Roentgencephalometry

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Cephalometric x-ray analysis is carried out for the purpose of evaluating the sagittal and vertical relations of the facial skeleton.

This evaluation is carried out on a profile cephalogram with the mandible in maximal occlusion. To visualize the contours of the condyle a second exposure with the mouth fully opened is sometimes performed.

An analysis of the transverse relations can be carried out on anteroposterior exposure. This analysis is, however, not carried out routinely.

On the basis of one profile cephalogram the following items can be studied:

1) The relations between the teeth in the upper and lower jaws
2) The relations between the teeth and the base of the alveolar bone
3) The relations between the basal bones of the upper and lower jaws
4) The relations of the jaws to the cranial base
5) The morphology of the cranial base and the mandible

This is termed a morphological analysis. On the basis of two or more profile cephalograms obtained at separate intervals of for example 1 year, the growth of the facial skeleton in relation to the cranial base can be studied. This is called growth analysis. If orthodontic treatment has taken place in the interval the result will be a combed growth and treatment analysis, and the results obtained on the facial skeleton and the dentition can be evaluated.

Radiographic Technique

During the exposure the head of the patient is positioned in the cephalostate by means of ear rods placed in the external auditory meatus. The patient holds his head in a normal posture and a vertical light source is used to control the parallelism of the median plane to the film.

The patient’s right side faces the film. The distance between the x-ray tube and the mid-sagittal plane is 180cm and the distance from the mid-sagittal plane to the film 10cm, the x-ray tube is adjusted so that the central beam passes through the ear rods.
Technical data

The target is squared and the size is defined by the length of one side and may vary from 0.2-1.2mm.

The exposure is defined by:

Kiltovoltage measured in Kv normally 60-95Kv and Current x time = mAs normally
120 mAs per second mAs x 0.6 seconds = 72 mAs per second.

Image formation by x-rays

As the emission of x-rays is cone-shaped a general magnification is produced

Fig. 1

By increasing the distance from the x-ray tube to the median plane of the object, in relation to the distance from the median plane to the film, a decrease in magnification is obtained (Fig. 1).

With the film focus distance of 190cm and the focus object distance of 180cm a magnification of the mid-sagittal structure will be 5.55%. This magnification is not, however, important in an analysis like Björk’s where only angular measurements are used, but when evaluating growth or treatment results the magnification must be the same.
As the cephalogram is a summation picture, the median and the bilateral structures are projected into one plane (Fig. 2). As a consequence the bilateral structures away from the film are enlarged to a greater extent than those close to the film, i.e. not only are the bilateral structures projected onto the same plane as the enlargement, but as the enlargement differs they will be seen as double contours on the image. As an example the lower border of the corpus mandibulae will be seen at different levels so that the one close to the film, i.e. the right side and the one close the focus are separated (Fig. 3). Likewise the posterior border of the right and the left side of the ramus are separated so that the side close to the film is seen closest to the ear rods i.e. posterior to the left side, as the magnification of this is the smallest.

Variation in position of the mandible at the time of exposure and the asymmetry of the mandible can, of course, result in deviations from the above.
Summation of the structure situated in different planes in relation to the film will result in **distortion**.

Distortion is the inaccuracy created when the distance between two points **not** situated in the same sagittal plane are measured on an x-ray image. As an example the image of the corpus mandibulae and the distortion will depend on what extent the lines connecting different structures deviate from the sagittal plane (Fig. 4).

Distortion will thus be greatest in individuals where the corpus mandibulae divert seriously in a posterior direction i.e. where the distance between the two gonion points is large.
X-Ray Image Quality

The quality and the amount of information in a radiographic image is a function of the number of elements contained in the picture. By increasing the number of elements an increase in the amount of information is stored in the radiographic picture.

A Radiographic image is characterized by:

1. Unsharpness
2. Contrast
3. Blackening

All three factors are of importance for the quality.

In the production of the image, sharpness and contrast are dependant on each other in a complicated way. To obtain an overall picture of the contrast and sharpness and their influences on the quality of the image, these are discussed separately.

Ad 1

a) Every radiographic image is characterized by certain unsharpness, due to the size of the focus target. This is called geometric unsharpness
b) Movements during the exposure will result in unsharpness
c) Finally, the structure of the film will affect the unsharpness

A 1A

Geometric unsharpness is due to the fact that the source of radiation is an area and not a point and can be expressed by the formula $U_g = b/a$ as seen in Fig. 5.
It is seen that the unsharpness = half shadow is directly proportional to the size of the target. With a smaller target the unsharpness will decrease. The minimum size of the target is, however, limited by the cooling system of the anode as 99% of the energy produced from the focus is heat and only 1% x-ray.

By diminishing the angle of the anode to the electronic beam, a relatively large area (the real focus) will obtain the beams from the cathode and absorb the heat, whereas the area which gives rise to the emission of the x-rays (the effective focus) is very small (Fig. 6). The efficiency of an anode is proportional to the atomic number of the target material and it is, therefore, advisable to choose a target material with a high atomic number and, consequently, a high melting point. For this reason tungsten is often chosen.

