Handbook of Cephalometric Superimposition

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Dedication

This book is dedicated to the memory of Professor Arne Björk, 1911–1996, in recognition of his great contributions to the understanding of postnatal human dentofacial growth.

Arne Björk was born in 1911 in Dalarne, Sweden. After his dental training in Stockholm, he practiced dentistry in Västerås from 1937 to 1951. During these years he studied anthropology and genetics with Prof Gunnar Dahlberg at the Swedish Institute for Human Genetics and Race Biology in Uppsala, Sweden. His famous dissertation, published in 1947, *The Face in Profile. An Anthropological X-ray Investigation on Swedish Children and Conscripts*, is an outstanding contribution. That monograph became the classic example for numerous scholars to follow so that, 25 years later, a second printing was necessary.

Prof Björk was the chairman of orthodontics in Malmö, Sweden, from 1949 to 1950. From 1951 until his retirement in 1981, he was a professor of orthodontics at the Royal Dental College in Copenhagen, Denmark. In 1949 to 1950, he was a research fellow and guest lecturer at Northwestern University in Chicago, Illinois. In 1958 he was a research fellow at the National Institutes of Health at Bethesda, Maryland.

His influential and historic longitudinal research studies of human postnatal facial growth, performed with the aid of metallic implants, are unique and brought him even greater international fame and acknowledgment. These studies provided new and as-yet-unsurpassed insights into the individual variation of postnatal facial growth patterns and made possible the development of the structural method of superimposition.

In 1973, Prof Björk received the Albert H. Ketcham Award of the American Board of Orthodontics. He delivered the Sheldon Friel Memorial Lecture to the European Orthodontic Society in 1980 and was nominated as an honorary member of the World Federation of Orthodontists in 1995. Prof Björk died in 1996 at the age of 85 years.

Foreword

In orthodontics, many of our controversies seem to be nearly immortal. For decades we have engaged in desultory arguments about extraction, about the effects of treatment on growth, about the "constancy" of facial form, even about whether or not maxillary molars can be moved distally. Sound and fury signifying nothing: After all, when everything works well enough to pay the bills, proof of efficacy is almost beside the point. Indeed, as long as our questions remain unanswered, we seem to be free to treat any way we want.

Times, however, are changing. We are said to have entered an era of "evidence-based treatment"—the application of the best available data to the care of individual patients. But how are we to know what is best? It seems to me that a continued reliance on carefully filtered "clinical experience," perceived popularity, and commercially funded "continuing education" are part of the problem, rather than the solution. We need more and better.

There are many sources of evidence; however, it is clear that some answers are to be found no farther away than our records room. For example, a few hours of tracing and superimposition would have demonstrated that, contrary to Brodie's assertion, distal molar movement is routine in some treatments (nonextraction) and rarely seen in others (premolar extraction). Indeed, many of our most important questions have been answerable for more than half of a century. The only preconditions are a desire to learn the truth and the skill to mine cephalograms for meaningful data. Unfortunately, like a chimney sweep's top hat, the cephalogram has become more a symbol of our calling than an actual day-to-day clinical tool. Clearly, we need to reassess the contemporary role of cephalometric imaging.

First, we need to examine the utility of our venerable descriptive analyses, many of whose measurements actually are numerical answers to questions first posed more than 50 years ago. These numbers had meaning to Downs or Steiner or Wylie; they may or may not have meaning to today's clinicians. Similarly, we can disagree with the goals depicted in the various visual treatment objectives. Should the mandibular incisors be placed at 90 degrees to the mandibular plane or should a contemporary face be "fuller"? In other words, for the average patient about to be treated by the average clinician, do cephalometric data make a difference? Time will tell; however, when it comes to arguments about the gross effects of a given treatment, there is neither a substitute for, nor an argument about, the value of cephalometric superimposition. This *Handbook*, therefore, is an important contribution whose timing is of great significance to the specialty.

On the one hand, this elegant book is almost too late; on the other, it is just in time. It is a definitive treatise on two-dimensional superimposition published just as the specialty seems to be in the process of abandoning conventional cephalograms in favor of three-dimensional cone-beam reconstructions. Although these visually captivating images may seem merely to be answers in search of questions, the specialty no doubt will eventually make a serious attempt to apply them to clinical practice. In terms of description and treatment planning, it remains to be seen whether a third dimension will improve the routine clinical utility of cephalometric imaging. However, when we turn our attention to an assessment of change resulting from growth and treatment, the scholarly concepts detailed in this book will come to the fore. They are ideas whose time has come.

Like it or not, we probably never will have much beyond Björk's two-dimensional implant data to guide us in three-dimensional superimposition. Cone-beam surface images look good; unfortunately, most of Björk's stable landmarks are internal, and some (eg, the mandibular canals) are stable only when viewed from a specific perspective. Accordingly, three-dimensional superimposition will be a problem solvable only by programmers who, in the process, must be guided by our knowledge of craniofacial growth. To that end, this book provides a critical synthesis of the literature, a definitive outline of the principles of superimposition, and precise, detailed procedures for assessing bony transformation and translation, as well as tooth movement relative to basal bone. For the foreseeable future of cephalometric superimposition, this book is the gold standard.

