cranial base at a relatively early age.

Next, the outline of the orbit may be traced at the lateral and inferior orbital rims. The remaining boundaries of the orbit are not well visualized and are effaced medially near the nose. The anterior wall of the maxilla and palate are outlined, including the maxillary central incisor and first molar. Similarly, the mandible is traced as completely as possible because it provides numerous reference points for study. Again, the central incisor and first molar are identified as components of the occlusal plane. Posteriorly, the external auditory canal is noted and outlined with the porion marked for analysis. The first cervical vertebrae are well ossified and also easily outlined. Although not technically part of the calvarium, they may be used as reference points to compare multiple tracings. Each separate tracing should be labeled with the patient’s name and medical record number or birth date as well as the date of the study.

**Bony Landmarks**

The midpoint of the sella turcica (S) is used as a posterior point of reference along the cranial base.
The nasion (N or Na) represents the anteriormost portion of the frontonasal suture. A line joining the sella and the nasion serves as an important representation of the cranial base. As mentioned, it will be used as a relatively stable horizontal line of reference.

Two other landmarks in the frontal bone are the supraorbit (SO), which is the most anterior portion of the roof of the orbit and the orbital roof proper (RO), which is the most superior portion. The superior orbital rim projects ahead of the inferior orbital rim approximately 14.1 ± 8.8 mm in males and 11.3 ± 6.2 mm in females. A point F is determined by dropping a line from the point of intersection between the orbital roof and internal plate of the frontal bone perpendicular to S-N. It approximates the position of the foramen caecum and represents the most anterior limit of the cranial base.

Within the temporal bones, the porion (Po) is the superiormost point of the external auditory canal. It is used in the construction of the other important horizontal line of reference, the Frankfort horizontal. Basion (Ba) represents the most inferior and posterior point on the occipital bone. It is used in the Ricketts’ analysis, as described subsequently.

Several important points have been described in the maxilla (Fig 4). The most inferior point of the bony orbit is referred to as orbitale (Or). It is used with Po in creating the Frankfort horizontal. The A point is the deepest point along the anterior surface of the maxilla inferior to the nasal spine. It is commonly used to evaluate the position of the maxilla as it relates to the cranial base and to the mandible. The palate is often outlined on the lateral cephalogram and extends in the horizontal plane from the anterior nasal spine (Ans) to the posterior nasal spine (Pns).

Of all the facial bones, the mandible has arguably been the most labeled (Fig 5). The B point of the mandible corresponds to the A point of the maxilla. It represents the deepest point of the anterior surface of the mandible. Like with the A point, it is commonly used to evaluate the position of the mandible as it relates to the cranial base and to the maxilla. Beginning in the temporomandibular joint region, the most superior point of the condyle is the condylion (Co). The gonion (Go) is a reconstructed point that lies at the intersection of the more posterior ramus plane and more inferior body plane. It may be thought of as the most inferolateral point on the mandibular angle. Anteriorly at the symphysis, the pogonion (Pog) and menton (Me) represent the anterior-most point and inferior-most point, respectively. The gnathion (Gn) is then derived from the intersection of one line passing through the pogonion and another passing through the menton. It represents the most anteroinferior point on the symphysis.

Care should be used when marking and labeling points. ANS and Ans represent two different things. The former represents an angle of midfacial depth, whereas the latter is a single point denoting the anterior nasal spine. For each point described here, numerous other points in the craniofacial skeleton have been mentioned; however, their clinical applications are of lesser importance.

**Reference Planes**

In addition to the sella-nasion (SN) approximating the cranial base and the Frankfort horizontal (FH),

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**Fig 4** Key bony landmarks in the midface on a lateral cephalogram tracing.

**Fig 5** Key bony landmarks on the mandible on a lateral cephalogram tracing.
there are several planes that are useful in making comparisons. The average cranial base length (SN distance) in males is $83 \pm 4$ mm and in females is $77 \pm 4$ mm. Any two intersecting planes create angles that may be compared with a set of established norms. Similarly, the average distance from porion to orbitale is $74.5 \pm 5$ mm in males and $70.5 \pm 4.5$ mm in females. In most patients, the SN plane forms an angle of $5$ to $9^\circ$ with the Frankfort horizontal. The maxillary plane (or palatal plane [PP]) runs from the anterior nasal spine to the posterior nasal spine. It forms an angle of $8 \pm 3^\circ$ with SN. The occlusal plane passes along the points of contact between the maxillary and mandibular teeth. Finally, the mandibular plane is formed as a tangent of gonion and menton. It generally forms an angle of $25 \pm 5^\circ$ with the palatal plane and may be duplicated as different lines in cases of asymmetry.