In a stationary anode a tungsten target of 2-3mm can be embedded in a copper block thus making use of the high heat conductivity of the copper so that a smaller focus can be used. Further by using a rotation anode where the area which receives the x-rays during the exposure is moving, an additional reduction of the target area can be carried out. The unsharpness is also directly proportional to the distance of the object from the film. This distance is, however, limited by the size of the object (Fig. 7).
The geometric unsharpness is inversely proportional to the distance from focus to object. This distance is, however, limited by practical circumstances such as the size of the room. The two above mentioned factors also effect the magnification (Fig. 7).

![Fig. 7](image)

Ad 1B

**Mobility and unsharpness.** By decreasing the exposure time, the possibility of movement during exposure is decreased and therefore better definition and sharpness are produced.

Ad 1C

**Material unsharpness**

1. **Grain size of the emulsion.** The unsharpness due to the quality as well as the speed of the film are directly proportional to the size of the crystals in the film.

2. **Intensifying screens.** In order to give the minimum x-ray dose to the patient, intensifying screens are used. By this means the x-ray dose can be reduced by 90%, but simultaneously the intensifying screens add to the unsharpness of the image. The intensifying screens consist of crystals of calciumtungstate, which fluoresce on exposure to x-rays. This light is emitted in all directions and thus adds to the blurring of the picture (Fig. 8).
Contrast. The contrast in an x-ray image is the difference in the blackening of the different areas of the film representing different structures, i.e. a result of how large a percentage of the x-rays can be absorbed by the different parts of the object.

The contrast is dependant on:

a) The wavelength of the x-rays
b) The atomic number of the objects
c) The thickness of the objects

Ad 2A

The wavelength is inversely proportional to the kilovoltage

Ad 2B

With increasing atomic number the absorption coefficient is increased, i.e. a larger part of the given x-ray dose is absorbed by a unit amount of the material.
Ad 2C

With an increasing amount of material, an increase in absorption will take place.

The contrast can be increased by choosing a lower kilovoltage (Kv) and therefore a larger wavelength as the absorption is directly proportional to the wavelength.

It is, however, not always desirable to have great contrast in the x-ray image. In many cases, having too high a contrast will cause the film to be too black in certain areas, too white in others and, therefore, the various intermediate shades will be lost. To increase the contrast of the soft tissue profile an aluminium filter is used (Fig. 9).

The importance of secondary radiation on the contrast

With an increase in kilovoltage (Kv), an increase in secondary radiation is created during the exposure. The secondary radiation emitted in all directions will, therefore, create a blurring of contrast on the x-ray film. This effect can, however, be diminished by application of a screen consisting of lead lamellas which absorb the waves whose direction deviates most from the primary radiation. The lead lamellas are positioned as radii with the centre at the anode. By moving the screen during exposure images of the lead lamellas of the x-ray film are avoided (Fig. 10).
Secondary radiation from surrounding air and walls

As previously mentioned the x-rays are emitted in a cone shape from the focus and can therefore cause secondary radiation from the air and the walls of the room. This radiation can, however, be diminished by adding a dimmer which restricts the emission to the area required. The diaphragm consists of lead (Fig. 11).

Ad 3

The blackening is a measure of the amount of light which will pass through the x-ray. From Fig. 12 it appears that the blackening in a large area is directly proportional to the x-ray dose.

mAs will not influence the contrast, but generally increases the blackening
The appearance of this curve will vary with the quality of the film.

Fig. 13. The film can have a varying degree of sensitivity

Fig. 14. A varying graduation

The sensitivity is increasing with increasing grain size in the emulsion. The gradation is defined as the inclination of the curve illustrating the relation between exposure and density. The gradation is increased with increasing content of AgBr in the emulsion.
X-ray anatomy – tracing technique

On the basis of an x-ray image a drawing of the profile used for the analysis is produced a so called tracing (see Fig. 16).

A. X-ray anatomy (Fig. 15)

Structures of importance to the cephalometric analysis:

1. os frontale
2. sinus frontalis
3. os nasale
4. orbita
5. orbital roof
6. medial border of the orbital roof
7. lamina cribrosa ossis ethmoidalis
8. sinus maxillaries
9. processus zygomaticus maxillae
10. anterior limit of fossa cranii media
11. fossa pterygopalatina
12. planum sphenoidale
13. tuberculum sellae
14. sella turcica
15. proc. Clinoidei ant. et post
16. dorsum sellae
17. clivus
18. condylus occipitalis
19. proc. Mastroideus
20. os occipitale
21. pars nasalis pharyngis
22. pars oralis pharyngis
23. canlis mandibulae
B. Tracing technique

The profile radiograph (with the teeth in occlusion) is placed on a light box. A piece of tracing paper is attached to the x-ray with tape. A tracing of the radiograph is drawn with a sharp pencil (Fig. 16).

