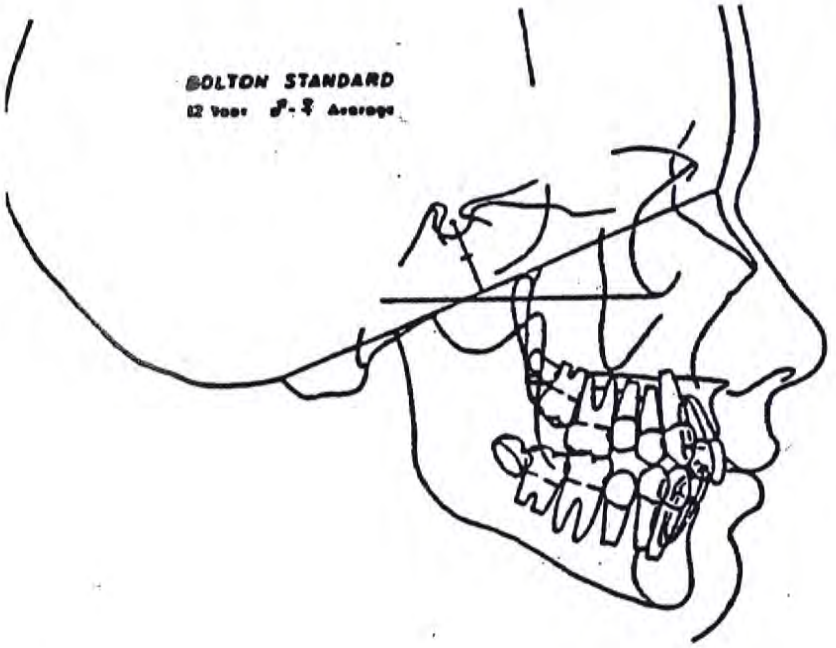
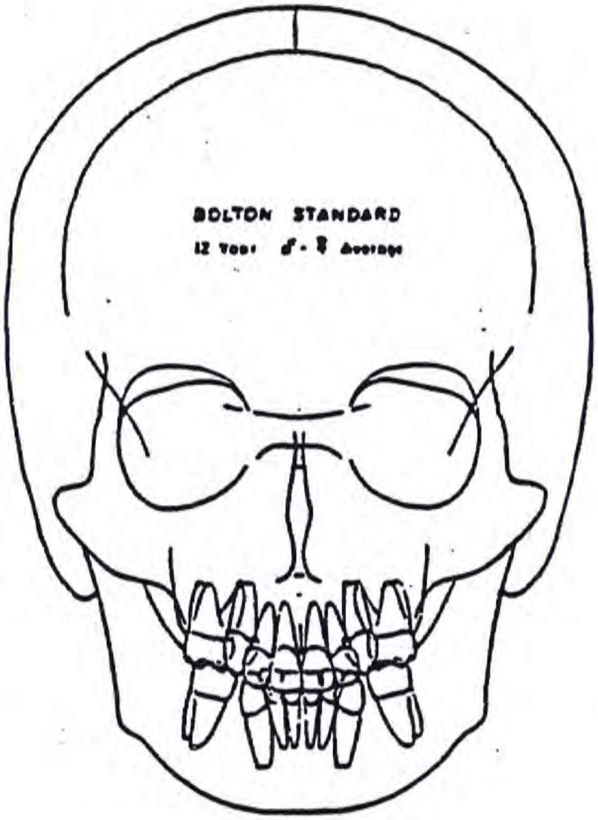
BOLTON STANDARDS OF DENTOFACIAL DEVELOPMENTAL GROWTH





BOLTON - BROADBENT - GOLDEN

BOLTON STANDARDS OF DENTOFACIAL DEVELOPMENTAL GROWTH

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To Frances, Bernice, and Char

in veneration of their infinite patience, love, and understanding

Foreword

It is given to few persons to inaugurate an era in any field. B. Holly Broadbent, Sr., has done this in the development of the Broadbent-Bolton radiographic cephalometer. This instrument and this method constitute a landmark in clinical and research orthodontics, as well as in the entire field of research in craniofacial growth and development. Literally one may dichotomize events in this area as B.B. (before Broadbent) and A.B. (after Broadbent).

In my own craniofacial researches I have run the gamut from craniometry (measuring the skull), to cephalometry (measuring the head), to radiographic cephalometry (tracing of an x-ray film of the head). First the *ansteck Nadel,* then the *ansteck goniometer,* then the *cubiscraniophor,* then the *dioptograph,* all of which facilitated the measurement and drawing of the skull. Then with the knowledge of T. W. Todd combined with the machinist skill of Joe Cherny, the Reserve craniostat was created in the Anatomical Laboratory of the then Western Reserve University School of Medicine.

It was Dr. Broadbent's awareness and his special genius that envisioned the transformation of the craniostat into the cephalostat. This meant going from the skull to the head *in depth* because it gave the peripheral and central details of the hard and soft tissue relationships of the entire craniofacial complex.

Here then is the first forward step: emphasis on the whole as the integrated sum of its parts. The second forward step, in my opinion, is the most vital: longitudinal or serial, in contrast to cross-sectional, growth progress, instead of growth status. Here at one bound, basic research and clinical interpretation–application were united.

I was a Cleveland Foundation Fellow in Anatomy under Todd during the period 1928 through 1929; I was Associate Professor of Anatomy and Physical Anthropology with Todd from 1931 to 1938. Also in those times, I had the great and real privilege of working and studying with Holly Broadbent. In simple terms these two men helped formulate my own professional career, Todd with the serial bodily growth studies of the Brush Foundation and Broadbent with the serial craniofacial growth studies of the Bolton Fund. In 1932 Todd wrote as follows:

> To Dr. Broadbent, as Director of the Bolton Study, passes the responsibility of carrying on the intensive investigation of facial and dental growth in children in the group research now being prosecuted in our Institution. . . . Such mantle as I have had I throw over his shoulders, though even now that mantle has shrunk to but a scantling through the vigorous growth of the truly Orthodontic shoulders upon which it has fallen. (*Int. J. Orthod.* **18:**799-811.)

That early vigorous growth has reached full adult status in the Standards herein presented.

I cannot conclude this foreword without recognizing the generous and farsighted support of Chester and Frances Bolton and their son, Charles. The Bolton-Broadbent team can be evaluated best in terms of resultant basic growth concepts and data and in terms of the thousands of children who have benefited from the application in many medical and dental specialties of the work of the Bolton Fund.

WILTON MARION KROGMAN, Ph.D.

Lancaster, Pa.

Preface

Probably no other discipline of the health professions has been more diligent in its search, or has had greater need, for standards of dentofacial developmental growth than the field of orthodontics. The need has been for a common yardstick, or norm, of chronologic values and morphologic development that would give a widely acceptable base for comparing cephalometric records of individual patients as well as sample population groups. The purpose of this would be for diagnosing, treatment planning, interpretation of treatment results, and standardization of fundamental values for use in research and assistance in communication both within the health professions and with the lay public.