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Foreword

An important part of orthodontic diagnosis deals with the radiologic evaluation of anatomical variation. Moreover, the study of longitudinal changes induced by growth, as well as by orthodontic treatment, offers important and interesting information for all those who are involved in orthodontics. Three-dimensional tomography is a hot topic today. The new imaging techniques certainly will offer new insights in the changes induced by normal growth, abnormal growth, or treatment. It will provide better data of transversal growth of the entire skull and especially of the cranial base. The present emphasis on minimizing radiation exposure, however, does not sustain the use of three-dimensional tomography on a routine basis in a conventional orthodontic practice. The high amount of radiation surely precludes its use for routine orthodontic treatment planning and evaluation of treatment results. Moreover, it is unknown whether the new techniques will offer new evidence that will differ markedly from our existing knowledge of craniofacial growth and differ from Björk's legacy.

The authors of this textbook propose to describe, illustrate, and evaluate Björk's structural superimposition method. They intend to reach orthodontic specialists who wish to refresh and/or update their understanding and specialists in training who need a thorough and sound scientific introduction to this subject. The state of the art of the structural superimposition method, introduced by Björk, is the main theme of this beautifully edited book. It remains most interesting to learn how in historic times, different scientists have tried to explain growth changes. Many ideas of craniofacial growth in the past are bypassed by Björk's implant studies. It remains amazing that for more than 200 years, the complexities of skull growth have fascinated many scientists. The authors of this textbook succeed very well in their attempt to follow Auguste Comte's statement: *"On ne connaît pas complètement une science tant qu'on n'en sait pas l'histoire."* ("One does not know a science completely without knowing its history"), as they themselves state.

The structural superimposition method, described by Björk, remains the most solid scientific way to evaluate facial growth. The authors are right when they conclude that it is still the best approach available, because it is evidence based, while all other methods lack any evidence base. Cephalometric analyses evaluate changes induced by growth and orthodontic therapy mainly by means of linear and angular measurements. It is well known that the definition of cephalometric landmarks as well as their identification is responsible for the greatest amount of error. A large number of traditional cephalometric points are periosteal landmarks, which are often unstable. External factors such as growth and function may cause changes in their position. Changes of cephalometric variables therefore may be statistically significant while lacking biologic significance. Moreover, different contributing factors (according to Enlow) for the observed changes remain imperceptible. The structural superimposition procedure is based on a different point of view: It attempts to visualize globally craniofacial changes over time. The critical point remains the biologic validity of the structures and their accurate registration if we are attempting to come to a correct interpretation of the observed changes after superimposition. Every methodology is susceptible to error, and the authors offer an excellent critical examination of the procedures dealing with the structural superimposition technique.

This book excels in its beautiful illustrations and layout and the critical evaluation of all composing aspects of the described methodology.

Recently, in several countries and areas, board examinations have been established in an attempt to improve the quality of orthodontic treatment. An important issue to achieve that goal is correct observation and interpretation. Observation and interpretation, moreover, are two different things. Observation requires mainly a curious and critical mind interested in phenomena that are not entirely established or recognized. It is the absolute essential first step to open up new vistas. Observation brings about new insights and questions requiring an answer. Reflection and interpretation are the next steps in attempts to understand and evaluate the established observation. This book succeeds by stressing the interaction between observation and interpretation in a critical way.

As a teacher, I experienced that, in the past, not enough emphasis was put on reliability in making tracings of cephalograms. Making reliable superimpositions, however, is even more demanding if we are attempting to really understand the issue of observed cephalometric change.

Handbook of Cephalometric Superimposition helps the reader to understand and improve the skills necessary to superimpose accurately. This book is a unique document, above all because of its critical and scientific approach, as well as the extensive amount of information gathered from the literature. This book belongs in the library of every university department as well as in the offices of postgraduate students and orthodontists: a book that I think the orthodontic world has been awaiting for quite some time.

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Preface

The purpose of this book is threefold: *(1)* to provide a critical in-depth review of the history of and evidence for cephalometric superimposition and the background and development of the structural method; *(2)* to provide a manual of how to apply the structural method; and *(3)* to provide help and instruction for correct interpretation of the resulting superimposition. The term *structural* in this book refers to superimposition on specific bony anatomical structures inside the radiographic image of a bony unit and/or on specific locations of the periosteal or endosteal surface outlines as determined by the implant method and/or confirmed by histologic data. Anatomical, best-fit, and cephalometric landmarks, lines, and planes are not used for reference or orientation.

To fulfill these goals, the book is divided into eight chapters, each of which stands on its own and contains specific information related to one of the three goals of this book. It is not essential, therefore, to read the chapters in any sequence. Thus, the book can be used in different ways and for different purposes.

Superimposition of cephalometric images is the universally used method for demonstrating and evaluating growth and/or treatment outcomes in the dentofacial complex in individual patients. A reference is needed in order for a superimposition to be able to record change relative to that reference. Such references must be consistently visible in the cephalograms of the individual, and they must be stable within the time frame of the observation period.