The mid-sagittal structures

The cranial base

The anterior cranial base consists of:

- The inferior, anterior part of the facies interior from os frontale
- Lamina cribosa ossis ethmoidalis
- Planum sphenoidale
- Tuberculum sellae
- Sella turcica
- Dorsum sale – note: in the mid-sagittal plane the posterior wall is not very high
- Clivus
- Facies externa pars basilaris ossis occipitalis and corpus ossis sphenoidalis

It is often very difficult to localize the cribriform plate which is the most inferior of 3 horizontal lines seen on Fig. 15: 5; the roof of orbitas, 6; the medial border of the orbital roof, and the most indistinct: the cribriform plate, 7.
The cribriform plate of the ethmoid

As a guide it should be remembered that the cribriform plate of the ethmoid is positioned lower than the jugum sphenoidale. The anterior surface of the frontal bone as well as the nasal bone and the naso-frontal suture can then be drawn. Finally, the posterior margin of the foramen magnum is added.

The Maxilla

First the anterior and posterior contours of the maxilla are traced, followed by the nasal and the oral surfaces of the hard palate, these meet at the anterior nasal spine. Posteriorly, there is often a tooth which obscures the contour of the nasal surface, but the contour of the soft palate can be of some help.

The anterior contour of the maxilla is often obscured by a double outline of the cheek. The outline of the anterior surface of the alveolar process follows that of the roots of the incisors as far up as the apex where the anterior surface then turns upwards anteriorly to the anterior nasal spine. The tip of the nasal spine can sometimes be difficult to determine, in which case it is established by continuing the anterior and nasal outlines until they meet.

Of the maxillary teeth the most protrusive upper incisor is used. As a rule there are no difficulties in drawing the outline of the crown, and it is usually easy to draw the labial surface and apex of the root in order to establish the axis. The lingual surface of the root from the cingulum to the apex is often obscured by the adjacent teeth and is, therefore, drawn from the knowledge of the root morphology.

The first molar or, if this has been extracted, the second molar is also traced. In this case the structures are bilateral so that there is a double outline on the picture. This problem is solved by drawing between the two lines or where there is a big difference, by drawing them both, assuming that it is not an exposure error in the picture which can be checked on the study models.

The pterygo – palatine fossa, the anterior border of which is the outline of the maxillary tuberosity, and the alveolar process are drawn.
The mandible

The external contour and the inner cortical lamella of the symphysis, the mandibular canal, the base of the body of the mandible and the posterior edge of the ramus are drawn. Here there is often a double outline, the contour midway between the two outlines can be drawn or both sides drawn. As in the maxilla the most protrusive lower incisor and the first molar and, if necessary, the second molar, as well as, the outline of the alveolar process are drawn.

The soft tissues

The outline of the soft tissue is added. Up till now the picture showing the jaws in occlusion has been used. To draw the outline of the condyle a picture taken with the mouth opened as wide as possible must be used.

By transferring the tracing of the second picture in such a way that the symphysis and the mandibular canal correspond, the contour of the condyle can be added to the first picture. In the case of a double outline, the line midway between the two can be selected. If the double outline shows a pronounced difference and no asymmetry is present the x-ray must be retaken. In case of asymmetry of the mandible it is necessary to supplement these pictures with two frontal views, one with the teeth in occlusion and an oblique frontal picture with the mouth opened as far as possible, angled so that a line through the condyle and the symphysis would be vertical.

Reference points and lines

Reference points

Some are well defined anthropological reference points and are readily found on the dry skull.

Example: Pogonion (pg): most prominent point of the chin. Other points are located at the intersection of contours that may lie in different planes in the skull but which in radiographs are projected on the median plane of the head. Such points are purely roentgen reference points.
Example: articulare (ar): intersection between the contour of the external base and the dorsal contour of the condylar head.

The reliability and the as such the value of a roentgen-cephalometric analysis is dependent on

1. the precision with which it is possible to mark the various reference points
2. variation of biological origin due to continuous remodelling in the structures involved.

The points included in the cephalometric analysis can be divided into mid-sagittal and bilateral points (Fig. 17).

**Mid-sagittal reference points**

**Basion (ba):** normal projection of the anterior border of the occipital foramen (endobasion) on the occipital foramen line. As a rule, the contour of the clivus is visible to an extent that permits an extrapolation downwards backwards to the intersection with the contour of the external cranial base at the anterior border of foramen magnum.

**Gnathion (gn):** lowest point of the mandibular symphysis

**Incision inferius (ii):** midpoint of the incisal edge of the most prominent upper central incisor.

**Infradentale (id):** highest and most prominent point on the lower alveolar arch. This point corresponds to prosthion in the upper jaw.

**Nasion (n):** most anterior point of the fronto-nasal suture. The suture, in the majority of cases can be distinguished clearly on the picture. It can, however, be difficult if the film is too dark in this area. Mashing off the distracting light areas with e.g. another radiograph can help.

Should it not be possible, despite these measures, to distinguish the most anterior part of the fronto-nasal suture, one can use the following method.

A line is constructed as a tangent to the most prominent points on the frontal bone and bony chin.

Nasion is the most posterior point on the curvature thus formed by the frontal and nasal bone (Van der Linden).
It is important to determine the exact localization of nasion as it forms part of a series of the most important measurements.

**Pogonion (pg):** most prominent point of the chin. While supramentale represents the apical base the point pogonion represents the mandibular base.

**Prosthion (pr):** lowest and most prominent point on the upper alveolar arch.

**Sella (s):** centre of the bony crypt known as the sella turcica. The upper limit of the sella turcica is defined as the line joining the tuberculum sellae and the dorsum sellae.