In this search, as anthropology and cephalometry have given way to radiographic cephalometry, linear and angular measurements have been used to establish statistical means; grids of norms, fabricated; polygonal patterns, established; and templates, devised. All these efforts have made their contribution toward the ultimate goal, but the statement of Krogman and Sassouni in their excellent publication *A Syllabus in Roentgenographic Cephalometry* probably still captures the pertinence of the problem before us:

> In all of our reading, and in the data herein presented, we have been struck by one ever-recurring fact: *a lack of standardization*. This is true all along the line, beginning oft-time with formulation of problem, and then extending forcefully into inadequacies of sampling, measurement, observation, procedures, all of which may influence interpretation. These strictures are not to demand rigidity in thinking, blind conformity in approach, and inelasticity of appraisal; but our feeling, without reservation, is that much is to be gained by a meeting of minds where there is a higher degree of objectivity and unanimity of approach.*

It is to this end—a standardization of cephalometric "normality"—that this book is presented.

As in other areas of research the Bolton Study has had three basic phases of endeavor to which it has directed itself: first, the collection and documentation of the fundamental data relative to the plan of inquiry; second, the analysis and distillation of the data as applied to many existing principles and newly developed concepts; and third, the communication of its conclusions and formulations for the application and use of others.

In the first phase the Bolton Study has had the good fortune of possessing more longitudinal cephalometric radiographic records than have most similarly based investigations. The data have been accumulated through the long-term and patient attention to procedures and details that has guided the study since its inception. The support, both financial and phys-

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*From Krogman, W. M., and Sassouni, V.: A syllabus in roentgenographic cephalometry, Philadelphia, 1957, Philadelphia Center for Research in Child Growth, p. 339.

ical, of the Bolton family has been no less than heroic and is without parallel in the history of dental research; it is the fundamental reason that the data accumulated are available for our use. The distillation of the data has gone through an unduly long process, as many similar projects of this nature have, with the original goal being a complete treatise on cephalometrics and dentofacial growth. Through the ensuing years the voluminous publications on dentofacial development and the rapidity with which they have been produced is of such magnitude that the "complete work" became less and less feasible. Our direction at this time, then, is not to present a complete publication on the all-encompassing subjects but rather to offer selected guidelines and techniques that it is hoped will bring about a more practical use of cephalometric radiography and its associated diagnostic procedures.

We present some of the fundamentals of cephalometrics and tracing technique for those who are newly initiated to these procedures and also for those who wish to become more standardized in their tracing methods. Clinical examples are included for interpretation with the associated transparencies of the Bolton Standards, so that an understanding of their simplicity of application may be developed as a foundation on which to expand our methods of categorizing and cataloging malocclusions and skeletal discrepancies. It seems apparent that, as the health professions become better able to standardize their interpretations, more critical treatment plans will evolve through the ever-expanding use of computerization and the sophisticated techniques currently available for comparative analysis.

The BSC (Bolton Standard Correlation), which is described as one of the uses of the Standards, involves the arbitrary assignment of a specific standard size to individual parts of the craniofacial complex. This method of chronologically describing the size of these structures can be of significant communicative value, in addition to making possible the comparison of overall morphology and dentition.

Although in a somewhat derogatory, yet humorous, vein the orthodontic profession has been referred to as *the 6-millimeter profession* and has been accused of reaching for "hopelessly oversimpleminded concepts of norms," clinical needs have demanded that interpretive procedures be brought to their most basic form. The term *standard,* instead of *norm,* implies in this instance a rule for measuring or an *optimum* for use in making comparative clinical observations.

As in all areas of simplification and generalization, numerous limitations will be described, but our desire is to emphasize one particular limitation at this point: the practice of orthodontics, as well as that of most of the health professions treating the dentofacial complex, necessitates a significant degree of training and practical experience before specific techniques or armamentaria may be comprehensively applied for the benefit of patients. The Bolton Standards do not in any way allow for the "absentee diagnosis" of dentofacial abnormalities! We wish to stress most emphatically the need for firsthand observation of the patient if one is to appreciate to any sensible degree the myriad of other interrelated diagnostic factors that demand understanding for proper clinical interpretations and for the development of acceptable treatment procedures.

Finally, the concepts and data presented herein are offered with the full knowledge that they are merely another step on a long path. We continue to be reminded of the ever-increasing frontiers in the understanding of developmental growth processes by the retort of the lad who, when asked what he had learned on his first day at school, replied, "Not enough; I have to go back tomorrow!" There is no end—just satisfaction in accomplishment along the way.

First and foremost in the group of associates whom we wish to acknowledge for their invaluable assistance in the production of this publication is the Bolton family. Former

Representative Frances P. Bolton and her son, Charles B. Bolton, have made possible for all the years of its existence the physical facilities, staff, and other necessities of the Bolton Study. Their loyalty, friendship, and dedication both to us and to the Study are beyond our ability to express, and they have our eternal gratitude.

We have been indebted for many years to the members of the Department of Anatomy of the School of Medicine of Western Reserve University for their continuous assistance and professional counsel. We also have had the generous support and cooperation of the faculty and staff of the School of Dentistry of Case Western Reserve University with Dean Emeritus Paul Boyle and Dean David B. Scott as notable examples.

Our genuine thanks go to our dedicated and esteemed colleague Dr. S. Idell Pyle for her many excellent suggestions in general and for her specific contributions to the section on skeletal maturation.

The statistical analysis of the Standards and the tables of measurements included are in no small part due to the fine cooperation and capable technical efforts of Dr. Geoffrey Walker of the University of Michigan. Dr. Walker's pioneering work in computer programming for the analysis of cephalometric tracings made possible the comprehensive measurement of the Standards.

Our grateful appreciation goes to the many devoted professional associates and secretaries who, over the years, have assisted so capably in gathering the data base of the Bolton Study. In particular we wish to note the loyal and invaluable assistance of Mrs. Ida D. Morrison who typed and retyped many times during production of this text.

Finally, to our wives and children, we wish to express our boundless love and appreciation for giving ''Dad'' great encouragement and much of their ''family time.''

B. HOLLY BROADBENT, Sr.
B. HOLLY BROADBENT, Jr.
WILLIAM H. GOLDEN

Contents

CHAPTER 1

Introduction

One of the primary goals in the development and utilization of cephalometric radiography for the study of the growing individual was the production of workable standards, or yardsticks, that could be widely applied to those of all ages for the analysis of individual variation and as a base line for comparative research. The Bolton Standards, as presented herein, are a series of averages of individual cases that have *optimum* facial and dental developmental growth. They are representative Caucasian male and female faces that have been synthesized to present a norm for direct morphologic assessment as well as for linear and angular comparative measurements. The method of selection of the individuals who were studied to make up the Standards will be discussed in greater detail in Chapter 4. At this point suffice it to say that they have been selected from the population of the Bolton Study, which has a data base of more than 22,000 recordings on over 5,000 youngsters, which were accumulated in the main as longitudinal series. Fig. 1-1 is a population chart of the Bolton Collection that gives a representation of the number of individuals from which the specific ''Bolton Faces'' were selected. These selections employed the criteria of excellent health history, very good dentition with normally developing occlusion (no orthodontic intervention), long-term longitudinal x-ray recordings, and favorable comparison to an ''optimum'' face. The optimum model, or ''mean face,'' was developed through a painstaking process of measurement and inspection of the multitude of originally collected data and updated over the years. Fig. 1-2 indicates the dimensions that were initially investigated in the early years of the Study. From a model of this type, derived through laborious statistical averaging and careful morphologic comparison, the basis for selection of cases was developed.