References may consist of *(1)* at a minimum, two selected landmarks or lines (where one serves as a registering landmark); *(2)* a contour, either skeletal or soft tissue; or *(3)* one or more skeletal structures. Furthermore, references must fulfill two conditions: validity and reliability. Validity, meaning that the superimposition procedure comes as close as possible to representing actual biologic events, is the dominant prerequisite. Validity requires that the reference truly represent an anatomical entity and that its use as a reference be based on evidence obtained through scientific research. Reliability relates to precision and reproducibility.

Superimposition methods have a long history, and many different references have been introduced. All these methods except one—the structural method—are based on circumstantial reasoning. Circumstantial reasoning means that the proponents of the method reasoned that the selected reference was stable and/or representative for the anatomical entity without providing evidence to support their assumptions.

A common method for evaluating changes from pretreatment to posttreatment is comparison of a set of angular and linear measurements. These procedures are widely used in clinical reports to evaluate treatment effects and applied in commercially available digital cephalometric programs. All these procedures are based on the use of periosteally located landmarks or dependent substitutes. They provide very limited information on change of size and shape. Almost all periosteal landmarks are unstable over time, however, because of growth and/or treatment. This makes interpretation of changes between pretreatment and posttreatment unreliable, regardless of the physical measurement error.[1]

The nature of the assumptions of stability varies and is based on overall or average interpretations of craniofacial growth studies. By its very nature, the selection of such references is subjective and provides further opportunity for opinion, argument, and controversy. Remarkably, the current acceptance of these widespread but unfounded methods is often claimed on the basis of convention and/or tradition, thereby neglecting the need for a scientific evidence base.

The structural method of superimposition, developed and introduced by Arne Björk, is based largely on his unique longitudinal implant studies.[2–9] The method has the best scientific basis because of the nature of the references used. It has the best-researched validity and reliability and is the only evidence-based method. Application of the structural method provides individualized, far-reaching insight into growth and treatment changes. Reliable measurement of local, actual changes in direction and amount is possible. This allows interpretation of the actual biologic events that took place.

The structural method has not become generally popular for clinical orthodontic purposes, presumably because of *(1)* inherent technical difficulties in its execution that led to erroneous interpretations, *(2)* the time needed to follow the original procedure correctly, and *(3)* the need for insight into and knowledge of growth and development. However, in recent years, two important and generally accessible improvements in the technique have been made. The first is the availability of modern equipment to ensure routine production of high-quality cephalometric radiographs in most orthodontic offices. This is an essential prerequisite for application of the method. The second is the availability of sophisticated conservative and digital techniques to improve reliability and enhance procedures. These improvements make structural superimposition the method of choice.

When preparing this book, to focus our review on superimposition methods, we returned to all the relevant original historic work as far as possible. The goal of that effort was to identify original ideas and to trace the originators of using superimposition to demonstrate growth of the face and to review how the procedures gradually developed with time.

Chapters 1 to 3 integrate data from radiographic, anatomical, and histologic investigations to provide a critical evaluation of superimposition procedures. Modern concepts of craniofacial growth are essential for understanding superimpositions.

Chapters 4 and 5 are focused on correct interpretation of radiographic images and tracing technique. Chapter 6 demonstrates, with clinical examples, the importance of a clear and systematic description of the result of application of the method. Clear descriptions enhance communication with patients and colleagues. Anyone who views a superimposition must be able to understand exactly what is being presented. Tangible benefits for the individual patient are established in this way.

Chapters 7 and 8 contain up-to-date, new recommendations for application of traditional and digital techniques to prepare accurate, reliable superimpositions. These chapters are replete with tips and tricks.

Serial cephalograms are not indicated for each orthodontic patient. The procedure is justified in patients only where there is an established indication for diagnosis and evaluation of growth and treatment by cephalometrics. The "ALARA" principle should be applied at all times—that is, the radiation dose should be "as low as reasonably acceptable." This implies that radiographs should have a tangible benefit for the individual patient.

The systematic use of the structural method is a powerful learning tool. It is an excellent way to gain insight in the individual variations in facial growth patterns and their interaction with treatment. A clinician's in-depth experience with the interactive effects of growth and treatment in his or her own patients is the best basis for a continuous drive to improve standards of clinical performance. The structural method is recommended for deeper understanding of the treatment process.

This book will help readers to produce superimpositions with maximal reliability, based on the best available scientific biologic evidence. Accurate cephalometric tracings and superimpositions represent the best way to demonstrate and evaluate changes resulting from dentofacial skeletal growth and treatment. Use of the structural method is different from all other suggested superimposition techniques. Structural superimpositions are records; all other superimpositions are illustrations. That is, all other superimposition methods may be useful for illustrating an idea, but that is different from a scientific approach to recording, investigating, and analyzing biologic events as precisely as possible. The structural method is the only evidence-based procedure. This book provides the reader with a complete background and tools for applying this scientific, evidence-based method in any orthodontic office procedure.

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The sculpture featured on the cover is by the British sculptress Patricia Volk and is reprinted with permission of the artist (www.patriciavolk.co.uk).

Recommended Reading

This book is written for orthodontic specialists who wish to refresh and update their understanding of cephalometric superimposition and for the specialist in training who needs a thorough introduction into the subject. For other workers in the field of human growth and development, the contents may also be helpful as an introduction to the field.