Dental Landmarks

When tracing out the various landmarks on a cephalogram, several dental references must be included. The palate within the maxilla is easily visualized and should be traced. The maxillary and mandibular first molars and central incisors should also be highlighted. The first molars are used to describe the intermaxillary occlusion as per Angle’s original classification. They are also important in determining the occlusal plane. Many described analyses use the inclination of the incisors in analyzing dental relationships.

Soft Tissue Landmarks

In advancing or retracting the bones of the facial skeleton, there will logically be noticeable changes in the overlying soft tissues. More experienced technicians are able to recreate the soft tissue envelope over the face while retaining the bony detail required for marking and analysis. Key points on the face include the glabella (G), which is the most prominent point in the forehead and should be differentiated from the soft tissue depression at the nasion termed the radix. The menton also has a corresponding soft tissue point over the chin (Ms). The most anterior points on the upper and lower lip should also be noted and traced.

Analysis

Analysis of a cephalogram involves comparing the plotted points and angles either with a set of normative data or with a patient’s earlier cephalogram. A single analysis should not be the only criteria used to formulate a treatment plan. Clinical evaluation must always be considered paramount. The earliest of numerous subsequent analyses was described by Downs in 1947. This was followed by those of Steiner (1953), Tweed (1954), Coben (1955), Ricketts (1960), and Wits (1967), among others. Since then, it may be argued that little significant new cephalometric analysis has been added for more than 30 years. More recent examples include those of Schwarz, Jacobson, Bjork, and Viazis, among others. No one analysis is best and orthodontists and surgeons often choose those “tools” that are most reliable and that work best for them. As a rule, however, a reliable analysis should follow several basic tenets:

1. Reference points should be chosen that are clearly defined and easy to locate.
2. As few measurements as possible should be included.
3. More than one bony reference plane should be used.
4. The patient’s head position should be considered because it affects the ultimate values generated.

Downs’ Analysis (1948)

Downs was perhaps the first to describe the variation in human facial relationships. Using many of the landmarks noted previously, he described several planes and angles in a sample of teenage individuals with excellent occlusion (Fig 6). The Frankfort horizontal, between the porion and orbitale, served as the horizontal reference line. The facial plane was...
proposed as a line passing between nasion to pogonion (NPog). The angle that was formed with the Frankfort horizontal (NPog-FH) described the position of the mandible in the anteroposterior plane. This was termed the facial angle and was calculated to have an average measurement of $87.8 \pm 3.57$° after facial growth. A more obtuse angle would be seen in patients with prognathism irrespective of the position of the maxilla.

The angle of facial convexity, formed by the A point of the maxilla, the nasion, and the pogonion (NA-APog), describes the position of the maxilla with respect to the mandible. The calculated mean in Downs’ sample was $-4.6 \pm 3.67$°, indicating that the anterior extent of the mandible lies slightly posterior to a plumb line running through nasion.

Downs also calculated the mean of the angle formed between the Frankfort horizontal and the mandibular plane, which he termed the mandibular plane angle, and noted it to be $21.9 \pm 3.24$°. He further described the occlusal plane, which bisects the points of contact between the central incisors and first molars, and the Y axis, an oblique line between sella and gnathion. The latter was related to the Frankfort horizontal with a mean of $59.4 \pm 3.82$°. Other points and lines included the Bolton point, which is the highest point on the concavity behind the occipital condyles, and the Bolton plane, which joins this point to the nasion.

Dental relationships that specifically examined the position of the teeth were also described. Commonly used landmarks were the incisors and molars. The angle between the long axis of the upper and lower incisors measured approximately $135.4 \pm 5.76$°. The inclination of the inferior incisors with respect to the occlusal plane was $14.5 \pm 3.48$°, to the mandibular plane $91.4 \pm 3.78$°, and to the anteroposterior plane $2.7 \pm 1.8$°.

**Steiner Analysis (1953)**

One of the more commonly used analyses was proposed by Steiner, who described the sagittal relationships of the facial skeleton. It used the sella-nasion line as the horizontal reference line. The position of the maxilla as it relates to the cranial base was described in terms of the SNA angle. Steiner noted a mean SNA angle of roughly $82 \pm 2$°. Similarly, the position of the mandible was described as the SNB angle, which had a mean angle of $80 \pm 2$°. The resultant ANB angle, relating the two jaws to each other, was roughly $2$° (Fig 7).