Since a complete delineation of the areas of application and utilization of a set of comprehensive standards of this type would be difficult to compile, the following is a cursory outline of the main objectives that we conceive in presenting the Bolton Standards for the use of the health professions.

1. *Clinical use*. The comparison of individual patients to the Standards for diagnostic assessment in orthodontic treatment, oral surgery, and maxillofacial surgery will allow the following:
   a. A critical appraisal of the craniofacial skeletal makeup, including the actual comparative size and spatial relations of individual bones or groups of bones in structural units
   b. An analysis of the relationship of the dentition to its supporting skeletal bases as well as that of the individual dental arches to one another
   c. A more critical differentiation among many of the intrinsic and extrinsic etiologie factors

2. *Research*. The Standards may be used as a base line for conducting studies of developmental abnormalities, selecting samples having predetermined characteristics or criteria,

and also for the interpretation of changes produced through orthodontic and surgical intervention.

3. *Teaching*. The Standards may be used as a comparative reference for instruction in the demonstration of "normal" versus "abnormal" growth processes and their variations in assessing dentofacial patterns in the following:

a. Student education in dental curricula and surgical diagnosis at both undergraduate and graduate levels

b. Lay education and for the presentation of proposed treatment plans to indicate diagnostic factors, prognosis, and specific limitations to patients, their parents, and other interested groups

The original material, which naturally divides into female and male faces, is demonstrated in Figs. 1-3 and 1-4 with chronologic intervals of three years between successive representative tracings for ease of visualization. These series are presented with the limited dental units of the first permanent molars and central incisors to minimize the visual confusion that results when all units are traced and superimposed one on the other. In the descriptive pages to follow, most representative cases and drawings observe this pattern of limiting the dental units to the incisors and first permanent molars for clarity: but in the Standards the complete dentition is included, so that individual dental units can be followed in their developmental growth process and any unit of the dentition can be assessed singly or within a group.

In viewing the dentofacial complex from a morphologic standpoint, one finds that the Standards offer an opportunity to divide the face into a simplified group of fundamental units.

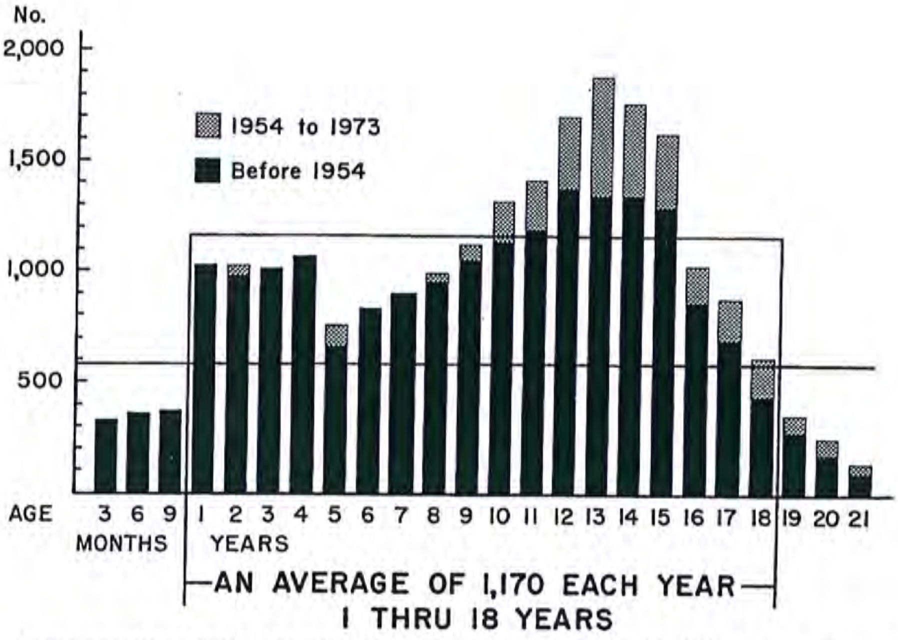

Fig. 1-1. Bolton population chart. The bars represent the number of individuals in each age group. Many of the individuals who started in the first year have been carried through on a longitudinal basis to adulthood. Also many records are but two or three years in length and fall into the cross-sectional data base.