This book presupposes knowledge of the anatomy, growth and development of the human head, development of the dentition, and radiographic cephalometry. The following textbooks and atlases are recommended for further study or consultation.

Anatomy

Standring S. Gray's Anatomy, ed 40. London: Churchill Livingstone, 2008.

Growth and development of the head

Enlow DH, Hans MG. Essentials of Facial Growth, ed 2. Ann Arbor, MI: Needham, 2009.

Meikle MC. Craniofacial Development, Growth and Evolution. Norfolk, England: Bateson, 2002.

Cephalometry

Broadbent BH Sr, Broadbent BH Jr, Golden WH. Bolton Standards of Dentofacial Developmental Growth. St Louis: Mosby, 1975.

Riolo ML, Moyers RE, McNamara JA Jr, Hunter WS. An Atlas of Craniofacial Growth, monograph 2, Craniofacial Growth Series. Ann Arbor, MI: University of Michigan, 1974.

Jacobson A, Jacobson RL (eds). Radiographic Cephalometry. From Basics to 3-D Imaging, ed 2. Chicago: Quintessence, 2006.

Miyashita K. Dixon AD (ed). Contemporary Cephalometric Radiography. Chicago: Quintessence, 1995.

Dentition development

Duterloo HS. An Atlas of Dentition in Childhood. Orthodontic Diagnosis and Panoramic Radiography. London: Wolfe, 1991.

Moyers RE, van der Linden FPGM, Riolo ML, McNamara JA Jr. Standards of Human Occlusal Development, monograph 5, Craniofacial Growth Series. Ann Arbor, MI: University of Michigan, 1976.

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CHAPTER 2

Validity and Reliability: Method Error

The structural method usually incorporates three different superimpositions: *(1)* general superimposition on the anterior cranial base, *(2)* local superimposition of the mandible, and *(3)* local superimposition of the maxilla. Each of these superimpositions has specific limitations related to method error. Insight into method error becomes particularly relevant if the time interval between the cephalograms is relatively short and the changes brought about by growth and treatment are relatively small. Such is often the case in the evaluation of orthodontic patients. The following sections discuss the method error of each of the three superimpositions with regard to their *validity* (ie, biologic significance) and *reliability* (ie, precision and accuracy). In addition to local superimpositions of the mandible and maxilla, regional superimpositions[1–4] are also used to investigate changes in the position of the mandible relative to the maxilla and vice versa. The validity and reliability of that procedure depends on *(1)* the validity and reliability of local superimposition of either the mandible or the maxilla and *(2)* the accuracy of registration of the occlusion. This chapter does not address the topic of regional superimposition.

Most studies on reliability predate the era when advanced computerized manipulation of radiographs became possible. Nevertheless, they provide the logical basis for work with newer digital methods. Chapters 7 and 8 address the practical aspects of structural superimposition.

Method Error in Structural Superimposition on the Cranial Base

Validity of structural superimposition on the cranial base

The validity of general superimposition using the structural method with natural reference markers is largely based on the histologic investigations of Melsen.[5] The principal findings of that study are summarized in Fig 2-1.

The application of structural anterior cranial base superimposition requires thorough knowledge of the anatomy of the region and how it is imaged in the cephalogram (Figs 2-2 to 2-7). The clinical significance of the results by Melsen[5] is the finding that two relatively distant structures are stable after the age of 6 years. The anterior part of the sella turcica (see Fig 2-1, surface 5) can be used to register the superimposed tracing in a horizontal direction, while the cribriform plate of ethmoid bone and the squamous part of the frontal bone (see Fig 2-1, surfaces 1 and 2) can be used to orient the superimposed tracing in a vertical direction. This can eliminate rotational errors to a large extent.

In many publications, only surfaces 3, 4, and 5 in Fig 2-1 are used for a best-fit superimposition, but the use of only these contours is not recommended for two reasons. First, the endocranial (meningeal) periosteal surface of the jugum

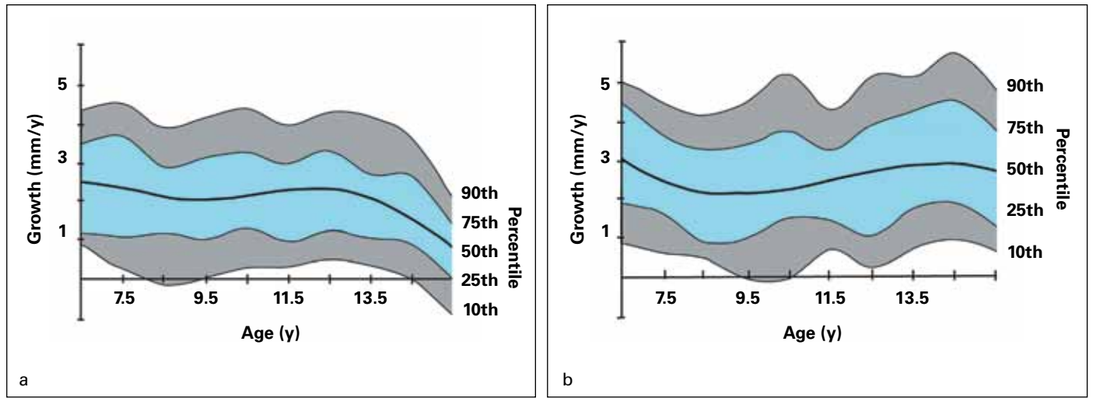

Fig 3-41 Incremental charts of total condylar growth in girls *(a)* and boys *(b)*, corrected for magnification. The charts can be used to evaluate condylar growth in individual patients (see Fig 3-42). Condylar growth is measured after the structural superimposition of the mandible on the cephalometric point condylion. Growth of the right and left condyles is averaged. (Reprinted from Buschang et al[154] with permission.)