**Spinal point (sp):** (acanthion): apex of the anterior nasal spine. As mentioned previously, the point of the anterior nasal spine is often difficult to establish and can be constructed by continuing the floor of the nasal cavity in a downwards direction and the anterior contour of the maxilla upwards. Acanthion is situated at the point of intersection of these lines.

**Subspinale (ss):** (Down’s A point): deepest point on the anterior contour of the upper alveolar arch. The point represents the area of the maxilla adjacent to the incisal apices and as such is called the apical base. One can establish the point by placing a set square with the one side along the nasal line (see below) and by moving it either backwards or forwards one can determine the tangent point to the anterior contour of the alveolar process (and thus subspinale).

**Supramentale (sm):** (Down’s B point): deepest point on the anterior contour of the lower alveolar arch. As is the case of the upper jaw it can be said to represent the apical base.

In the case of both supramentale and pogonion the base line used in their construction is the mandibular line.

**Bilateral reference points**

**Articulare (ar):** intersection between the contour of the external cranial base and the dorsal contour of the condylar head.

**Condylion (cd):** top of the condylar head. It is found in the following way: a tangent to the condyle is constructed parallel with the mandibular line. A line, at right angles to this line, and as a tangent to the posterior margin of the condyle is then constructed. The right angle thus formed is bisected, and the point condylion is then established as the point at
which the line of bisection intersects the contour of the condyle. In the case of a double contour a point midway between the two points of intersection on the bisecting line is used. It is used in growth analysis in describing the direction of growth of the condyle.

The use of the point condylium presupposes that the condyle is drawn in. Should this not be the case, the point articulare can be used in describing the direction of growth of the condyle.

Gonion (go): a point on the bony contour of the gonial angle determined by bisection the tangent angle.

Pterygomaxillare (pm): point representing the dorsal surface of the maxilla at the level of the nasal floor. The point is located on the dorsal contour of the maxilla, which above forms the anterior limit of the pterygo-palatine fossa where this contour intersects that of the hard and soft palates.

Reference lines (Fig. 18)

The foramen magnum line: a tangent through the anterior and posterior lower borders of the occipital foramen.

Chin line (CL): tangent to the chin through the infradentale.

Mandibular line (ML): tangent to the lower border of the body of the mandible through the gnathion.

In cases where the lower border of the mandible exhibits a pronounced angular region, construction of the line presents no problem.

In cases where the lower contour of the body of the mandible exhibits no prominent angulus, construction of this line is more difficult, since in such a case the line will intersect the contour of the lower border of the mandible. It is frequently drawn than it should be.

Nasal line (NL): Line through the spinal point and the pterygomaxillare. The line represents the hard palate.

Nasion-Sella Line (NSL): Line joining the nasion to the sella. It represents basis cranii anterior.
It is thought that the surutal drowth of the anterior cranial fossa ceases at the age of 8-9 years. The anterior cranial base forms therefore, at an early age, a relatively stable structure from which one can judge the growth of the cranium.

**Nasion-Sella Perpendicular (NSP):** line through the sella and perpendicular to NSL.

**Occlusal Line, inferior (OL₁):** line through the incision inferius and the distobuccal cusp of the lower first molar. (If this tooth is absent the mesiobuccal cusp of the upper second molar).

**Occlusal Line, superior (OL₂):** line through the incision superius and the distobuccal cusp of the upper first molar. (If this tooth is absent the mesiobuccal cusp of the upper second molar).

**Ramus Line (ar-tgo):** tangent to the posterior border of the mandibular ramus and through the articulare. Ramus line to the condyle: tangent to the posterior contour of the mandibular ramus and the condyle.

**Sella-Articulare Line (s-ar):** represents the lateral part of the posterior cranial base.

**Sella-Basion Line (s-ba):** denotes the medial part of the posterior cranial base.

**Axis of upper incisor (IL₁):** line from is through the apex.

**Axis of lower incisor (IL₂):** line from ii through the apex.

**Morphological Analysis**

The analysis diagram developed by professor Björk of the Institute of Orthodontics at the Dental School in Copenhagen is divided into 3 columns numbered II, III and IV representing the dento-basal and the cranial relationships as well as the growth zones. In each section a set of measurements is carried out.

Corresponding to each measurement there is a series of five columns; A, B, C, D and E intended for the registration of a succession of results each time a new series of results is taken.

There is also a column, M, giving the mean value, in whole degrees, for the respective measurements, taken from professor Björk’s investigations.

Finally, the range of standard deviations is recorded.

68% of individuals in a normal population are found in the range ± 1 sd. Results ranging from M- 2 sd up to M+ 2 sd include 95% of the population.
Results of the order $M \pm 3\,sd$ will include 99.7% of all individuals. It is, therefore, very rarely that one meets values greater than $M + 3\,sd$ or smaller than $M - 3\,sd$.

The morphological analysis of the dental arch relationships can also be separated into measurements of the sagittal, vertical and transverse relationships as well as those already mentioned. Measurement of the sagittal and vertical relationships is carried out on the cephalometric radiographs. These results are separated from each other by the thick horizontal lines on the form. Both the sagittal and vertical measurements are divided into dento-alveolar and basal components.