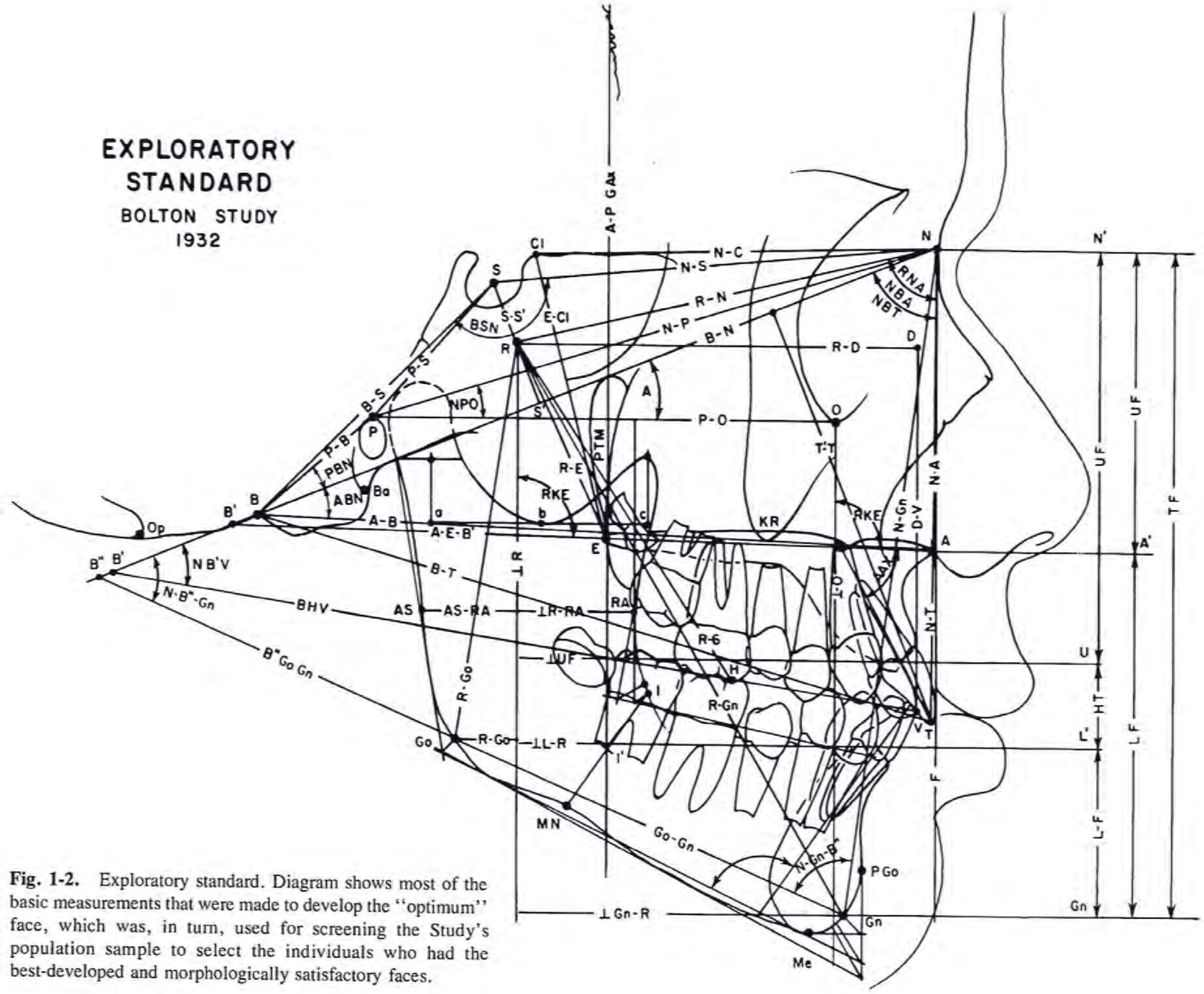

Fig. 1-2. Exploratory standard. Diagram shows most of the basic measurements that were made to develop the "optimum" face, which was, in turn, used for screening the Study's population sample to select the individuals who had the best-developed and morphologically satisfactory faces.

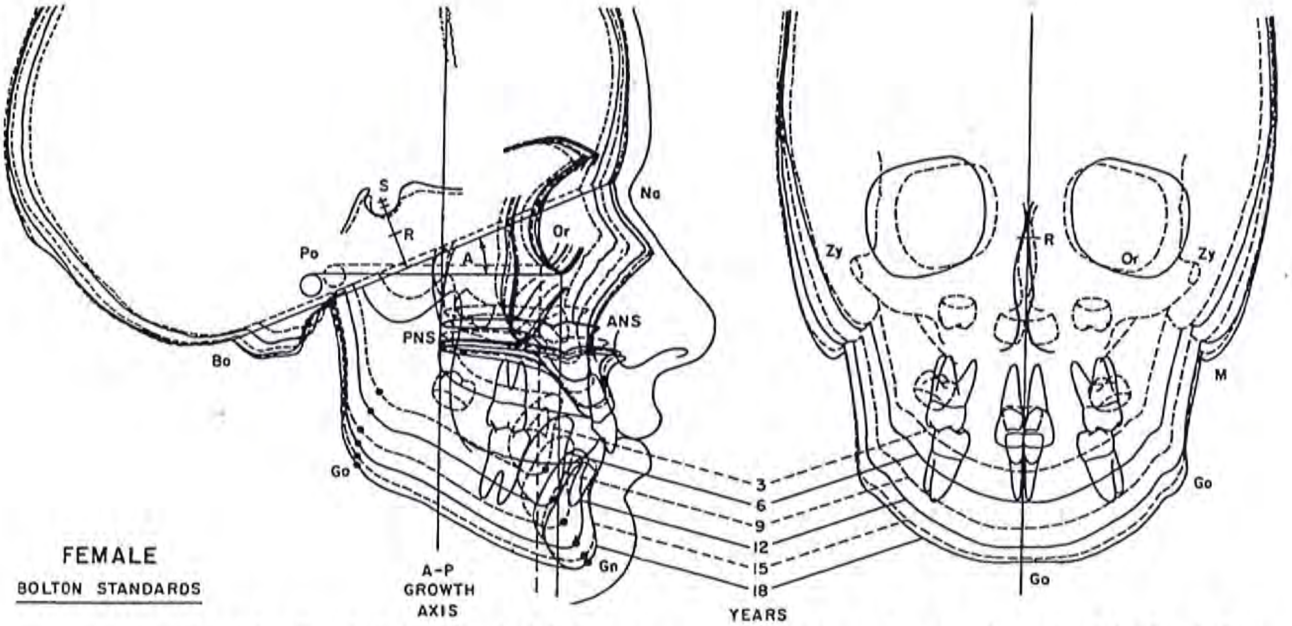

Fig. 1-3. Female Bolton Standard. These are superposed tracings at three-year intervals of the female Standard and indicate the symmetrical and uniform growth pattern depicted when registered on the *R* point with Bolton planes parallel.

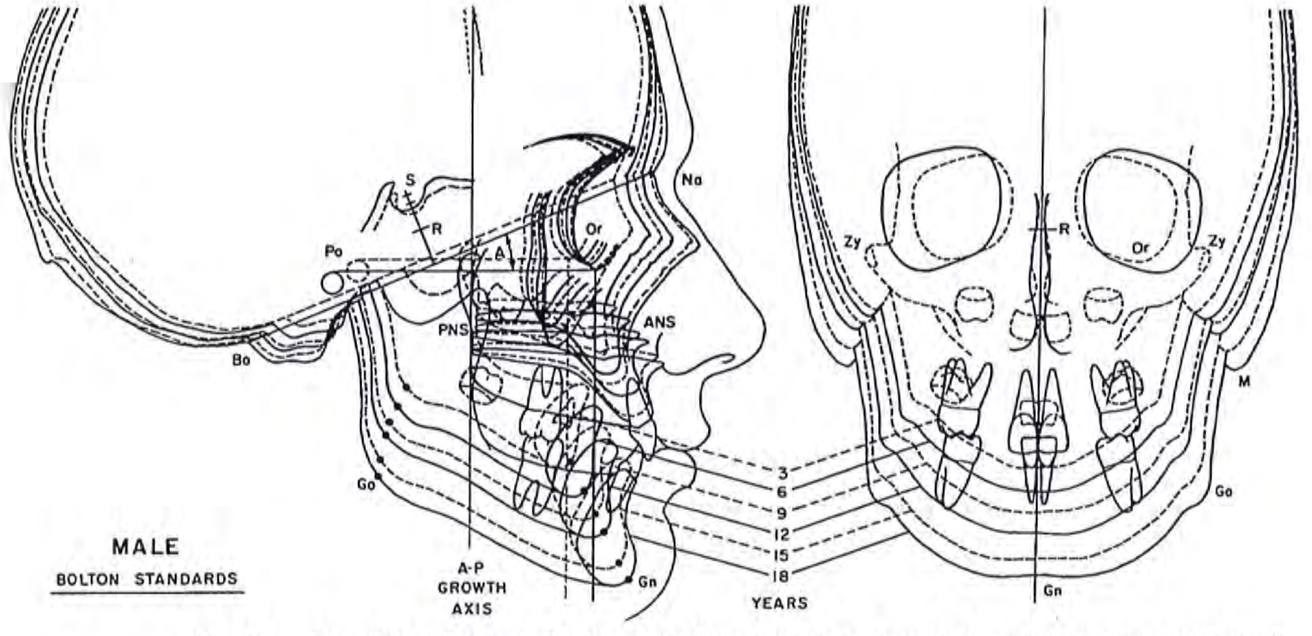

Fig. 1-4. Male Bolton Standard. Tracings also at three-year intervals and registered in Bolton relation. Note that the pattern is strikingly similar to that of the female Standard.