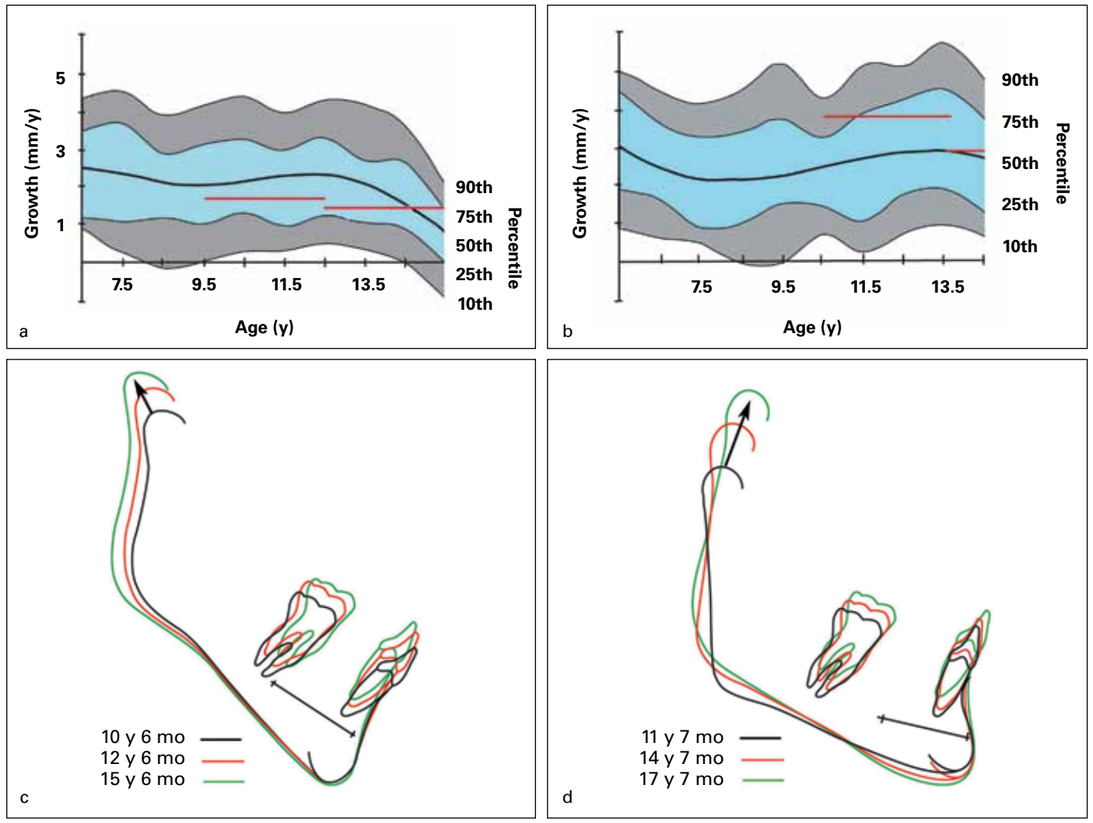

Fig 3-42 Estimates of annual condylar growth. The use of the incremental growth charts is demonstrated in the contrasting implant patients. *(a and c)* A female patient recorded at 10 years 6 months, 12 years 6 months, and 15 years 6 months, exhibited backward growth rotation. Condylar growth over the total period was 9.8 mm. Growth during the first 3 years was 1.7 mm/y. During the second period, growth was 1.6 mm/y, which is between the 25th and 50th percentile. *(b and d)* A male patient recorded at 11 years 7 months, 14 years 7 months, and 17 years 7 months, exhibited extreme forward growth rotation. Growth over the total period was 20.4 mm. Growth during the first 3 years was 3.77 mm/y. During the second period, it was 3.3 mm/y, which is above the 75th percentile. (Data from Björk and Skieller[6]; adapted from Buschang et al[154] with permission.)

Table 3-2 Percentile distribution for condylar growth rates measured in millimeters per year*†

	Males					Females				
Age	10%	25%	Average	75%	90%	10%	25%	Average	75%	90%
6.5	0.88	1.87	3.07	4.47	5.10	0.88	1.19	2.69	3.50	4.37
7.5	0.57	1.58	2.46	3.65	4.50	0.27	1.07	2.13	3.68	4.53
8.5	0.42	0.83	2.17	3.28	4.17	–0.15	1.15	2.01	2.85	3.88
9.5	0.14	0.94	2.12	3.44	4.50	0.04	0.97	2.11	3.08	4.11
10.5	–0.12	1.46	2.25	3.74	5.23	0.26	1.27	2.25	3.21	4.36
11.5	0.65	1.41	2.48	3.27	4.31	0.27	0.92	2.31	2.93	3.90
12.5	0.20	1.04	2.72	3.95	5.19	0.47	1.18	2.21	3.25	4.25
13.5	0.74	1.78	2.90	4.32	5.21	0.29	1.01	1.92	2.64	4.11
14.5	0.98	1.91	2.95	4.58	5.80	–0.05	0.83	1.48	2.60	3.61
15.5	0.66	1.31	2.79	3.77	4.79	–0.95	–0.01	0.94	1.35	2.06

*Data from Buschang et al.[154]
†One value in boys and four values in girls show negative growth.

