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Review Article

Etiology and Development of Malocclusion Studied with Metallic Implants

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Abstract

With the many new developments in treatment mechanics and techniques it is understandable that orthodontist sometimes forget to pay attention to the role of facial growth and development when planning treatment for their young patients. The etiology of malocclusions is in many cases multifactorial, and a main component is facial growth. Muscle function and the soft tissues also play important roles in the development of the occlusion. Ignoring these factors when planning treatment can sometimes lead to problems later in treatment. In this review we shall investigate how these factors can contribute to the development of malocclusion. Changes seen during treatment can be caused by the soft tissues that unexpectedly have influenced the occlusal development. It is not uncommon to see undesirable changes despite all the good efforts. These problems can often be avoided or minimized with a better understanding of the individual's facial growth pattern and stage of maturation at the completion of treatment. In this review we shall discuss the information on facial growth from studies using metallic implants and how the implant studies have contributed to a better understanding of the etiology and development of malocclusions. Understanding how the soft tissues and the facial muscles play important roles in the development of malocclusion will be reviewed and how these structures can affect the stability of treatment. We shall finally discuss how residual growth after treatment in some cases can result in relapse and when an individualized retention protocol is needed to ensure the long-term stability.

Keywords

Facial growth; Implant studies; Mandibular rotation; Residual growth

Introduction

General facial growth has long been seen as a straightforward affair, as exemplified by the illustrations in the Bolton Atlas [1,2]. Although these illustrations of general facial growth have helped get an idea of the average facial growth, it was not until the technique using metallic radiographic markers showed that this information was not the whole story [3,4]. An example of general facial growth in a subject over seventeen years using the conventional way of superimposing serial head films can be seen in figure 1. In this example the superimpositions have been done on structures in the anterior and median cranial base that have been shown to be stable from an early age [5,6]. In this example the facial growth changes look fairly simple with downward forward growth of both maxilla and mandible, however, in reality the changes are more complex. An important detail in this superimposition is that the maxilla and mandible do not appear to change shape over time. This is deceptive as a more detailed analysis based using implant superimpositions of the maxilla and mandible will be illustrated by the following examples. The implant studies by Björk and others have all demonstrated that there is considerable individual variation in both growth direction and velocity of jaw growth from patient to patient [7]. We also know from these studies that the changes in the jaw position over time are not simple linear translations but include a rotational component [7,8]. This latter change was not discovered until the implant studies showed the complexity of the growth changes. An important detail from the implant studies is that not only do both jaws undergo rotational changes but that these often are masked by surface modeling of up to 90 percent [9-12]. In other words when we look at the subject in figure 1 it seems that the growth changes are limited to just a simple downward forward growth pattern of the mandible and maxilla. When we analyze the individual changes in more detail using the implants as fixed reference markers the picture changes completely.

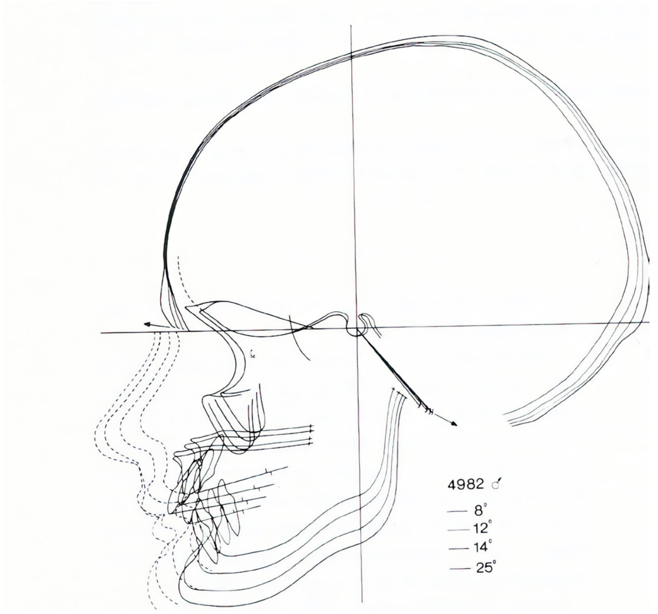

Figure 1: General facial growth in a patient over a period of 17 years. Notice the downward forward growth direction of both the maxilla and mandible. It appears that both the palatal plane and the mandibular plane remained almost unchanged during this period [11].

As explained by Björk A, et al., both maxilla and mandible undergo surface modeling during growth as an adaptation to the soft tissues surrounding the maxilla and mandible. These changes result from muscle and soft tissue adjustments over time or, as Björk A called it, adaptations to the "soft tissue matrix" [11,12]. This adaptation can be seen in the mandibular superimposition on the implants of the subject in figure 1. The mandibles have been isolated and superimposed on the mandibular implants (not shown). In this example, the mandible underwent pronounced reshaping with apposition under the anterior lower border and resorption of the posterior lower border (Figure 2). As shown by Baumrind S, et al., show such changes cannot be observed with conventional so-called "best fit" superimposition but require individual superimposition of the maxilla and mandible on the implants or radiographic markers [13,14].