Each one of these areas, as seen in Fig. 1-5, is understood to be a combination of skeletal elements or anatomic parts; but, in the analyzing of cephalometric radiographs, they lend themselves to group association and analysis.

The division of the face depicted separates the cranial base *(1)*, which we refer to for simplicity as *CB*, from area *2* of the midface, or once again more simply *MX* for maxillary. Area *3* is the mandible, or *MN;* finally, the abbreviation *ST* refers to the soft tissue profile.

It is interesting to note at this juncture that historically cephalograms have been utilized in communication primarily by way of angular and linear interpretations. The work of individuals such as Downs[1] in his excellent publication of 1948, which brought cephalometric interpretation into routine use in treatment planning in the clinical office, has been repeatedly expanded and modified over the years by many talented clinicians and researchers. However, Steiner,[2] an exceptionally capable teacher of clinical orthodontics, stated humorously but significantly that "it is not Willie's sella turcica that his mother is interested in, but his chin." Orthodontists have been accustomed to dealing at a diagnostic and treatment level with landmarks and measurements that are not only often an enigma to themselves but also, equally important, beyond the technical knowledge of the lay person. The application of the Bolton Standards as transparent templates allows all interested parties to view in an easily understood

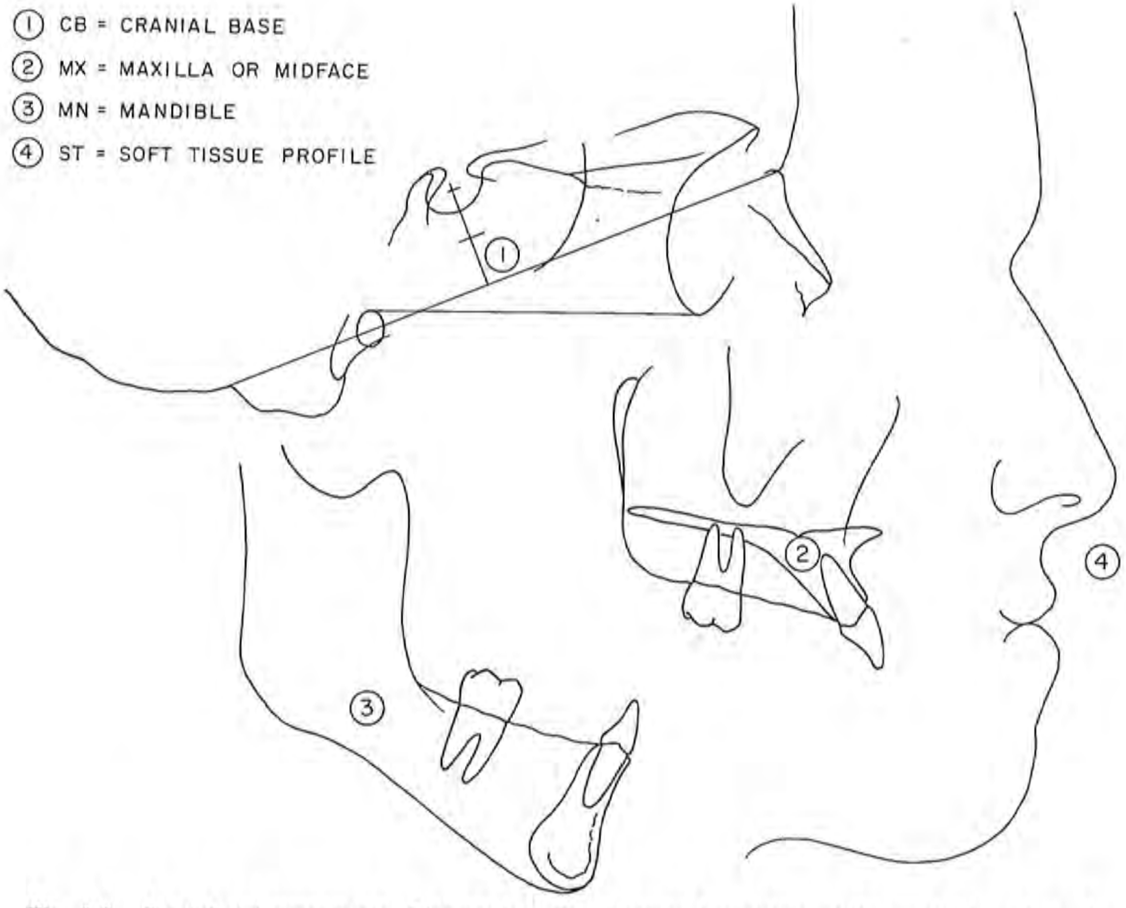

Fig. 1-5. Craniofacial components. Diagram indicates arbitrary dissociation of the cranial base from the maxilla, mandible, and soft tissue profile. These anatomic elements may vary both in size and morphologic pattern, and their spatial positioning basically dictates the relationship of the dental arches.

and graphic manner the variations from the optimum that give vital clues to the reasons for the dentofacial anomalies presented and in turn for the treatment plan selected.

Although clinicians are aware of the myriad of intrinsic and extrinsic factors that lead to so-called abnormalities of the dentofacial complex, one utilizing the Bolton Standards will rapidly come to realize that the morphologic relationships and spatial position of the dentition is to a great degree dependent on Nature's organization of the three basic craniofacial skeletal components as they influence the spatial position of the dentition and the configuration of the soft tissue profile.

Over the years, concentration on the relationship of maxilla to mandible has partially obscured the frequently significant influence of the total cranial base on this association. As an example, Fig. 1-6, *A,* is a tracing of a cephalometric radiograph of a 12-year-old female, indicating an excellent morphologic pattern with a Class I dental relationship. In Fig. 1-6, *B,* the skeletal parts have all been maintained except for the length of the cranial base, which was elongated 4 mm. through the body of the sphenoid bone. This lengthened cranial base produces an obvious change in the spatial association of the midface to the lower face and brings about the typical Class II relationship often observed clinically in the dentition and soft tissue profile.