In patients with class II malocclusion, the cephalometric profile reflects an SNA angle more than $2$° greater than the SNB angle. Similarly, in patients with class III malocclusion, the SNA angle will be less than the SNB angle. In each case, it is important to then examine each value to determine which of the two jaws is out of place. Often, maxillary hypoplasia in the setting of a facial cleft will present with a lower than normal SNA and a relatively normal SNB. Despite the actual values, the surgeon in such a case should focus on the maxilla because the maxilla is likely affected by the earlier surgery, whereas the mandible is less commonly involved.

Steiner also examined the vertical relationships of the face. He used the position of the cranial base (SN) to describe the cant of the occlusal plane (OcP). The angles between the lines GoGn and SN (mean, $32$°), the occlusal plane to SN angle ($14.5$°), and the interincisal angle (mean, $130$°) were also described.

Steiner’s analysis has been criticized because it is most dependent on the horizontal and vertical positions of the sella. Changes in sella position, without moving the jaws, will affect the numeric results of these two important measurements. Also, rotation of the occlusal plane, without moving the jaws either forward or backward, will affect the ANB and give a false impression of a difference in the sagittal position.

**Tweed Analysis (1954)**

Tweed was an orthodontist who described the dentofacial relationships in 95 patients, most of whom were not orthodontic candidates and did not have facial imbalance. He used the Frankfort horizontal as the horizontal reference line to describe a triangle of three interconnecting lines: the Frankfort
horizontal, the inclination of the central mandibular incisor, and the mandibular plane angle. The angle formed between the first two lines was referred to as FMIA and had a mean of 68.2°. The angle formed between the second two lines, IMPA, was roughly 86.9°, whereas that between the first and the third, FMPA, was roughly 24.6°. From comparison to a normative set of data, conclusions could then be drawn regarding specific cephalometric findings.

**Ricketts Analysis (1960)**

Ricketts described a large number of white patients with common orthodontic problems. Among 1000 consecutive cases, 399 had a class I occlusal pattern; 367 were class II, division 1; 217 were class II, division 2; and 17 were class III. No patients were class III requiring surgery and none were patients who were operated on for cleft palate. He used the Frankfort horizontal as the horizontal reference line.

Novel landmarks used in Ricketts' analysis include point CC, in which a line connecting basion and nasion and the facial axis intersect; point DC, a point in the center of the condyle along the line Ba-N; PM, a point along the anterior border of the mandible between B and Pg where the curve changes from concave to convex; and XI, the geometric center of the ramus of the mandible.

**Wits Appraisal (1967)**

The "Wits" appraisal of jaw disharmony is a simple method whereby the severity or degree of anteroposterior jaw dysplasia may be measured on a lateral cephalometric head film. Wits examined the relative position of the two jaws to each other by studying 46 white adult patients with excellent occlusion. The method entails drawing perpendicular lines from points A and B on the maxilla and mandible, respectively, onto the occlusal plane. In his analysis, the functional occlusal plane is used as the horizontal reference line. Novel landmarks used in Ricketts' analysis include point CC, in which a line connecting basion and nasion and the facial axis intersect; point DC, a point in the center of the condyle along the line Ba-N; PM, a point along the anterior border of the mandible between B and Pg where the curve changes from concave to convex; and XI, the geometric center of the ramus of the mandible.

**Treatment Planning**

Once a diagnosis is established, the cephalogram tracing is used to determine the direction and degree of orthodontic manipulation and/or skeletal repositioning required to correct the deformity. For orthognathic procedures, a second tracing may be made of the component part intended to be moved, either the maxilla or mandible. This may be the palate, including the first molar and incisor, to represent the LeFort osteotomy of the maxilla (with advancement or retraction) or the anterior mandible and respective teeth to represent the sagittal split of the mandible.

The component may be taped to the original cephalogram tracing in its new position as determined by the surgeon's analysis of choice and the distance measured. For the Steiner analysis, the maxillary tracing, including the A point, can be "advanced" until an SNA angle of roughly 82° is achieved. Similar movements can be planned for the maxilla. Newer technologies perform these changes rapidly and store the treatment plans digitally.

Very little good would come from attempting to use all of the information ever described in trying to diagnose and treat a specific craniofacial anomaly. Comfort with one or two standard analyses is usually all that is required for most craniofacial surgeons. It must be emphasized that any analysis must be interpreted in the context of the patient. Thorough clinical evaluation should be supplemented with such tools or measurements that correctly diagnose the problem and suggest proper treatment options.

**References**