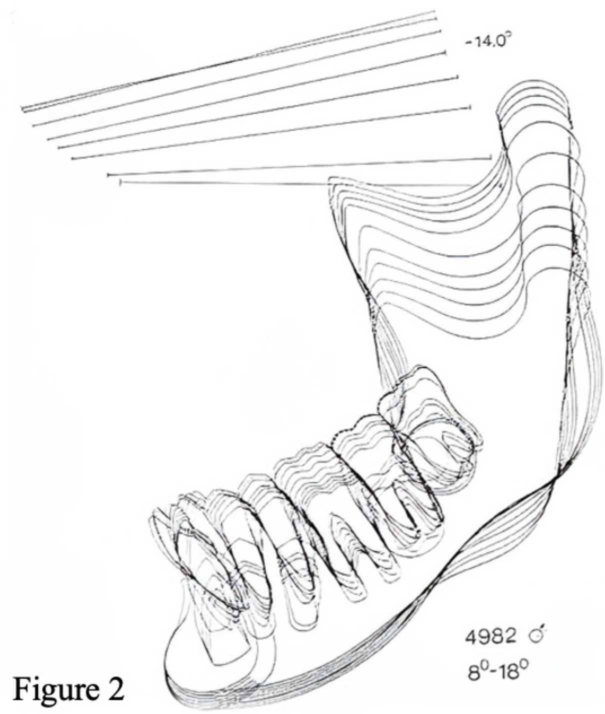

Figure 2

Figure 2: Mandibular superimposition on implants showing ten years of growth. During the ten-year period of growth, the mandible underwent as much as 14 degrees of forward or anterior rotation as demonstrated by the changes in the nasion sella lines. Notice also the position below the anterior lower border and resorption under the posterior border [11].

In most cases the condylar growth direction is upwards and to some degree forwards. In a few subjects, however, this growth direction is more posteriorly directed or backward and associated with posterior growth rotation of the mandible during growth (Figure 3). In those cases, limited surface modeling usually takes place and according to Björk those cases are much less common. We shall address this growth pattern later in this review.

Growth rotations and malocclusion

One may ask what is the clinical importance of rotational growth changes? The answer is that under certain conditions growth rotations can contribute to mild or even severe malocclusion. When the rotation of the mandible is in a forward or anterior direction it often can result in a deep overbite. In the subject seen in figure

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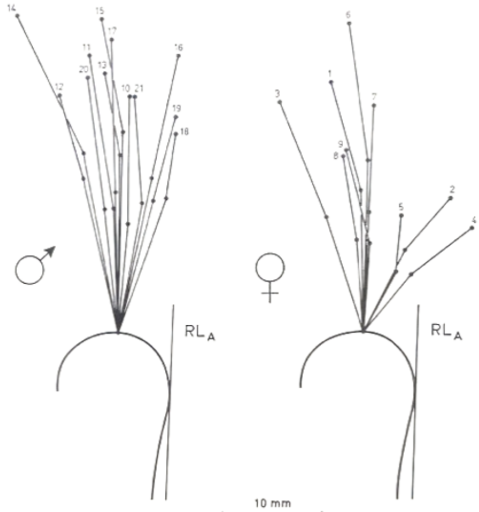

Figure 3: Condylar growth direction over a six-year period in 21 boys and girls. Notice that only two subjects had upward backward growth of the condyles. The mandibles are arranged with respect to the ramus line [10].

4 there was an intense previous finger sucking habit that has created a severe overjet that now is associated with a lip and tongue dysfunction. The position of the lower lip at rest and during function has resulted in a further deterioration of the overjet over time and prevented any normal dentoalveolar compensation. During growth this young man had pronounced forward, or anterior mandibular growth rotation as illustrated by the changes of mandibular implant lines. The implant superimposition shows that his condylar growth direction had been upwards and forwards. The rotations of the mandible combined with the lip dysfunction, that inhibited any dento-alveolar compensation resulted in an increase in the overjet of 3 mm over the 6-year period shown. Another side effect of the rotation was a change in the occlusion with 1.5 mm increase in the distal occlusion.

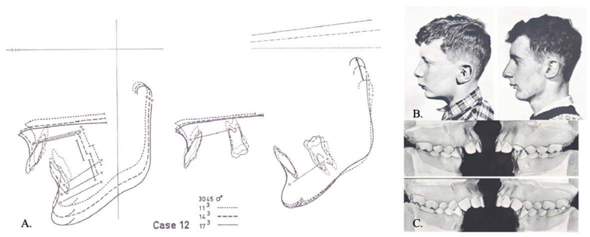

Figure 4: This subject from the implant studies by Björk A, et al., has a Class II, Div. 1 malocclusions with an excessive overjet. A. The general facial B. growth superimposition shows downward forward of the lips. B. Facial photos showing the increase in chin prominence between age 113 and 173 yrs. C. Study casts showing a Class II, Div. 1 malocclusion with a severe overjet [10].