Clinically it is important to establish which factors are responsible for e.g. the clinical symptom that presents as an increased overjet, as both the time of treatment as well as the method of treatment depends on these.

**Sagittal occlusion**

**Column II: Dento-basal relationships**

Increased overjet is a discrepancy in the sagittal plane and is the result of one or more of the following factors.

1) increased alveolar prognathism in the upper jaw
2) alveolar retrognathism in the lower jaw
3) proclination of the upper incisors
4) retroclination of the lower incisors
5) retrusion of the mandibular base compared with the maxillary base

The first four represent the dento-alveolar discrepancies whereas the fifth must be regarded as a basal discrepancy i.e. a discrepancy in the relationship to the two jaw bases, and is described as the sagittal jaw relationship.

The extent of alveolar prognathism is measured by the angle pr-n-ss and in the lower jaw by the angle between the chin line and ML. Both measurements represent the position of the alveolar process in relation to the jaw base. The inclination of the upper incisors is indicated by the angle $IL_g/NL(3)$ and in the lower jaw by the angle $IL_i/ML(4)$. 
The difference between the protrusion of the upper and lower jaws, described as the sagittal jaw relation, is measured by the angle ss-n-pg whilst the angle ss-n-sm denotes the sagittal relationship between the apical bases (apical base relationship).

With regard to the upper jaw the same point as in the sagittal jaw relationship i.e. ss (Down’s A point) is used. The reason is that in practice it is very difficult to differentiate between the jaw base and the apical base, though in the case of growth analysis the anterior nasal spine (sp) is used as a reference point.

In the lower jaw there is a special reference point for the apical base, sm (Down’s B point). Another way of describing the sagittal apical base relationship is by the angle ANB.

The apical base relationship can vary considerably from the skeletal base depending on variations in the inclination of the mandible and of the prominence of the symphysis.

Incisal sliding is noted if it is observed in the clinical examination. Such “posturing” can result in false values of the sagittal jaw relationship and the apical base relationship as the mandibular is translated forward to obtain habitual occlusion (e.g. pseudo class III).

If the measurements of the dento-basal relationship have established that a discrepancy in the sagittal jaw relationship is present, it is of importance to determine whether this is caused by the maxilla being protruded in relation to the cranial base while the mandibular position is normal or whether the maxillary position is close to the mean values while the lower jaw is retruded in relation to the cranial base. Both possibilities will result in an increased overjet.

This problem is elucidated by the measurements in column III.

**Column III: Cranial**

At this point the two skeletal bases are evaluated in relation to the cranial base, or more accurately in relation to the anterior cranial fossa.

In the sagittal plane the position of the maxillary skeletal base in relation to the cranial base is expressed by the angle s-n-ss.

a) If the maxillary skeletal base is anteriorly displaced – an increase in the angle will exist – indicating maxillary prognathism.

b) If the angle is less than the average that is the maxillary skeletal base is more posteriorly placed than normal maxillary retrognathism is indicated.
The position of the mandibular skeletal base is evaluated in a similar way from the angle s-n-pg.

Corresponding to the expression used for the upper jaw the term mandibular prognathism is describing cases with an increased s-n-pg angle. When this angle is less than the average value the term mandibular retrognathism is used.

In cases where both the upper and lower bases are protruded the situation is described as one of total facial prognathism.

Should both upper and lower bases be retruded, the term total facial retrognathism is used.

In cases of total facial prognathism or retrognathism the sagittal jaw relationship can be normal.

As appears from Fig. 19 the sagittal jaw relationship comes out as the difference between maxillary and mandibular prognathism.

Fig. 19

Centres of growth
In cases where discrepancies between the relationships of the skeletal bases are noted these should be considered in relation to the growth centres. The development and growth of the cranial base and growth of the mandibular condyles affect both upper and lower jaw relationships to each other. Consequently, a continuous state of occlusal change can exist throughout the entire period of growth. Even before puberty, at the age of 8-9 the sutural growth of the anterior cranial fossa has ceased. There still exists, however, an appositional growth in the region of the glabella which grows forward at the same time as the forward-downward growth of the facial skeleton occurs.

The most anterior part of the internal cranial base represents at an early age, a relatively stable structure. The growth pattern of the facial skeleton is therefore related to NSL and NSP. (NSP is a line drawn at right-angles to NSL at point N).

In relation to the anterior cranial fossa, the middle and posterior cranial fossae grow in a posterior and inferior direction until adulthood. On average the downward and backward growth rates are of the same magnitude so that the line between SNL and the clivus n-s-ba, also called the cranial base angle, remains unchanged. Individual variations such as a predominant inferior or posterior growth can occur causing a respective increase or decrease in the cranial base angle.

In cases where the n-s-ba angle is less than the mean value M, the cranial base is described as bent which implies that the middle cranial fossa is positioned further forward and lower than average in relation to the anterior cranial fossa. In cases where the angle is greater than the mean the cranial base is flattened and the middle and posterior cranial fossae are positioned further back and higher in relation to the anterior fossa.