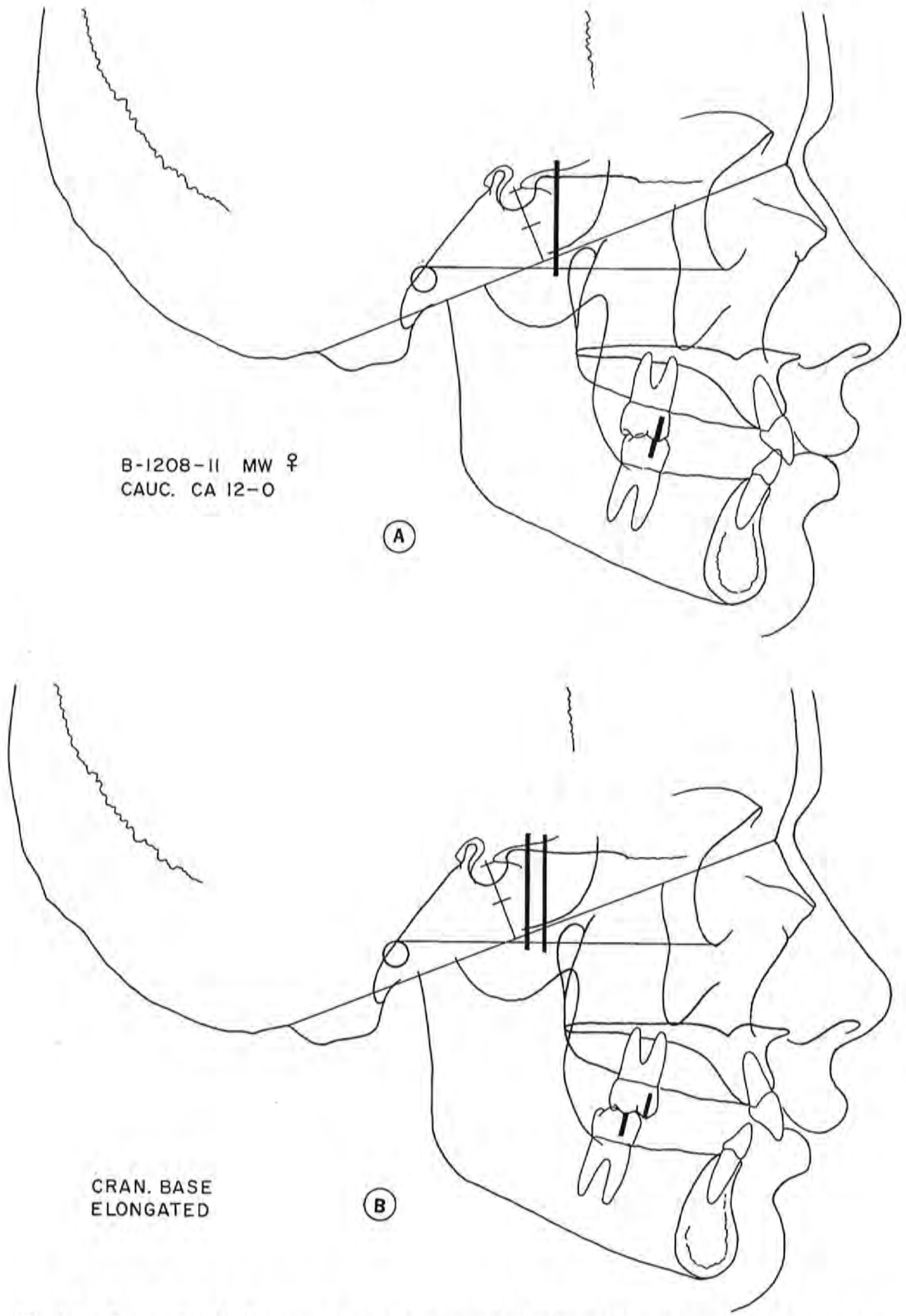

Fig. 1-6. Case B-1208. **A,** Tracing of the twelve-year record of a female Caucasian patient. **B,** Same tracing, which has been altered by increasing the length of the cranial base in the area of the anterior body of the sphenoid by approximately 4 mm. Change in the relationship of the midface to the mandible is easily observed.

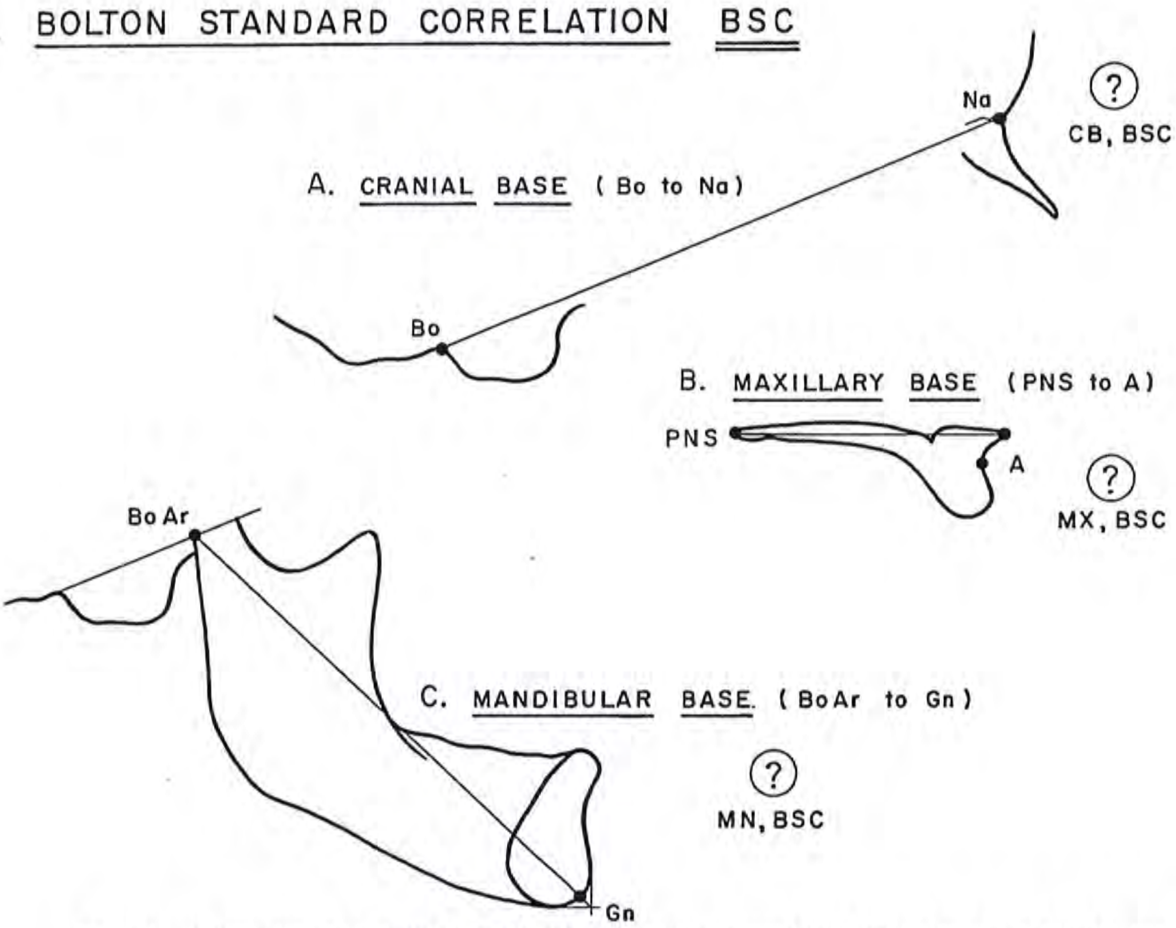

Fig. 1-7. Bolton Standard Correlation (BSC). Diagrammatic representation of the landmarks employed when the composite Standards are used for assigning Bolton Standard age levels to the three skeletal components of the craniofacial complex.