Maxillary growth

While we have focused primarily on mandibular growth and the associated modeling changes there are also surface adaptations that take place of the maxilla. The maxilla's growth in all three dimensions has been studied using metallic implants in both treated and untreated patients [15-18]. One finding from these studies is that the maxilla also rotates similar to the mandible but much less. The implant studies also showed that there is a horizontal rotation of the two halves of the maxilla that takes place during growth [17]. The implant studies have further shown that there is an adaptation to the rotational changes in the form of modeling of the nasal floor that in most cases is greater anteriorly than posteriorly [19,20]. These changes are adjustments to the rotation so that the nasal floor can maintain its inclination in relation to the soft tissues. With conventional best fit superimpositions these changes would not have been revealed as demonstrated by Isaacson RJ, et al [21].

The implant studies

To better understand the significance of the implant studies it is helpful to look at their scientific background and application. The idea of using metallic radiographic markers to study jaw growth, or as Björk called them "metallic implants," originated from earlier studies of guinea pigs where they were used to study facial growth [15]. These animal studies showed that radiographic markers inserted below the surface of the jaw bones remain stable over time and therefore can provide fixed references points for more detailed examinations of growth. This technique was at the time a novel method to avoid the problem with the influence of extensive bony surface modeling that takes place during growth in both the maxilla and the mandible in animals as well as humans [22,23]. Björk's studies using this technique in humans provided new and improved understanding of growth of the jaws previously not possible. During the years of observation where the subject remained untreated, the markers serve as stable radiographic reference points that could enable detailed analysis of facial growth. One may ask why do the metallic markers not move once placed below the bony surface? The answer is that there is no interstitial bone growth in the maxilla or mandible, and all changes during growth occur on the outer surfaces [3].

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It has long been known that maxillary growth is primarily sutural growth and that there also is appositional growth at the tuberosity that further helps bring the maxilla forward. On the other hand, the mandible grows only at the condyles. It was not until the implant studies known that there often is extensive modeling of the bony surfaces as an adaptation to the soft tissues surrounding the bones and the muscles attached to the lower jaw. The main goal of Björk's implant studies was to understand better normal and abnormal facial growth without the changes caused by bony modeling and the influence of treatment. By 1968, the sample of implant cases had increased to include about 200 subjects with and without malocclusion. All participants had annual examinations, and most subjects remained in the Study until their facial growth was completed. The implants used in these studies were placed into the jaw bones under local anesthesia using a pencil-like instrument shown in figures 5A and 5B.

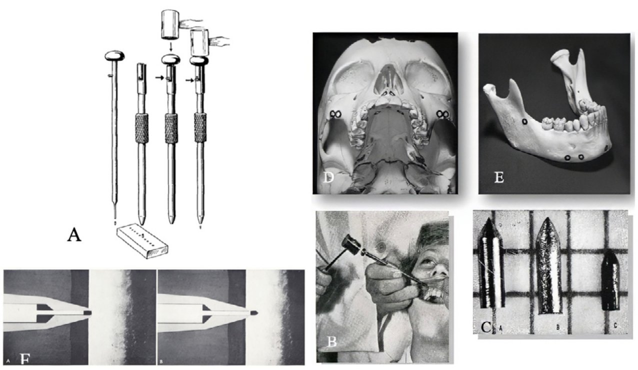


Figure 5: A. Pencil shaped instrument and lead hammer used to place the implants. B. Placement of an implant under local anesthesia. C. Different sizes implants used in the studies. The middle implant is made of Chrome-Cobalt alloy (B), the other two are made of Tantalum (A, C). D. Location of implants in the maxilla E. Implant location in the mandible. F. Method for insertion of the implant underneath the surface of the bone [4].

Initially, the implants were made of chrome-cobalt, which later was substituted by Tantalum, which is a more rigid material, and better tolerated by the tissues (Figure 5C).

Facial growth and Class III malocclusion

To illustrate the application of the implant technique, we are showing the general facial growth changes in a subject with excessive mandibular growth. The subject has a Class III malocclusion and a mandibular overjet (Figure 6A). The overall growth initially appeared to be linear and primarily forward and downward. However, upon closer examination, it is evident that this growth direction changed somewhat over time and later became more vertical. A similar curved path can also be seen in the maxilla, but to a lesser degree.

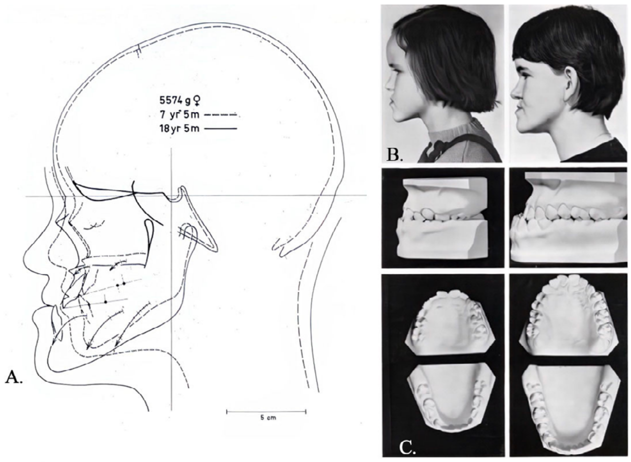


Figure 6: A. General facial growth, facial photos and study casts of a young women with a severe Class III malocclusion and mandibular overjet. Notice the changes in growth direction of maxilla and mandible over time. B. Facial photos of subject with a prominent chin and a concave profile. C. Study casts at age 7 yrs. and 11 yrs. Notice the change in occlusion that became even more Class III during this period [18].

