REVIEW ARTICLE

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Cephalometric evaluation of condylar and mandibular growth modification: a review

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Structured Abstract
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Objective – Based on a wealth of orthodontic archives, this work aims to review the cephalometric analysis systems that can identify the changes in condylar and mandibular position as well as growth direction in response to bite jumping therapy.
Design – Numerous cephalometric approaches were screened to testify their feasibility and reliability in accurately depicting the growth modification of the condyle and the mandible. The critical assessment of the working mechanisms of these cephalometric methods was elaborated to help build up the rationale and justification for their clinical use.
Results – 1) The changes in condylar and mandibular size, position and growth direction can be identified by using lateral cephalograms with closed-mouth or open-mouth posture. 2) With superimposition methods where the anatomical structures for superimposition registration must be stable and reproducible, the growth modification of the condyle and the mandible between two time-points is qualitatively demonstrated in a diagram if reference lines are not constructed. The growth modification can be quantitatively identified if the reference lines are created. 3) With non-superimposition methods, the size and position of the condyle and the mandible are separately identified for each time-pint by relating them to the stable reference structures. The growth modification between two time-pints is evaluated by comparing the two separate measurements.
Conclusion – The application of a standardized and well designed cephalometric evaluation system may reduce the bias that attribute to the arbitrariness of the clinical effects of bite jumping functional appliances.

Key words: cephalometrics; growth modification; superimposition

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Introduction

The recent animal experimentations have reported a significantly increased endochondral ossification in the condyle in response to mandibular protrusion (1–3). The concurrently prospective clinical trials, on the other hand, have demonstrated no substantial growth enhancement, or an increased mandibular growth only at the initial stage of bite jumping therapy, with the growth phenotype of the mandible returning to its original pattern afterwards (4,5). The almost contradictory conclusions drawn from these two modes of studies have again placed the bite jumping therapy to the frontier of debate. The different approaches with which the results are obtained could be important factors that might account for the contrary findings. Contrary to the rapid advancement of biochemical techniques applied to animal experiments for detection of cellular or even genome changes, the clinical trials examining the effects of bite jumping therapy rely on the cephalometric gross measurement, a technique that is susceptible to producing errors and bias (6). Cephalometric gross measurement may not be capable of truly depicting the delicate changes in condylar and mandibular growth patterns and therefore may not be reliable for detecting small treatment effects of bite jumping. Furthermore, cephalometric parameters in different clinical trials are usually created and set by individual researchers, which leads to a lack of comparability between these studies (7). Tulloch et al. (8) have reviewed 50 studies reporting treatment of young patients with bite jumping therapy and failed to conclude whether the functional appliances influence the growth of the condyle, because of the multiple indices of treatment effects and inconsistency in data collection. All these factors highlight the importance of creating the cephalometric analysis systems that are commonly recognized and used to detect the skeletal changes in the condyle and the mandible in response to bite jumping appliances. The growth modification resulted from bite jumping therapy reflect on the changes in condylar and mandibular size, position and growth direction (9). Based on a review of the literature, this article was designed to explore the cephalometric analysis methods that can accurately detect the changes in size, position, and growth direction of the condyle and the mandible. The critical assessment of their advantages and weaknesses, and the in-depth exploration of their working mechanism were intended to rationalize the clinical application of the well designed analysis systems. A better understanding of standardized and well designed cephalometric approaches may reduce the bias that attribute to the arbitrariness of clinical effects of bite jumping functional appliances.

Lateral cephalograms for identification of growth modification

Cephalograms with closed-mouth position

Lateral cephalograms of this category are taken when the patient's teeth are occluded in centric occlusion (CO) or centric relation (CR), and are commonly used when condylar or mandibular position is evaluated in relation to the cranial or maxillary references. The cephalograms in CO are taken with the patient's teeth occluded in the maximal intercuspation and are optimal for patients whose condyles are properly seated in the glenoid fossae. The cephalograms in CR are taken when the patient's teeth occlude in a retruded position and the condyles are seated in the glenoid fossae. A true CR position could be reinforced by using leaf gauge method (10). Lateral cephalograms in CR are considered when the patient is undergoing functional appliance therapy and an obvious deviation between CO and CR is identified. This type of cephalogram is also preferably considered where linear length of Articulare (Ar) – Pogonion (Pg) is measured to represent mandibular length (11).