Development of the cranial base influences the entire face. In the case of a bent cranial base i.e. with a small angle between the s-n-ba, the maxillary complex, because of its attachment to the cranial base, is placed further forward in relation to the anterior cranial base. Bending of the cranial base influences the position of the mandible through the articular fossa situated on the external cranial base in the middle cranial region. In the case of a bent cranial base the mandible is therefore often positioned further forward in relation to the anterior cranial base resulting in a total facial prognathism (Fig. 19).

Conversely in the case of individuals with a flattened cranial base, that is, where the n-s-ba angle is greater than average the upper face is retruded, in relation to the anterior
cranial fossa, since the middle and posterior cranial fossae are placed further back and higher up. This influences the position of the mandible because the articular fossa is placed further back and thus the mandible itself is also further back.

The facial skeleton in the case of flattened cranial base is characterized by both upper and lower jaws being positioned further back, i.e. total facial retrognathism.

The shape of the cranial base also influences the vertical dimension. In the vertical dimension the term rotation is used. Since in a morphological analysis one is describing a static analysis the term implies an inclination of the upper and lower bases compared with average values.

In growth analysis (see later) where the expression rotation is also used, it is more meaningful since here on is describing actual rotations, i.e. altered inclination of upper and lower bases in the vertical plane related to the cranial base.

Rotations are divided into anterior and posterior.
A) the term anterior rotation is used when the posterior facial height is over developed in comparison to the anterior facial height.

B) The term posterior rotation is used when the anterior facial height is over developed in comparison to the posterior height.

In the case of a diminution of the cranial base angle, the middle and posterior cranial fossae and consequently the articular fossa are placed lower than average and this can result in an over development of the posterior facial height (anterior rotation). Simultaneously with the lowering of the lower jaw the posterior height of the upper face increases (the distance s-pm. This development is shown by the fact that the angles describing vertical dimensions NSL/ML and NSL/NL decrease.

In the case of a flattened cranial base angle (increased cranial base angle) the middle and posterior cranial fossa together with the articular fossa are placed higher than average and the height development in the posterior part of the facial skeleton is limited (posterior rotation). In this case the angle NSL/ML and NSL/NL will be found to be greater than average.

The shape of the cranial base also influences the position of the occipital condyles and thus the axis of balance of the head. E.g. a flattened cranial base with a retrognathic type of face results in the head being lifted so that the facial profile, despite the prognathism can be described as vertical.

The angle n-s-ba, as well as, the angle n-s-ar representing the lateral part of the cranial base and thus the position of the mandibular condyles is recorded. Apart from the shape of the cranial base the grow zone of the lower jaw is measured and recorded in part IV of the form.

From a developmental point of view the lower jaw can be considered as a basal arch stretching from the chin region to the condylar cartilage. Situated on this arch are three points of development: the coronoid process, the alveolar process and the angle of the mandible.

The shape of the mandibular base is evaluated by the $\beta$ angle and the mandibular angle.
In both cases there are two angles to be considered, a $\beta$ angle at condylion and one to the point ar. Correspondingly a mandibular angle to the condyle (cd) and one to the point ar.

The shape of the mandible is determined by both the direction of growth of the condyle and remodelling of the mandibular base. Both factors are extremely variable. If the majority of the growth has a vertical direction (upwards and forwards) the height of the ramus increases. In such a case the mandibular base bends and this is reflected in a $\beta$ angle larger than average and a mandibular angle smaller than average (Fig. 21).

If the condyle growth is chiefly in a horizontal direction (i.e. sagittal upwards and backwards a low ramus height and a straightened mandibular base develops, which is reflected in a reduced $\beta$ angle and an increased mandibular

Like the cranial base the shape of the mandibular base influences facial morphology:

A) A curved mandibular base resulting from a condyle exhibiting a vertically directed path of growth develops a comparatively high ramus height and, therefore, comparative over development of the posterior facial height in relation to anterior. Thus an anterior rotation (Fig. 21) occurs.

B) A straightened mandibular base as a result of a sagittal (horizontal) condyle growth direction will result in a lower ramus height which results in a low posterior facial height compared with the anterior i.e. this type of rotation is stated as posterior rotation.

It is apparent from this short synopsis of growth zones how facial shape is to a great extent decided by the individual combination of cranial and mandibular bases.

**Vertical occlusion**

The term vertical occlusion refers to the relationship of the dental arches in the vertical plane. From the fact that the so called rotations influence both sagittal and vertical relations it is apparent that these two cannot be thought of as entirely separate entities. The vertical relationships can vary from extreme deep bite to open bite both in the incisal region or laterally. Discrepancies occurring in the buccal region are usually of the open bite type.
An anterior open bite can be the result of dento-alveolar factors, such as reduced eruption of either the upper or lower incisors or insufficient height development in the
incisal alveolar processes. The basal factor will be a posterior rotation of the lower jaw. In radiographic analysis discrepancies in the upper jaw are expressed by the angle NL/OL$_S$ and in the lower jaw by the angle OL$_I$/ML. These angles represent the total discrepancy of the dental and alveolar factors (in the dental and alveolar arch) in the upper and the lower jaw, respectively, since in the vertical dimension it is difficult to differentiate between the degree of dental or alveolar discrepancy. The vertical jaw relationship i.e. the position of the upper jaw in relation to the lower jaw is expressed through the angle NL/ML. In the case of a deep bite the development of the dento-alveolar factors is just the opposite, and the basal factor will be an anterior rotation without incisor contact.