The subject seen in figure 6 has a malocclusion primarily due to excess mandibular growth. The Study shows how the malocclusion worsened over time (Figure 6C). The general superimposition shows a down-forward growth direction of both jaws and that the mandible outgrew the maxilla (Figure 6A). Each annual observation is marked on both the maxillary and mandibular implant lines and illustrates the variations in annual growth rates. To get the complete picture of the actual changes within the maxilla and mandible, each jaw is superimposed on the implants, as seen in figures 6B,6C.

The superimpositions show that in the mandible, the posterior teeth erupted vertically (Figure 7). The posterior teeth also migrated mesially in the maxilla and became more mesially inclined. These differences in the eruption patterns can explain why the molar occlusion deteriorated as the teeth moved in opposite directions. Transversally, the maxillary dental arch increased significantly in arch width. In the mandible, on the other hand, the arch width remained almost unchanged during this period. These compensatory dental arch changes are adaptations to the continuously changing sagittal jaw relationship [24-26].

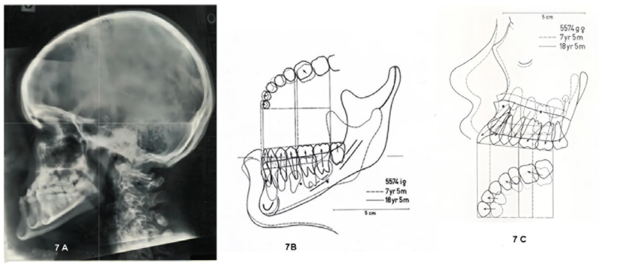


Figure 7: A. General facial growth from age 7 yrs. 5 mos. to 18 yrs. 5 mos. Superimposition on anterior cranial base. B. Mandibular superimposition on the implants. The condylar growth direction was primarily vertical with extensive modeling of the ramus. Notice the vertical direction of eruption of the posterior teeth whereas the incisors erupted slightly posteriorly decreasing the lower dental arch length. C. Maxillary superimposition on the implants. Notice the appositional growth at the tuberosity and the resorptive modeling of the nasal floor [4].

Growth rotation and occlusal development

As previously mentioned, one of the most important observations from the implant studies was that rotational changes of the mandible occur during growth in most subjects. Typically, some degree of forward rotation is regular and continuous during the whole growth period. As a result of this rotation, vertical malocclusion can frequently develop, and it is therefore important to have a good anterior occlusion. The lower incisors need a solid contact point with the upper incisors to allow the jaw to rotate around this point (Figure 8A). However, in cases with poor anterior occlusion, as illustrated in figure 8 B, the overbite will gradually get worse over time.

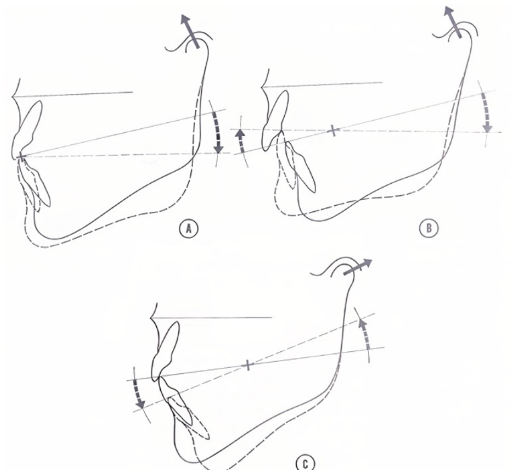


Figure 8

Figure 8: A. Anterior growth rotation in a case with a solid fulcrum point at the incisors. B. Poor anterior tooth contact. The overbite deepens over time. C. Posterior rotation with a fulcrum in the posterior occlusion. Notice the condylar growth direction is upwards and backwards [9].

Class II, Division 2 malocclusion

One of the more common malocclusions treated in the orthodontic office is the Class II malocclusion. Epidemiological studies have shown that worldwide on average this malocclusion is present in about 20% of individuals. The young man seen in figure 9 is an example of an untreated Class II, Div. 2 malocclusion with a deep overbite. We shall now take a closer look at his facial growth pattern to better understand how this malocclusion developed and how the soft tissues played an important role in its development.