To simplify further the interpretation of the craniofacial components as described, it is suggested that an arbitrary comparison to the Bolton Standards, which we have termed the *Bolton Standard Correlation (BSC),* be made to compare or measure these three basic skeletal components with the Standards directly. The cranial base is arbitrarily measured between the Bolton point (Bo) and nasion (Fig. 1-7) and is, by virtue of this comparison to the Standards, given a chronologic value. In midface the posterior nasal spine's dimensional relationship to point *A* is compared to the standard maxilla as it is superposed on the tracing of the case to be assessed. This allows an arbitrary assignment of a maxillary Bolton Standard Correlation *(MX, BSC).* In the area of the mandible, the landmarks used to denote the "effective length" of the mandible are Bolton articulare to gnathion, thus delineating the *MN, BSC.* (Definitions used to support the locations of these landmarks will be given in the Glossary.)

To illustrate the use of the BSC in its clinical application and in communication, Fig. 1-8 is a tracing of a cephalometric radiograph of a Caucasian boy, 10 years of age, who had a bilateral cleft palate associated with the typical anterior facial pattern observed in this type of clinical pathology. With the Standards, an assignment level of a 10-year cranial base correlation indicates an optimum, or normal, development of this component. The mandible presents a BSC of 10 years, once again in keeping with the boy's chronologic age. The assignment of

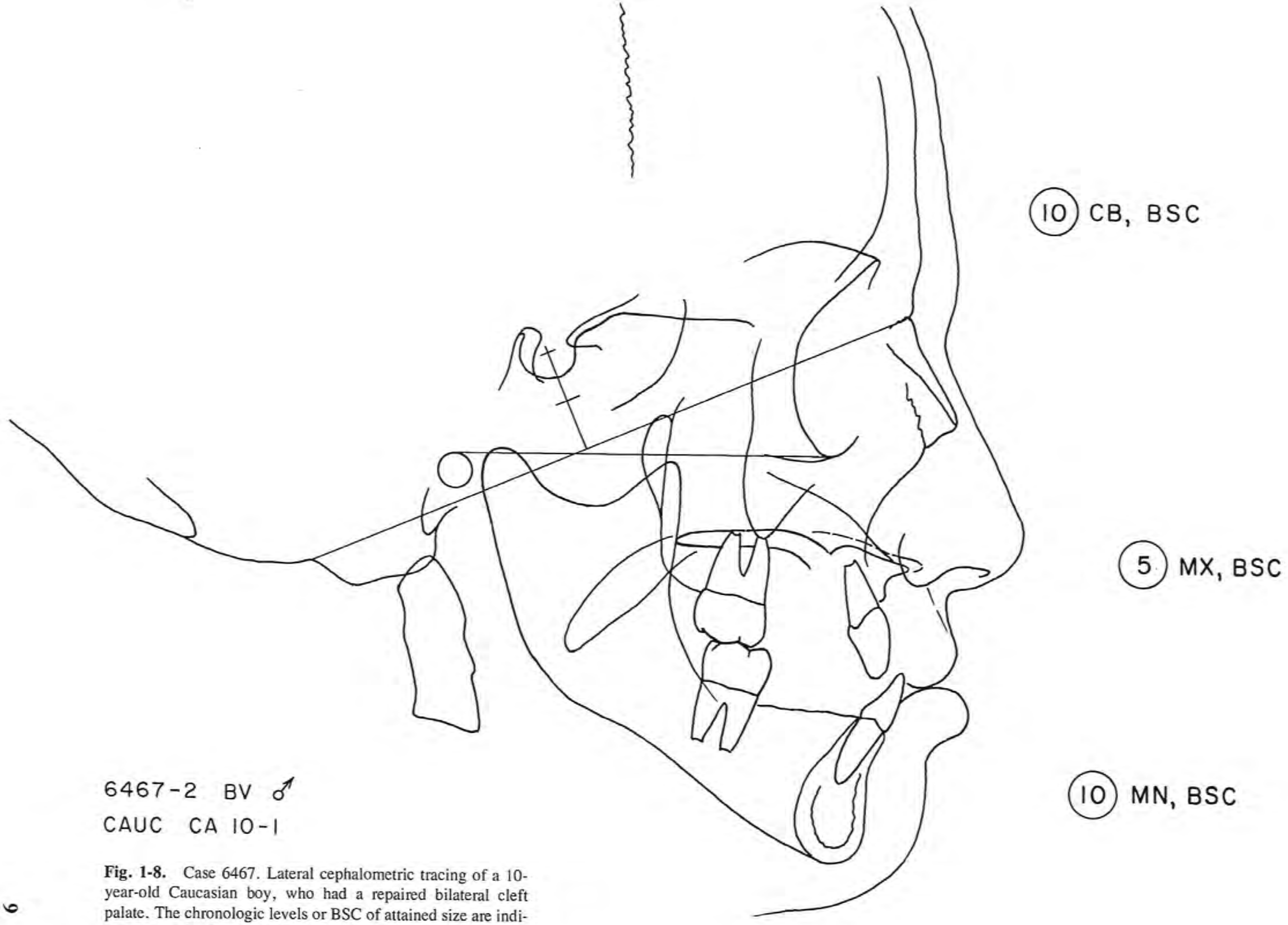

Fig. 1-8. Case 6467. Lateral cephalometric tracing of a 10-year-old Caucasian boy, who had a repaired bilateral cleft palate. The chronologic levels or BSC of attained size are indicated opposite the cranial base, midface, and mandible.