It has been reported that Ar is a highly reproducible and reliable point (12,13) and is sometime chosen over the landmark Condylion (Co) because the condyles are often not clearly visible on cephalogram (11,13). Baughan et al. (14) have reported the coefficient of reliability for Ar at 0.95 and found it to be similar to that for Sella, while it is considerably less for point Co. They recommend that the anatomically defined point Co be replaced by the constructed point Ar. However, there is a problem when Ar is used to define mandibular length (15,16). Because Ar is the intersection between the outlines of the pharyngeal surface of the cranial base and the posterior surfaces of the condylar processes, its location will depend on the positioning of the mandible. Thus, in cases where the condyles are forward, Ar may appear on a more posterosuperior part of the condylar process and the Ar–Pg will be longer than if the condyles are in their fossae (17,18). Therefore the CR position is required to seat the condyle within the glenoid fossa, in order to eliminate or minimize the bias caused by the potential forward positioning of the mandible (11).

Cephalograms with open-mouth position

Cephalograms can be taken in a full mouth opening position to clearly expose the contoure of the condyle (19). It has been recommended that changes in mandibular length and sagittal and vertical changes in mandibular condylar growth be analyzed by means of mouth-open profile roentgenograms (19,20–22).

A study by Haas et al. (23) has been designed to compare these two techniques in measuring mandibular length. A strong correlation is found to exist between the measurement of Ar–Pg by using closed-mouth position with CO and CR occlusions respectively, and the measurement of Co–Pg by open-mouth position. This correlation is not dependent on whether the patient is postured in CO or CR.

Evaluation of condylar growth modification

Superimposition approaches

Superimposition approaches are used to identify the changes in condylar size, position and growth direction between two time-points, by superimposing the two cephalograms on a stable craniofacial structure with the registration at stable landmark point(s). Superimposition approaches enhance the precision of the information regarding the changes during growth and the functional therapy, because of the fact that they allow the evaluation of the mandibular displacement in its vertical and sagittal components separately (24). The superimposition structures, especially the registration point(s), are mainly stable anatomic structures and natural structures which are unlikely to be altered or influenced during the orthodontic treatment (25). The superimposition approaches for evaluation of condylar growth modification can further be divided into two types:

Superimposition with constructed reference line(s)

With this type of superimposition, the condylar position in the space is identified by relating it to the reference line(s), and therefore could be quantified by determining the linear distance between the condyle and the reference line(s). The methods created by Pancherz and Hägg (20) and Hägg and Pancherz (22) are among the few approaches that can quantitatively define the changes in condylar position and direction. Superimposition is registered on anatomical structures – anterior and inferior mandibular bony contours. Two reference lines (or a reference grid) are established to which the condylar spatial position is related: the original occlusal line (OL) as an *x*-axis and occlusal line perpendicular (OLP) as a *y*-axis (Fig. 1). Open-mouth cephalograms are optimal for this method to allow for a clear and distinctive contour of the condyle.

One of the advantages of this method is the establishment of the reference grid. The reference grid used in this method has made it possible to 1) quantify the changes in condylar positioning; 2) identify the condylar growth direction by decomposing it into horizontal and vertical components; and 3) compare the changes of the condylar positioning and growth direction for a group of patients. Another important aspect of this method is that the reference grid is transferred from the first tracing to the chronologically next tracing(s), making the position of the reference grid remain unchanged throughout the serial of the tracings. A fixed reference grid allows an accurate comparison between different time-point tracings.

The weakness of this method, however, might be the choice of the superimposition registration structures. The anterior and inferior mandibular bone contours might not be stable structures as apposition of bone on the chin occurs in some cases (6). Therefore, this

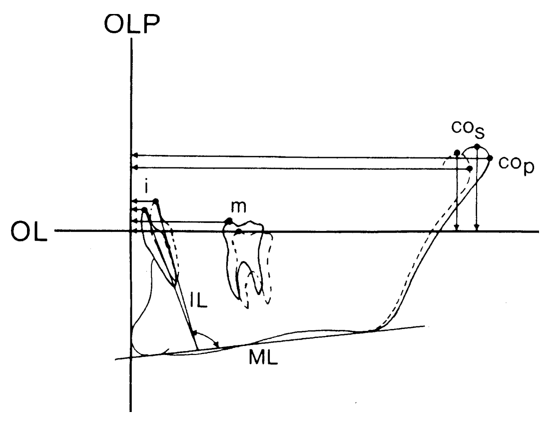

Fig. 1. Pancherz's superimposition method for quantitative evaluation of condylar growth modification. The changes in condylar size, position and growth direction are identified by relating them to the constructed reference grid OLP and OL [courtesy of Pancherz and Hägg (20)].

method is implied for the evaluation of changes occurring during a short-term period.