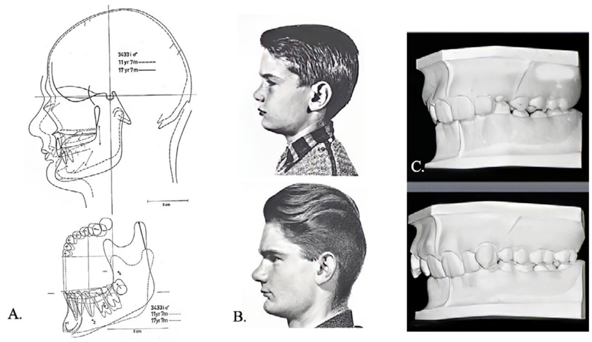


Figure 9: Class II, Div. 2 malocclusion in a subject with metallic implants. A. The general superimposition shows a downward forward growth pattern of the mandible. Mandibular growth rotation was in anterior direction as reflected by the changes in the implant line. B. The facial profile is concave with a prominent chin that over time became more prominent. C. Study casts showing severe deep overbite and crowding of the upper anterior teeth and a Class II malocclusion [10].

At age 11 he had already developed a deep overbite, with the lower incisors impinging upon the palatal mucosa. From the implant studies, we have seen that this malocclusion results from the rotational growth of both maxilla and mandible. An additional and often-overlooked factor that contributes to the misalignment of the upper anterior teeth is the lower lip's strength and position. It has been shown by Thüer U, et al., that the lower lip plays an important role in the eruption pattern of the maxillary incisors (Figure 8) [27]. Their Study showed that the strength of the lower lip influences the path of eruption of the front teeth. The lower lip position relative to the upper incisors is another factor that affects anterior occlusion. Table 1 shows the lip resting pressure of the upper and lower lips in subjects with Class I, Class II, Div. 1, and Div. 2 malocclusions.

Table I. Lip strength, pressure and malocclusion.

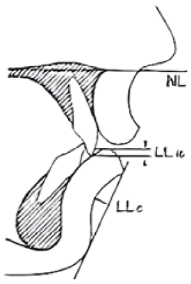
	n	Upper lip resting pressure (g/cm^2)	Lower lip resting pressure (g/cm^2)
Class I	30	1.4	8
Class II, div.1	34	3.6	11
Class II, div.2	12	-1.4	14

Class I vs Class II, div.1 (upper lip): p=0.06; Class II, div.1 vs Class II, div.2 (upper lip): *

* = $0.01 < P < 0.05$ Median lip pressure in Angle Class I and Class II occlusion

Notice the significantly greater lip strength of the lower lip in Class II, Div. 2 compared to Class I occlusion. Another factor to consider is the position of the lower lip and "stomion" relative to the maxillary incisors (Table 2). Here, Thüer U, et al., found that the lower lip typically is located significantly higher up on the maxillary incisors in patients with Class II, Div. 2 malocclusion than in cases with Class I and II, Div. 1 malocclusion.

Table II: Lower lip coverage and Malocclusion



Class I	2.0 mm
Class II, Div. 1	1.5 mm
Class II, Div. 2	5.0 mm

(From Thüer and Ingervall 1986)

This lower lip position will hold back the expected forward movement of the upper incisors and result in retroclination of these teeth. Proffitt WR has discussed the role of soft tissue equilibrium. He concluded that the significant primary factors in the dental equilibrium that determine the position of the teeth are the resting pressures of the tongue and lips and forces created within the periodontal membrane. This in Proffitt's opinion is analogous to the forces of eruption [28]. Thüer U, et al., reached a similar conclusion and suggested that the pressure from the lips on the teeth determines the incisor position [27].

Facial growth and soft tissue profile

The facial growth pattern not only affects the occlusion but also the facial profile. In the subject seen in Figure 9 it is evident that his profile is more concave at age 17 yrs. than at age 11 yrs. This is the result of forward growth rotation of the mandible combined with the influence of the soft tissues that held the dentition back and increased the dentoalveolar retrusion in the mandible. Although this example may seem to be a more extreme case of Class II, Div. 2 malocclusion it has been estimated that about 75% of our patients have this type of growth pattern albeit often to a lesser degree according to Sacocomanno S, et al., and Alhamamadi MS, et al. [29,30].

The role of soft tissues and malocclusion

In patients with the Class II, Div. 1 there is often an increased overjet and a deep overbite. This malocclusion, that studies have shown occurs with a frequency of about 20% in the population, is frequently associated with lower lip dysfunction. During swallowing and at rest the lower lip typically is placed between the upper and lower incisors as seen in the patient in figure 10. As a result, this lip dysfunction can contribute to a further increase in the overjet over time and should be corrected early [31]. Another factor to consider is that lack of anterior tooth contact often results in overeruption of the lower incisors and a deep overbite. This besides the increased risk of damage to the upper front teeth is another good reason for initiating treatment in the mixed dentition.

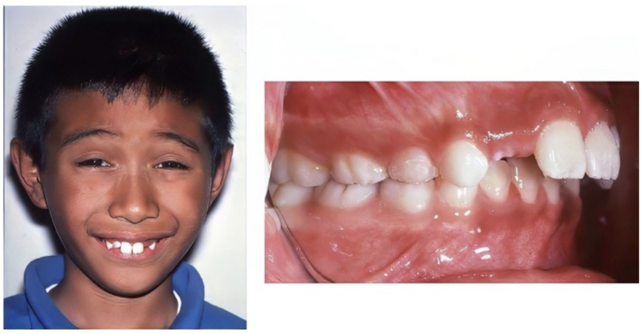


Figure 10: 8-Year-old patient in early mixed dentition with a Class II. Div. 2 malocclusion. He has an excessive overjet of about 7 mm and a deep impinging overbite. Notice the lower lip position seen on the facial photo [31].