Lateral open bite can be a result of tongue thrust or cheek biting, as well as of anterior rotation of the lower jaw where the growth in height of the alveolar process laterally is insufficient.

**Cranial relationships**

Growth and rotation of the upper and lower jaw are described under sagittal relationships. The rotation of the upper face can be expressed by the angle NSL/NL and in the case of the lower jaw through the angle NSL/ML. A discrepancy in the vertical jaw relationship occurs in those cases where the rotation in the two jaws does not correspond.
As appears from Fig. 24 the vertical jaw relation is the difference between maxillary and mandibulry inclination.

Fig. 24

Relations to the growth centres

A large posterior facial height can result from pronounced lowering of the middle cranial fossa or from a large vertically directed condyle growth. The opposite will occur in the case of a flattened cranial base or in the case of sagittally directed condylar growth.

To complete the description of the morphological analysis two conceptions closely connected to the cephalometric analysis, and which aid the comprehension of occlusion development, will be discussed.

1) Dysplastic changes

A change in the dento-alveolar section (see column II in the form), which accentuates a basal discrepancy. As an example one could name the dysplastically increased alveolar prognathism in the upper jaw or labial inclination of the upper incisors in case of finger sucking.
2) Compensatory changes

A change in the dento-alveolar factors which reduces the discrepancies in the occlusion.

By compensatory changes, the position of the teeth and alveolar processes adapt to the variation in the relative positions of the two jaw bases. Cephalometric radiographs can illustrate these changes. Fig. 25, 26 and 27 are examples of compensatory changes in sagittal, vertical and transverse directions.

Compensatory modifications occur to a large extent during the normal development of an occlusion, and growth analysis makes it possible to follow the dento-alveolar changes, which serve to maintain a normal occlusion, despite changes in the relative positions of the jaw bases during growth.

These compensatory changes in the dental and alveolar arches are very dependent on the remodelling effect of the lip and tongue musculature as well as the forces transferred to the teeth during chewing.

To what extent normal compensation occurs depends therefore to a large degree on a normal lip and tongue function as well as good intercuspidation. In the case of malfunction of either lip or tongue musculature or lack of intercuspidation the compensatory growth mechanism can fail partly or completely. The term compensatory mechanism was introduced by Björk who has pointed out that failure of the compensatory dento-alveolar development is more frequently the cause of a malocclusion than dysplastic change, a fact which was corroborated by the findings of Solow (1966).

Fig. 25. Dento-alveolar compensation for discrepancies in the sagittal jaw relationship in individuals with relative mandibular prognathism (D32) and mandibular retrognathism (D81). Notice the difference in the axial inclination of the upper and lower incisors.
Fig. 26. Dento-alveolar compensation for discrepancies in the vertical jaw relationship in individuals with a low anterior facial height (D17) and a high anterior facial height (D70). Notice the difference in the height of the alveolar process.

Fig. 27. Dento-alveolar compensation as a result of a difference in the width of the dental bases. Notice the difference of the angulation of the teeth and alveolar processes.

**Growth analysis**

The term growth analysis implies an analysis of lateral cephalometric radiographs taken of the same individual at different stages of development.

A growth analysis can be performed:

1. After a period of observation to give an impression of an individual growth pattern before treatment
2. After a course of treatment to evaluate tooth movement as well as changes in the dento-alveolar and basal relationship as a result of the treatment

In principle a growth analysis can be performed to evaluate:

1. Changes in the relationship between the jaws and cranial base
2. Changes in the inter-jaw relationship
3. The degree of growth of each jaw
4. Tooth movement
The routine method involves the drawing of three tracings which demonstrate:

1. The growth of the facial skeleton as a whole
2. Tooth movements in the upper jaw
3. Tooth movements in the lower jaw as well as the size and direction of growth of the mandible
4. Finally the mandibular rotation can be measured (Fig. 28)

Fig. 28
In evaluation the growth of the jaws in relation to the cranial base it is important that the reference structures in the cranial base are constant. It is known that both nasion and sella move during growth in relation to the other structures in the anterior cranial base. NSL can thus alter its position and therefore cannot be used as a reference line in growth analysis. Certain structures in the anterior cranial base only alter position very slightly and can therefore be used as reference structures. These structures are:

The contours of the cribriform plate of the ethmoid the detail in the trabecular system in the ethmoid cells (Fig. 29) and often the anterior wall of the sella.

By superimposing the two radiographs in such a way that the reference structures cover each other it is possible to observe structures. In the surgery this method can be used to obtain a quick evaluation of growth.

For a more accurate evaluation of growth a drawing of the two pictures superimposed as mentioned above is used. This gives rise to certain difficulties as it is not possible to draw through two radiographs at one time and the reference structures are so fine that they cannot be drawn accurately enough to give certain orientation of the pictures. An alternative method is used when drawing growth changes.