Theoretically, implants inserted into the mandible are the most stable objects compared with any natural structures and anatomical points for superimposition. Björk (26) establishes growth velocity curves of the mandible by means of fixed registration points using metal implants. Condylar growth is estimated by measuring the changes in position of the landmark Co with cephalograms orientated on two metal implants inserted within the mandible (26). Hägg and Attström (6) term this method the 'scientific method', distinguishing it from the 'standard methods' that measure the increase in distance between two cephalometric landmarks defined on the mandible on lateral cephalograms. This method makes it possible to measure the magnitude and identify the direction of the condylar growth more accurately and closer to the true growth direction of the condyle (6). The reference lines in Björk's method (26) are the tangent to the posterior border of the ramus and the tangent to the lower border of the mandible. The direction of condylar growth is determined by the angles between these reference lines and the axis of condylar dorsal border. Although this is a sound solution to the establishment of a true registration structure, this method, however, might not be accepted as a clinical routine because of its invasive procedures and ethical issues (27).

Superimposition without constructed reference line(s)

Superimposition without reference line(s) demonstrates the growth modification in a schematic way, giving an overall impression of the changes in condylar position and direction (28). With this approach, the identification of the changes in condylar position is not quantitative and therefore can only be used for individual evaluation. An example of this type of superimposition is the Ricketts' method (29). When lateral films are superimposed by orientating along the corpus axis and registering at Pm, the changes in condylar position could be visualized but not quantified.

Non-superimposition approaches

Non-superimposition approaches evaluate the condylar growth modification by measuring the condylar size, position and growth direction of the serial of tracings separately and then identifying the differences of the measurements between two time-points. Because there is no superimposition registration, the reference line(s) to which the condylar position is related must be the natural or anatomical structures that are not influenced by the functional appliance therapy.

SN plane is commonly used as the reference line in non-superimposition cephalometrics. A reference grid has been constructed by adding a perpendicular through point Sella (S) (30,31). The position of the condyle to S is determined by the horizontal distance between Co to SN plane perpendicular (S–Co_{hor}), and the vertical distance between Co and SN plane (S–Co_{vert}).

The angular measurements are also designed to evaluate condylar position with non-superimposition method. Sella angle (N–S–Ar), for example, indicates the condylar position relative to the anterior skull base, and Articular angle (S–Ar–Go), on the other hand, indicates its position relative to the posterior cranial base (32).

The validity of measurements using non-superimposition is closely associated with the stability of reference structures. Although SN commonly serves as the superimposition registration line and the reference line, there is evidence that both S and N are fluctuating with local remodeling during growth (33–35). Melsen (36) has observed a change in S and N over a period of 7 years. Therefore, the evaluation of the condylar position relative to SN might be significantly affected if the span between two time-points exceeds 7 years, depending on age and growth potential of the patient.

Evaluation of mandibular growth modification

Superimposition approches

The changes in mandibular position and growth direction in response to bite jumping therapy can be measured by superimposition of serial tracings registering on relatively stable bases or regional contours. Stability and reproducibility are most important criteria for a superimposition registration structure (37). Therefore, the growth changes affecting registration structures used for superimposition must be taken into consideration for growing patients (38).

Superimposition with constructed reference line(s)

Like the superimposition method for detection of condylar position, reference line(s) are established to which the mandibular position and direction is related.

The Pancherz method. Two cephalograms are superimposed on the nasion-sella line (NSL) with sella (S) as the registration point. A reference grid is established by drawing the occlusal plane (OL) and its perpendicular plane (OLp) through sella point on the initial cephalogram. Mandibular positional changes are measured from the movement of the landmark Pg along the initial OL to OLp (39).

The Pancherz method establishes the reference grid which is used to quantitatively evaluate the changes in mandibular position occurring along the occlusal plane. This quantitative analysis makes it possible to evaluate and compare the mandibular repositioning for the patients in groups. Another advantage of this method is the location of the reference grid. One of the reference grids is the occlusal plane, which is thought to be close to the area of interest (38). According to Johnston (40,41), it is the horizontal component during growth along the functional occlusal plane, that is decisive to the treatment outcome of anterior–posterior occlusal discrepancies. The reference grid would not be affected by the treatment, since it is constructed on the initial cephalogram taken prior to treatment and is transferred to the second cephalogram taken after treatment. A fixed grid is crucial for a comparative evaluation between both intra- and inter-individuals.