Facial growth and the long-face patient

The skeletal open bite presents a great challenge for the orthodontist. Here the implant studies once again have provided the orthodontic profession with critical information that can help us better understand the development. The facial development and growth pattern of a subject with a skeletal openbite is seen in figure 11.

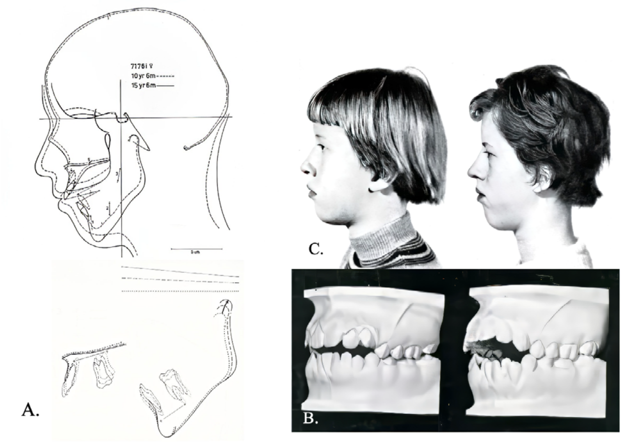


Figure 11: A. Facial growth in a patient with a skeletal open bite. B. The study casts show Class I occlusion with an anterior open bite and significant crowding of the anterior teeth. Notice how the open bite increased over the six-year period shown here. C. The patient's anterior face height and convexity increased significantly during this period. The mandibular superimposition shows that the posterior teeth erupted vertically with no mesial migration [4].

The analysis shows a very different facial growth pattern from the one seen in subjects with short-face development. In those subjects the mandible grows primarily forward and downward and the growth direction at the condyle is vertical. In this example there is in addition to the vertical growth pattern also some degree of posterior rotation of the mandible. In response to the rotation there are also pronounced changes in the anterior occlusion where the open bite severely increased. The lower incisor crowding also increased notably over the 6-year period shown. A more detailed analysis of the occlusion shows that the lower incisors erupted posteriorly which resulted in the increase in crowding (Figure 11B).

The steep mandibular plane angle and long anterior face height at age 10 yrs. are signs that this subject had a potential for vertical growth. If we further look at the "structural criteria" as suggested by Björk they also indicate a strong potential for posterior rotation [32]. These signs include a vertical symphysis, an anterior lower border that is straight and no signs of any apposition under the symphysis. We have previously described these structural signs in great detail. In cases with facial features similar to this subject there is very limited vertical condylar growth, and the treatment mechanics must therefore be very carefully chosen. Any mechanics that can result in extrusion of the posterior teeth would be contraindicated and could lead to further opening of the bite. An additional factor is that the masticatory muscles often are significantly weaker than in the average patient and the patient is therefore less able to resist any extrusion of the posterior teeth.

Facial morphology and masticatory muscles

There are some characteristic differences in muscle development between the two facial types we have discussed that are inherent with the facial type. It has been demonstrated in several studies of masticatory muscle strength and activity that this varies depending on the patient's facial type. Electromyographic studies by Møller showed a strong correlation of masticatory muscle strength during mastication with the facial morphology [33]. Similar findings have been reported by Proffitt, Ingervall and Helkimo [34-36]. Typically subjects with a short anterior face height have greater muscle strength than subject with a long anterior face height where the muscles are weak [36]. This makes patients with an increased anterior face height and a vertical growth pattern hard to treat orthodontically as they have difficulty resisting extrusive movements of the teeth as previously mentioned. Attempts have been made to increase the bite force in children with the so-called long-face syndrome by masticatory muscle training. Despite an initial increase in bite force in these subjects the studies show that long-term the bite force gradually returned to previous values [37].

Prediction of mandibular growth rotation

Can this type of growth pattern with rotation of the mandible in an anterior or counterclockwise direction be predicted? The implant cases from Björk's studies show that certain structural signs can suggest which type of mandibular rotational pattern is likely to occur during growth. These indicators of rotational tendency originally proposed by Björk in 1932 have since been modified and now include the criteria listed in figure 12 [38].