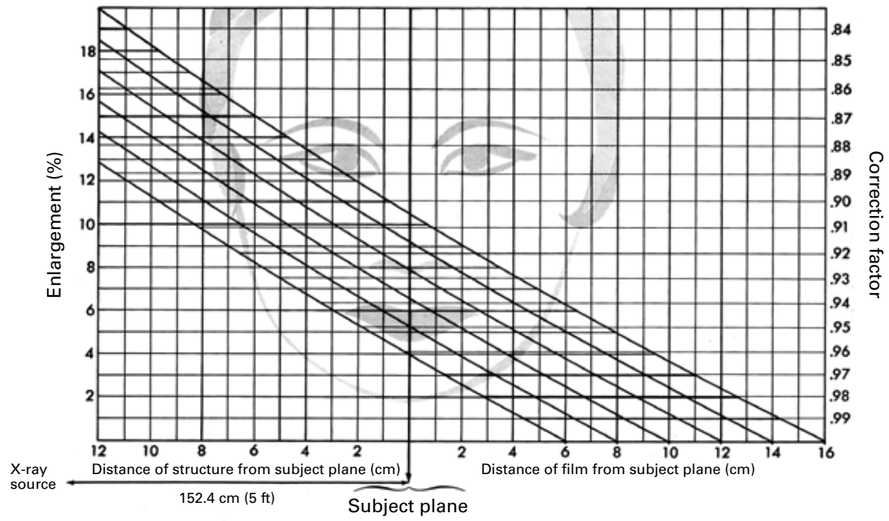

Fig 3-43 It is necessary to determine the exact enlargement correction factor to ensure accurate use of the condylar incremental growth charts. A permanently fixed distance between the midsagittal plane and the film should be used so that the correction factor is constant. Diagonal lines indicate film positions, in centimeters, from the midsagittal plane of the patient. The horizontal scale indicates the distance of any structure from the sagittal plane. Intersection of this line with the diagonal line of film position will provide the enlargement factor *(left)* and the correction factor *(right)*. (Adapted from Thurow[156] with permission.)

Timing of Facial Growth

A massive amount of data relating to dimensional and angular facial growth changes is available. An excellent reference is the data provided in the *Atlas of Craniofacial Growth* by Riolo et al.[155]

Buschang et al[154] devised a trial that studied the incremental growth of the mandibular condyle. Annual records taken between the ages of 6 and 16 years for 113 boys and 108 girls were used in a mixed longitudinal study design. The growth at condylion was measured after a structural superimposition of the mandible.

From their data, Buschang et al[154] developed incremental growth charts for girls and boys (Fig 3-41 and Table 3-2). For comparison of individual patients to these charts (Fig 3-42), the actual growth at condylion is measured in millimeters on the structurally superimposed tracings. This value must be multiplied by the correction factor (Fig 3-43) to ensure accurate comparison to the incremental growth chart. The