The superimposing registration structures in this method might weaken the reliability of the evaluation. Both S and N undergo change within some period of time by local remodeling during the growth (33–36). Therefore, if the time between two tracing points is too long, the overall superimposition on SN line might have a relatively low degree of validity. Furthermore, the superimposition in this method is registered at S rather than N. Point S is usually more difficult to identify than point N. It has been recommended that, when the tracings are superimposed on the SN line, nasion be registered rather than sella, if there is a difference in the cranial base length (28).

The designation of registration structures for cranial superimposition has been an arguable topic in the literature. The stability of SN line is challenged by some researchers (33,42) and is favored by others (38). Some argue that the bony anatomy from the anterior half of sella turcica to the region of the foramen and the internal outline of the frontal bone is relatively stable and thus can support a meaningful anterior cranial base superimposition (43,44). Björk and Skieller (43) have suggested that the following natural structures be employed: the anterior wall of sella turcica and its point of intersection with the lower contours of the anterior clinoid, the greater wings of the sphenoid, the cribriform plate, the orbital roofs, and the inner surface of the frontal bone. The posterior half of sella turcica and the structures in the region of nasion, however, are ignored.

Wieslander's method. Wieslander (19) created a superimposition system similar to that of the Pancherz method. SN is used for superimposition line with S for registration point. The reference grid is established by the occlusal plane and its perpendicular through S. However, the mandibular position is localized by identifying linear length between Point B to the vertical grid line along the occlusal plane.

The pitchfork analysis. The pitchfork analysis (40,41) is designed to produce a detailed summary of antero-posterior change of the mandible measured parallel to the occlusal plane. With this method, the changes in mandibular position, which is reflected by point D (the center of the symphysis), is related to the occlusal

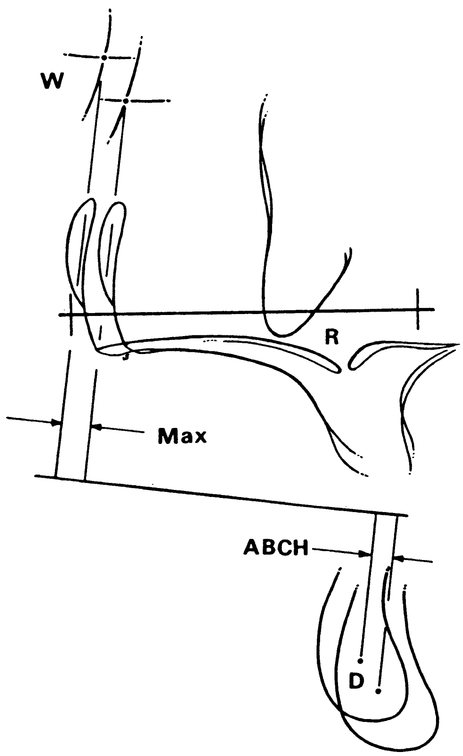

Fig. 2. The Johnston's pitchfork analysis for evaluation of the changes in mandibular position. Mandibular displacement relative to maxilla (ABCH) is measured at D, the center of the symphysis and executed parallel to mean functional occlusal plane (MFOP) [courtesy of Johnston (45)].

plane with the superimposition on the maxilla (Fig. 2). The unique aspect of this analysis is that the skeletal change is measured as actual physical displacement of the mandible, rather than as apparent changes in the position of the conventional landmarks which are possibly produced by surface remodeling. This is exercised by selecting landmarks that have a good chance of being physically stable between two time-points. Therefore, point Pg, which is commonly selected for the evaluation of mandibular position, is not used in pitchfork analysis. Like the Pancherz method (39), the pitchfork analysis measures the changes projected onto the occlusal plane. The reason for so doing is that, according to Johnston (45), while the face undergoes many changes during the course of bite jumping treatment, only the effects that occur at the level of the occlusion can have the impact on the molar and incisor relationships. Unlike the Pancherz method in which the reference grid (two lines) is constructed, the pitchfork analysis designates a single reference line by creating an average occlusal plane between two tracings which is passed through to each tracing.