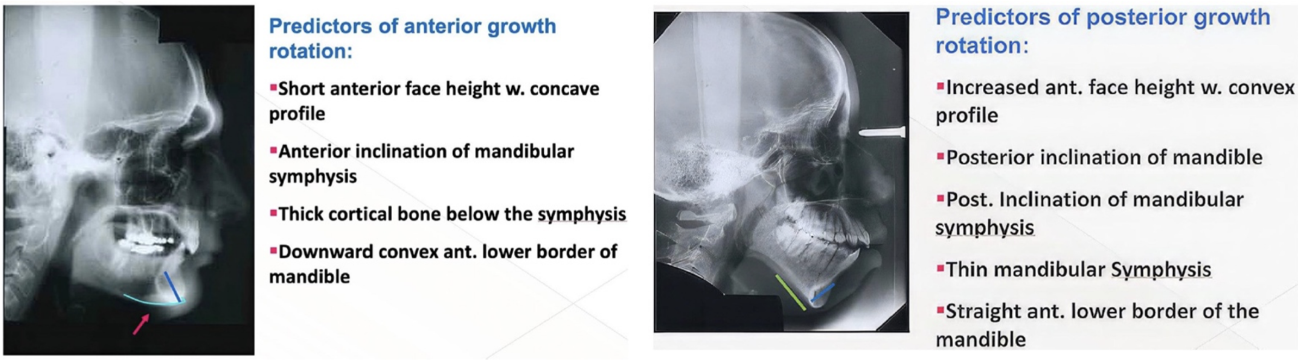


Figure 12: Predictors of mandibular growth rotation. The structural signs indicate either forward or backward rotation of the mandible during growth.

It is important to understand that these signs mainly apply to the more pronounced cases of facial growth, where they can indicate which way the patient's lower jaw most likely will rotate during treatment. However, in a patient with a more average growth pattern, these signs can give the clinician a suggestion of what to expect.

Facial growth post treatment

Growth of the mandible during and after the retention period is an often-ignored concern. Late mandibular growth can in some cases be the cause of crowding of the lower incisors. This is frequently not taken into consideration when planning retention for a patient. Relapse of the lower incisors after treatment has sometimes been attributed to the eruption of the third mandibular molars pushing the lower posterior dentition forward. Several studies have found no association between crowding and third molar eruption [39,40]. To reduce the risk of late crowding of the incisors, retention especially of the lower anterior teeth, should not be discontinued too soon. Far too often orthodontist include only two years of retention in the treatment contract only to see the patient return a few years later complaining of crowding of the lower front teeth. Understanding in what cases there may be an increased risk of late crowding and the association with the mandibular growth pattern is important and should not be ignored. Patients with a malocclusion that is associated with more pronounced forward or posterior mandibular rotation are particularly at risk for later changes in the anterior alignment of the teeth and should be retained until all growth has seized.

Summary

The intention with this review is to bring greater attention to the important role of facial growth and development in orthodontic treatment. Most malocclusions treated in the orthodontic office are of multifactorial origin and the main cause of the malocclusion is facial growth. It is therefore important to understand how growth affects the occlusal development. Previous longitudinal studies that used simple superimpositions on the lower border of the mandible and the anterior nasal spine along the palate have in most case given incorrect information. Not until the development of the implant technique did the orthodontic profession gets reliable and reproducible information about facial growth and development. The Björk studies are unique in that not only do they provide accurate information about the facial and dental changes over time, but they are also done on subjects that did not receive treatment while they were in the study. The better understanding of the dynamics of facial growth and in particular the rotational changes of jaws added a new appreciation of how malocclusions not only develop but also how they can deteriorate over time. As we have pointed out these growth changes can over time result in mild to even severe malocclusions. An often-overlooked aspect of these growth changes is that they continue after treatment in most cases and can have a long-term effect on the stability of orthodontic treatment. The role of the masticatory muscles and their influence on the bite force in different facial types has also been discussed. Understanding the importance of a patient's facial growth pattern and its relationship to malocclusion is important for every clinician to provide the best possible treatment for their patients.