Case 2

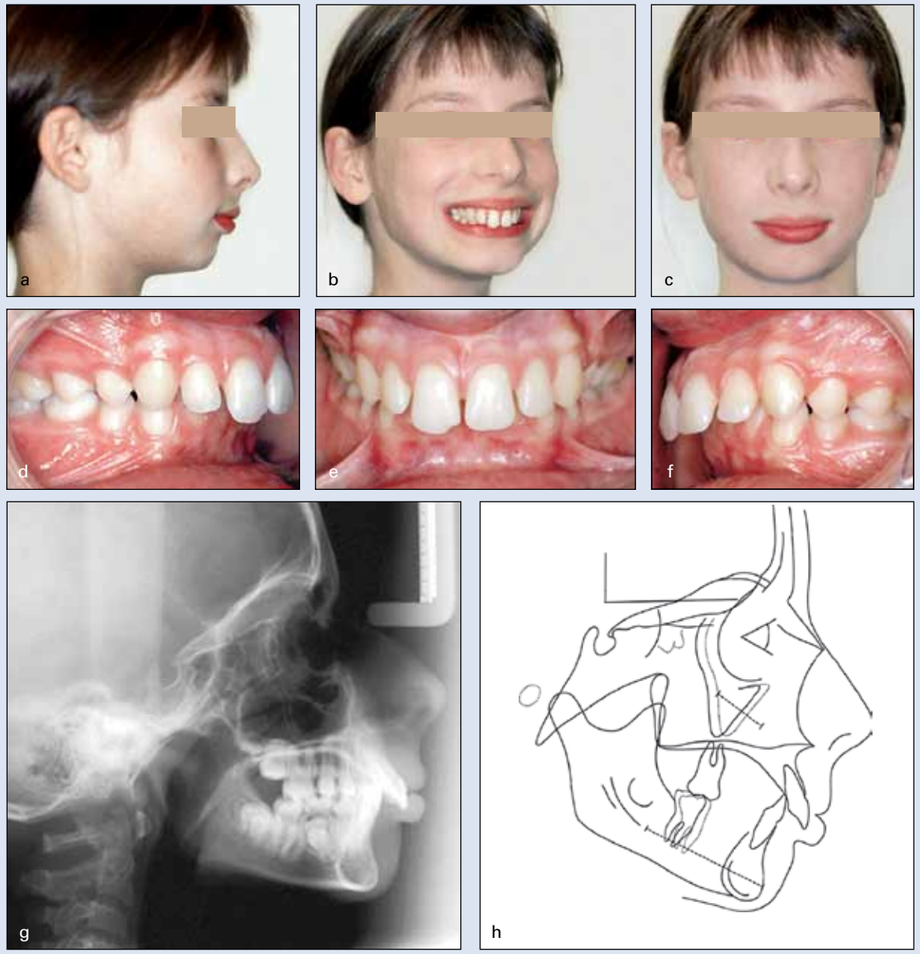

Fig 6-4 Case 2. Pretreatment records of a girl, aged 11 years 2 months.

Observations: *(a to f)* Severe Class II, division 1 malocclusion with convex facial profile, large and long nose, lower lip interposition, enlarged overjet, and very deep overbite. *(g)* Head position in the cephalometer shows anterior tilting. *(h)* The pretreatment tracing with the transfer guide and implant lines is rotated in the horizontal position. Note the convex skeletal profile and the deep overbite.

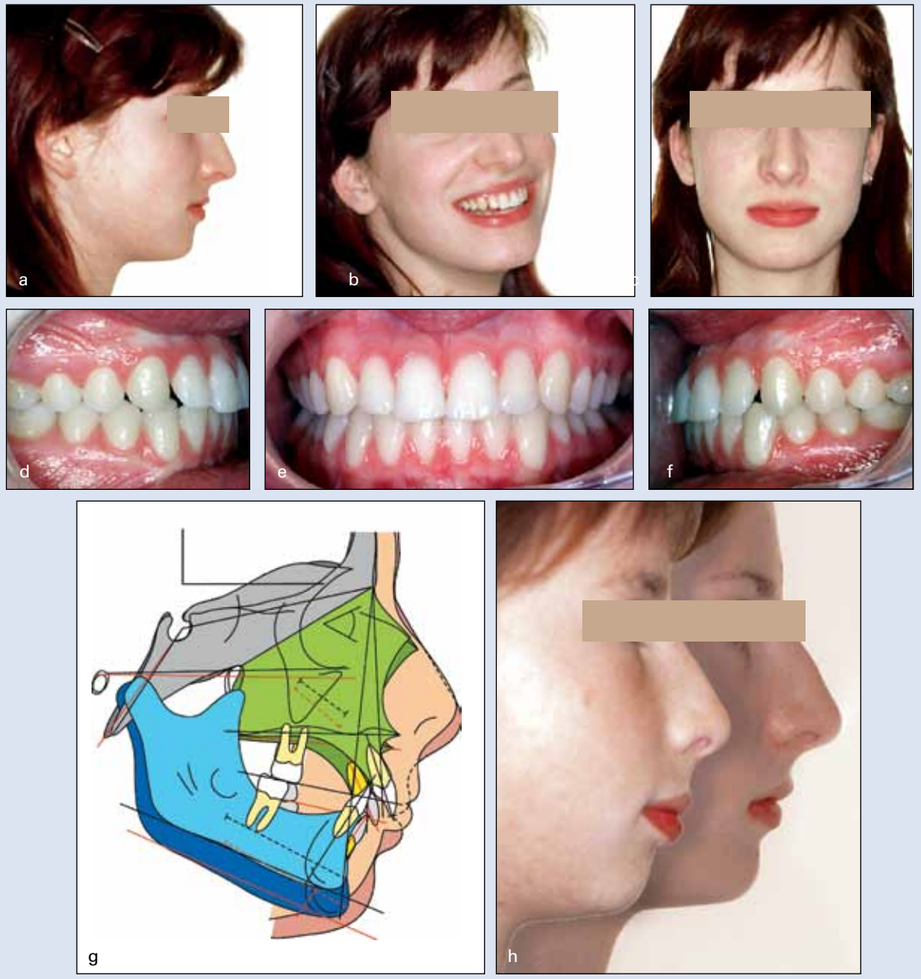

Fig 6-5 Case 2 *(cont).* Records at 17 years of age.

Observations: *(a to f)* Stable result with a solid Class I occlusion. Retention continued with mandibular bonded retainer. *(g)* Structural superimposition shows posteriorly rotating maxillary growth with mandibular vertical displacement and no or minimal rotation. Adding color can be an efficient means to enhance clear presentation. *(h)* Superimposed facial profile photographs to demonstrate profile changes. Facial height is identical. Note the corrected lip profile, the relaxed mouth closure, the balanced mentolabial sulcus–chin contour, and the change in the inclination of the lower face.