**Method of drawing growth diagrams**

1. Firstly the cross NSL/NSP (a cellophane sheet with a printed cross can be used) is drawn
2. A second radiograph is laid on the first using the reference structures for orientation
3. The second cross is then positioned on the second radiograph over the first cross (since points n and s will have moved this NSL line will often vary from the real line)
4. The two radiographs (the first using a dotted line and the second a solid line) are then traced
   a. The NSL/NSP cross is drawn on a piece of acetate paper which is then placed on the first radiograph in such a way that the crow corresponds to the first cross and then the lateral cephalogram is carefully traced
   b. Next the tracing paper is transferred to the second picture and is orientated according to the second cross, which often deviates from the line NSL/NSP cross in picture no. 2
   c. Finally, the contours of the second picture are drawn. Despite the complicated method with regard to NSL/NSP the pictures are now orientated according to the stable structures in the anterior cranial base which come to correspond on the growth sketch. The cross used could in fact be placed in any position but it has been shown to be convenient to use the NSL/NSP-intersection.

If it is desired to take measurements (i.e. a morphological analysis) and they are to be compared with the ones obtained from the first picture it is necessary to use the transferred NSL line (NSL ref.) (not the true NSL) since this allows for changes that have taken place in the position of n and s in the vertical plane during the period of observation. From the second picture a perpendicular line is drawn from the true nasion and sella to the NSL line and in this way the picture is orientated in the anterior-posterior direction.

Evaluation of the growth of the jaws
The mandible

It is difficult to evaluate the condylar growth because appositional and resorptive changes of the structures and bone surfaces take place continuously and hardly any parts are able to be used as stable reference points. An accurate evaluation of the growth and remodelling of the individual jaws can therefore only be carried out if metal implants, which are tested to be mutually stable, are used as references in a longitudinal analysis.

With this method it has been possible to establish that certain structures in the mandible can be used with reasonable accuracy as reference points in the study of growth and remodelling of the mandible itself.
The frequently used orientation on the mandibular base, the ML line, is the most inaccurate (page 1.3). Due to the marked remodelling of the inferior border of the mandible only a very rough estimate of the growth direction of the condyle can be obtained with this method. A much better, although somewhat more difficult, method is the application of the following structures which according to the implant studies are stable as reference points.

1. The internal cortical lamellae of the mandibular symphysis
2. The lower limitation of a tooth bud in which root formation has not yet started
3. Part of the canalis mandibularis

![Fig. 30](image)

This method which requires a high degree of accuracy of the x-ray exposure is carried out in the following way:

On acetate foil a line parallel to the inferior edge is drawn. This foil is then mounted on the profile exposure with the mouth. Open in such a way that the line represents the mandibular line (ML). The contours of the mandible are then carefully drawn. Then, the internal contour of the symphysis (1), the bottom of a developing tooth without root formation (2), and the greatest possible length of the canalis mandibularis (3) is added (Fig. 30).

The acetate foil is removed from the profile cephalogram and accurately placed on the second cephalogram with the above mentioned structures superimposed. Finally, the contour of the mandible on the last cephalogram is drawn. In relation to the stable points it is now possible to evaluate

1. The growth direction of the condyle
2. Changes due to remodelling of the corpus mandibulae, as well as
3. Tooth movements caused by treatment which has taken place between the two exposures

Of special interest is the mandibular rotation e.g. the change in the mandibular inclination which takes place. The mandibular rotation is dependent on the growth direction of the condyle and is of the greatest importance to the alternations of the sagittal as well as the vertical relations of the facial skeleton. In the morphological analysis the inclination of the mandible is expressed through the angle NSL/ML. The mandibular line is, as mentioned before, subject to serious changes due to remodelling. Changes in the NSL/ML angle are therefore a very poor expression of the true rotation of the mandible. Applying the reference structure suggested in the growth analysis of the mandible it is, however, possible to compensate for the remodelling changes in the following way.

A transparency with a cross is placed on the first profile cephalogram so that the cross represents NSL and NSP. This cephalogram with the transparency is now superimposed on the stable structures in the cranial base on the second profile cephalogram. Another transparency with a cross is attached to the second cephalogram in such a way that it is superimposed on the first cellophane cross.

**Measurement of mandibular rotation**

Finally, the two profile cephalograms with the attached transparencies are superimposed on the previously described stable structures in the mandible. The angle formed between NLS\textsubscript{1} and NSL ref now expresses the rotation of the mandible which has taken place between the two exposures. If the two NSL lines cross anteriorly to the nasion, the rotation has been anterior, if they cross posteriorly to n the mandible has been rotating posteriorly. The mean (average) rotation during the pubertal growth spurt is 3° anteriorly.
Fig. 31
The maxilla

In the maxilla it is even more difficult to find stable reference structures. For this reason the analysis has often been confined to the evaluation of tooth movements with reference to the hard palate. This method of registration is, however, very unsatisfactory as it has been shown by means of implants in the maxilla as reference points, that the hard palate throughout the postnatal development is subject to remodelling, resorption on the nasal and apposition on the oral side. NL will thus be displaced downward, and as remodelling can be of different proportions anteriorly and posteriorly a rotation of NL seems to take place. It has, however, been shown by Björk (1976) that the anterior contour of the zygomatic process seems to be stable from the age of eight years. This structure can therefore be used as a reference when remodelling of the maxilla or intramaxillary tooth movements are to be studied.