References

1. Broadbent BH, Golden WH (1975) Bolton standards of dentofacial developmental growth. St. Louis, MO: Mosby.
2. Broadbent BH (1931) A new X-ray technique and its application to orthodontia. Angle Orthod 1: 45-66.
3. Björk A (1955) Facial growth in man studies with the aid of metallic implants. Acta Odontol Scand 13: 9-34.
4. Björk A (1968) The use of metallic implants in the study of facial growth in children: method and application. Am J Phys Anthropol 29: 243-254.
5. Melsen B (1974) The cranial base: the postnatal development of the cranial base studied histologically on human autopsy material. Acta Odontol Scand.
6. Nielsen IL (2018) Cephalometric analysis of growth and treatment with the structural Technique: A review of its background and clinical application. Taiwanese J Orthod 30): 68-81.
7. Björk A (1963) Variations in the growth pattern of the human mandible: Longitudinal radiographic study bythe implant method. J Dent Res 42: 400-411.
8. Ødegaard J (1970) Growth of the mandible studied with the aid of metal implant. Am J Orthod 57: 145-157.
9. Björk A (1969) Prediction of mandibular growth rotation. Am J Ortho 55: 585-599.
10. Björk A, Skieller V (1972) Facial development and tooth eruption. An implant study at the age of puberty. Am J Orthod 62: 339-383.
11. Björk A, Skieller V (1983) Normal and abnormal growth of the mandible. A synthesis of longitudinal cephalometric implant studies over a period of 25 years. Eur J Orthod 5: 1-46.
12. Björk A (1991) Facial growth rotation-reflections on definition and cause. Proc Finn Dent Soc 87: 51-58.
13. Baumrind S, Ben-Bassat Y, Korn EL, Bravo LA, Curry S (1992) Mandibular remodeling measured on cephalograms. 1. Osseous changes relative to superimposition on metallic implants Am J Orthod Dentofacial Orthop 102: 134-142.
14. Baumrind S, Ben-Bassat Y, Korn EL, Bravo LA, Curry S (1992) Mandibular remodeling measured on cephalograms: 2. A comparison of information from implant and anatomic best-fit superimpositions. Am J Orthod Dentofacial Orthop 102: 227-238.
15. Björk A (1955) Facial growth in man studied with the aid of metallic implants. Acta Odontol Scand 13: 9-34.
16. Nielsen IL, Bravo LA, Miller AJ (1989) Normal maxillary and mandibular growth and dentoalveolar development in Macaca mulatta A longitudinal cephalometric study from 2 to 5 year of age. Am J Orthod Dentofacial Orthop 196: 405-415.
17. Bravo LA, Nielsen IL, Miller AJ (1989) Changes in facial morphology in Macaca mulatta: A cephalometric study from 1.5-5 years of age. Am J Orthod Dentofacial Orthop 96: 26-35.
18. Björk A (1966) Sutural growth of the upper face studied by the implant method. Acta Odontol Scand 24: 109-127.
19. Björk A, Skieller V (1977) Growth of the maxilla in three dimensions as revealed radiographically by the implant method. Br J Orthod 4: 53-64.
20. Björk A, Skieller V (1974) Growth in width of the maxilla studied by the implant method. Scand J Plast Reconstr Surg 8: 26-33.
21. Iseri H, Solow B (1995) Average surface remodeling of the maxillary base and the orbital floor in female subjects from 8 to 25 years. An implant study. Am J Orthop Dentofacial Orthop 107: 48-57.
22. Baumrind S, Korn EL, Ben-Bassat Y, West EE (1987) Quantitation of maxillary remodeling. 2. Masking of remodeling effects when an "anatomical" method of superimposition is used in the absence of metallic implants. Am J Orthod Dentofacial Orthop 91: 463-474.
23. Nielsen IL (1989) Maxillary superimposition: a comparison of three methods for cephalometric evaluation of growth and treatment change. Am J Orthod Dentofacial Orthop 95: 422-431.
24. Isaacson RJ, Worms FW, Speidel TM (1976) Measurements of tooth movement. AM J Orthod 70: 290-303.
25. Nielsen IL (2022) Factors affecting mandibular growth and displacement and their effect on treatment outcome. Taiwanese J Orthod 34: 127-137.

26. Marotta A, Buschang PH, Melo AC (2004) Transverse skeletal adaptations with Bionator therapy: A pilot study. Am J Orthod Dentofacial Orthop 126: 666-671.

27. Vargervik K (1979) Morphologic evidence of muscle influence on dental arch width. Am J Orthod 76: 21-28.

28. Thüer U, Ingervall B (1986) Pressure from the lips on the teeth and malocclusion. Am J Orthod Dentofacial Orthop 90: 234-242.

29. Proffitt WR (1978) Equilibrium theory revisited: Factors influencing position of the teeth. Angle Orthod 48:175-186.

30. Saccomanno S, Deli R, Cintio GD, Corso ED, Paludetti G, et al. (2018) Retrospective epidemiological study of mandibular rotational types in patients withorthodontic malocclusion. Acta Otorhinolaryng Ital 38: 160-165.

31. Alhamamadi MS, Halboub E, Fayed MS, Labib A, El-Saaidi C (2018) Global distribution of malocclusion traits: A systematic review. Dent Press J Orthod 23: 40.e1-40.e10.

32. Nielsen IL (2024) Timing of orthodontic treatment (Part I). Taiwanese J Orthod 36: 57-68.

33. Møller E (1966) The chewing apparatus. An electromyographic study of the action of the muscles of mastication and its correlation to facial morphology. Acta Physiologica Scand Suppl 280: 1-229.

34. Proffitt WR, Fields HW, Nixon WL (1983) Occlusal forces in normal and long-face adults. J Dent Res 62: 566-570.

35. Ingervall B, Helkimo E (1978) Masticatory muscle force and facial morphology in man. Arch Oral Biol 23: 203-206.

36. Chiu YT, Ko WC (2009) A review of the relationship between facial morphology in vertical dimension and the masticatory musculature. Taiwanese J Orthod 21: 19-25.

37. Ingervall B, Bitsanis E (1987) A pilot study of the effect of masticatory muscle training on facial growth in long-face children. Eur J Orthod 9: 15-23.

38. Nielsen IL (2023) Facial growth: Does it play a role in long-term stability of orthodontic treatment? Taiwanese J Orthod 35: 107-119.

39. Richardson ME (1989) The role of the third molar in the cause of late crowding: A review. Am J Orthod Dentofacial Orthop 95: 79-83.

40. Lyros I, Vasoglou G, Lykogeorgos T, Tsolakis IA, Maroulakos MP, et al. (2023) The effect of third molars on the mandibular anterior crowding relapse-A systematic review. Dent. J (Basel) 11: 131.