Interpretation: The perception of a convex profile remained due to the continued growth of the nose.

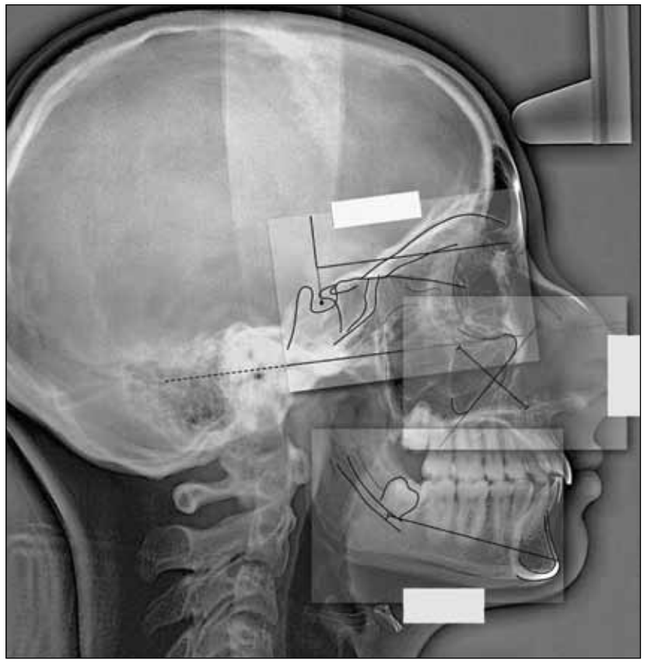

Fig 7-46 Superimpose the mandibular template on the natural reference structures in the mandible and tape the template. Then position the red preprinted tracing sheet exactly over the transfer guide (do not use Frankfort horizontal as a reference).

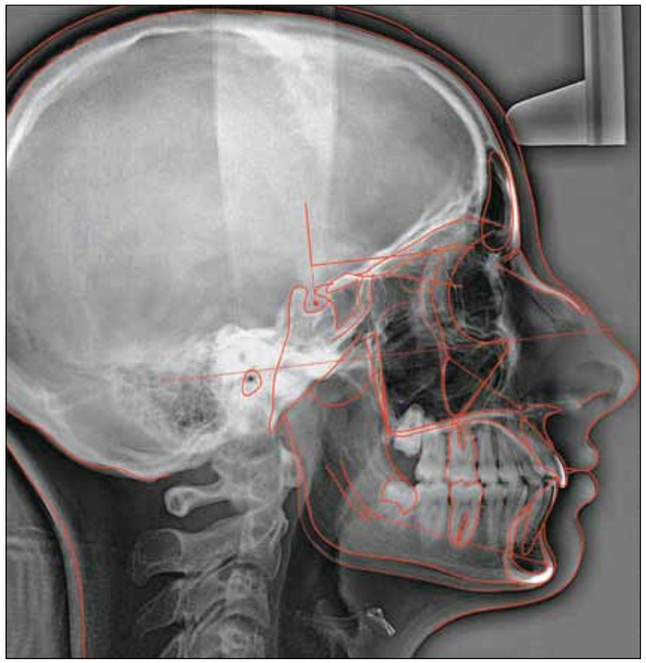

Fig 7-47 End-of-treatment cephalogram with completed red tracing. Check and compare with black tracing to make sure all details have been traced.

Fig 7-48 Completed red tracing in horizontal position on red preprinted tracing sheet.

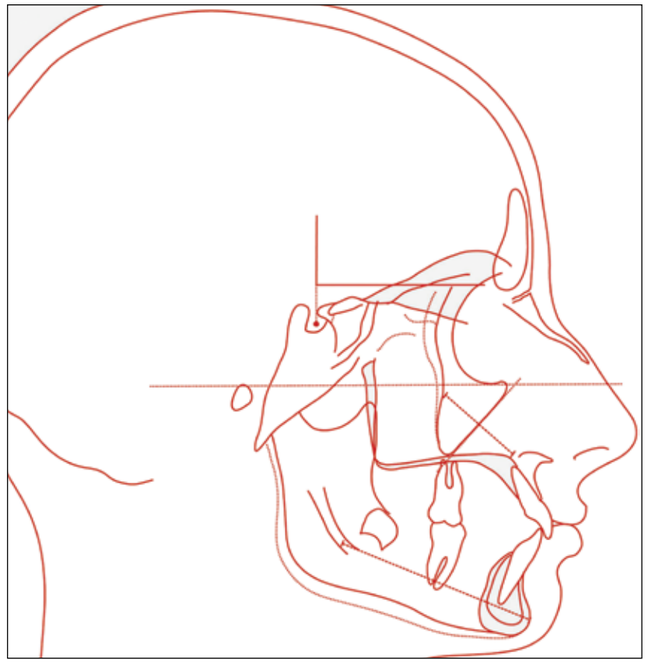

Fig 7-49a Carefully compare the end-of-retention cephalogram (C) with the pretreatment and end-of-treatment cephalograms (A and B).

Tracing the end-of-retention cephalogram

Preparation of the end-of-retention tracing (C) is similar to tracing of the pretreatment cephalogram (Figs 7-49 to 7-52). Use a green pencil and the preprinted green tracing sheet.