The maxillary superimposition in this method is conducted by registration on both the zygomatic process of the maxilla and on the bony anatomical details superior to the incisors. Like cranial superimposition, the reliability of the registration structures for maxillary superimposition also remains debatable. Maxillary superimposition commonly uses an ANS–PNS orientation in conjunction with registration on ANS. This method, however, introduces considerable bias, especially in terms of vertical displacement of the molars and incisors (46–48). In contrast, Björk's structural method (49–53) is said to approximate implant superimposition and uses the zygomatic process of the maxilla, especially its anterior surface, for registration. But the 'key ridge' often is difficult to see and is too short to assist in orienting the tracings. Nielsen (48) examines the serial cephalograms of a sample of implanted subjects and has found that the zygomatic process is unusable about half of the time. This might account for the pitfall that this method consistently provides an overestimation of the skeletal effects and under-estimation of the dental changes (54).

The precision of two regional superimposition methods (cranial vs. maxillary) in depicting the mandibular displacement has been investigated by many studies (55,56). It has been stated that, in growing children, post-treatment displacement of mandibular skeletal component should be assessed by both maxillary and cranial base superimpositions, as maxillary is subject to rotational and translational changes during growth that may affect the position of the mandible relative to the maxilla in a way inconsistent with the mandibular displacement perceived upon cranial superimposition (55).

Superimposition evaluation without reference line(s)

Björk's structural method. Björk's structural method (26,53) is based on the results from a series of implant studies. It is concluded that the anterior surface of the zygomatic process remains unchanged during growth. Thus, superimposing the cephalograms on this structure could be used to detect mandibular skeletal changes.

Ricketts' four position method. The Ricketts' method (29) comprises four steps to evaluate orthodontic functional treatment. Position I is used to display the mandibular skeletal changes. The lateral films are superimposed on the BaN plane with registration at Pt.

Superimposition without establishment of reference line(s), like the two methods mentioned above, cannot quantify the changes in madibular position. It can only display the mandibular repositioning between pre- and post-treatment in diagrams (38). Therefore, whether the evaluation is quantitative or qualitative is the key difference between the methods with reference line(s), such as the Pancherz method (39) and the methods without, such as the Ricketts' method (29). Another difference between the two types of superimposition is the range of the subjects to be assessed. Superimposition without reference line(s) could only be used to make a schematic estimation of the changes intra-individually. The methods with reference lines(s) or a grid, on the other hand, could quantify mandibular positional changes and therefore, could evaluate or compare the changes between the patients.

Stability of the registration structures in Björk's method might be better than that of the Ba–N reference in Ricketts' method. However, the reliability of the treatment changes assessed by these two methods and the Pancherz method is at the same level (38). You and Hägg (38) have reported that two factors are related to the accuracy of the evaluation using cephalometric superimposition without reference line(s): 1) the length of superimposition registration structures, and 2) the distance between the landmarks used for assessment and the superimposition registration structures. The longer the superimposition registration plane, the closer the assessment landmark to the superimposition registration line, the more precise the evaluation would be.

Non-superimposition approaches

The non-superimposition approaches evaluate the mandibular position separately between two time-points tracings. The changes in mandibular position and direction are assessed by comparing the two separate measurements. Mandibular position and growth direction are localized by relating it to the following reference structures:

1) *Anterior cranial skull base*: SNB, SNPg, and SNGn are used to evaluate the anteroposterior position of the mandible relative to the anterior cranial base SN. As both S and N are affected during growth, these parameters might not mirror the true position of the mandible (25).

2) *Frankfort Horizontal Plane (FH)*: An important aspect of the Ricketts' analysis (57) is to locate the chin in the space. In the Ricketts analysis, the major reference line is the true FH (using anatomic, not machine Porion). Other FH related reference lines in Ricketts' method are the Nasion–Basion and the Pterygoid vertical which is established perpendicular to the FH at the root of the pterygo-maxillary fissure. Six of the 11 measurements in this method are aimed at identifying mandibular position by locating the chin position in the space, mainly relative to the FH.

3) *Maxillary structures*: the ANB angle indicates the jaw discrepancy anterioposteriorly, and the mandibular position relative to the maxilla (58). This parameter, however, is influenced by two factors other than the anteroposterior difference in jaw position. One is the vertical height of the face. As the vertical distance between nasion and points A and B increases, the ANB angle will decrease. The second is that if the anteroposterior position of nasion is abnormal, ANB will be affected (28).

4) *Occlusal plane*: the Wits analysis (59) is used to analyze maxillo-mandibular relationship by measuring the distance between points A and B parallel to the occlusal plane (60). In this method, the difference parallel to the occlusal plane also lends itself to an analysis of the effects of growth and treatment. It is important for the Wits analysis that the functional occlusal plane, drawn along the maximum intercuspation of the posterior teeth, be used rather than an occlusal plane which is influenced by the vertical position of the incisors (28).

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