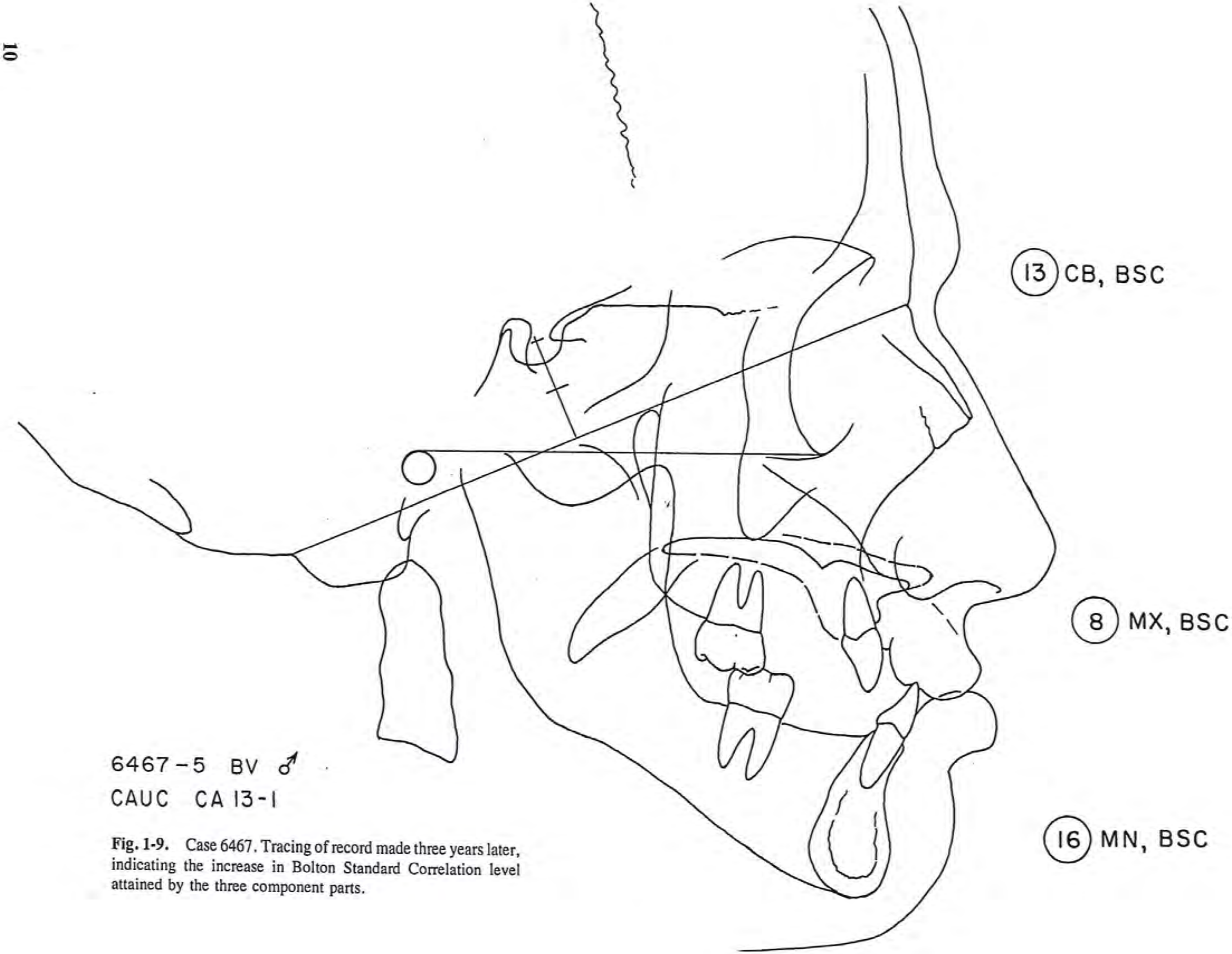

Fig. 1-9. Case 6467. Tracing of record made three years later, indicating the increase in Bolton Standard Correlation level attained by the three component parts.

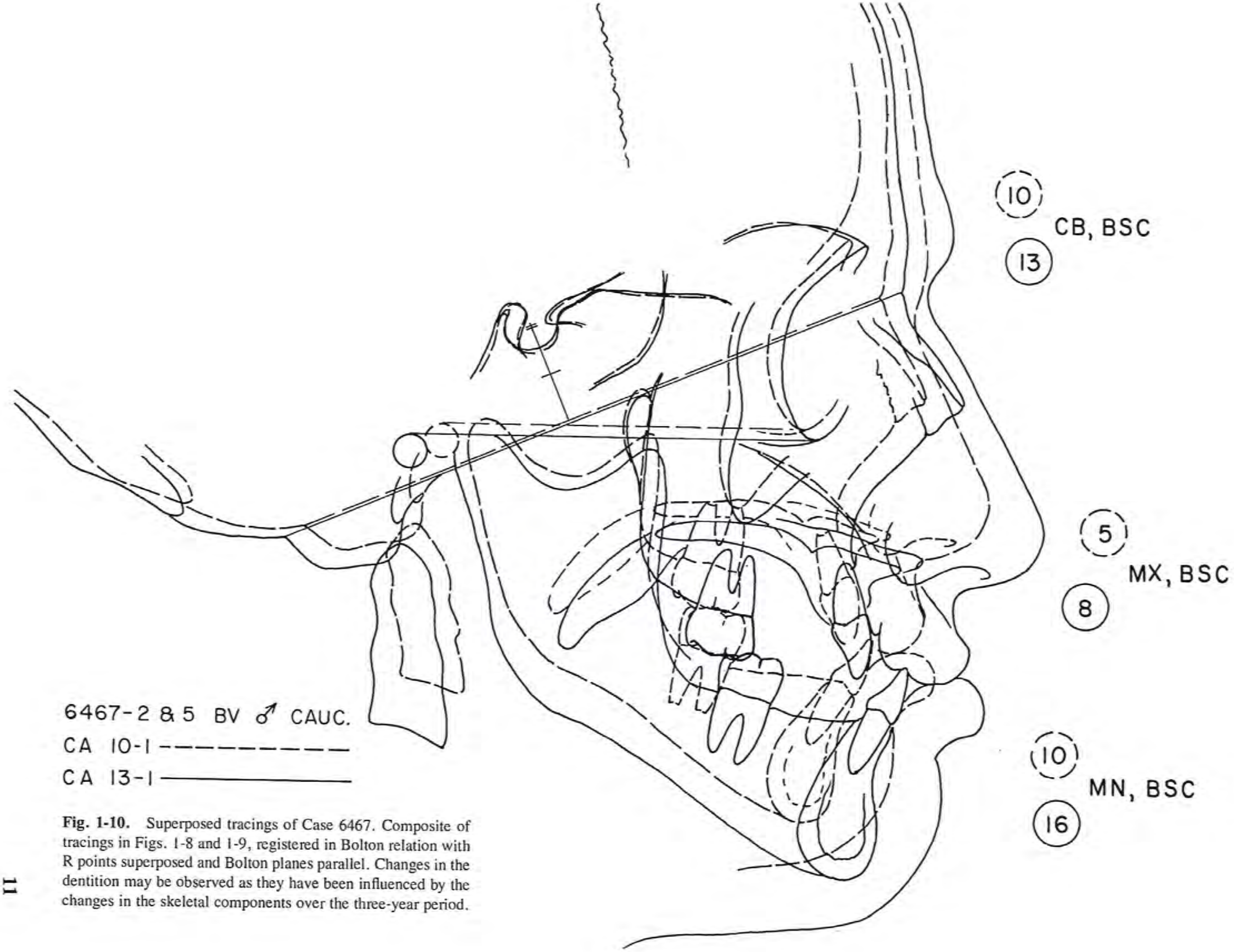

Fig. 1-10. Superposed tracings of Case 6467. Composite of tracings in Figs. 1-8 and 1-9, registered in Bolton relation with R points superposed and Bolton planes parallel. Changes in the dentition may be observed as they have been influenced by the changes in the skeletal components over the three-year period.

a 5-year level for maxillary (MX) development indicates, however, a significant impairment and would logically lead to the interpretation that the midface is the cause of the dental malrelationships.

Fig. 1-9 is a tracing of the same boy three years later at 13 years of age. After the same sequence of assignment of BSC, the cranial base increased, as one might expect, to the 13-year level. The maxillary component increased to the 8-year level, which indicates a developmental growth pattern of 3 years, still significantly less than Standard size for the boy's chronologic age. The mandible, however, rates an assignment at this 13-year level of 16 years BSC, which indicates that its developmental growth was 6 years linearly during the three between the two records.

Fig. 1-10 superposes the 10-year record over the 13-year record and demonstrates on a numerical basis that not only does this case present a dramatic lack of maxillary development but also the facial disproportions are compounded by the Class III (overgrown) mandibular component.

The use of a numerical assignment to facial components clearly depicts the changes from one record to another or, as will be seen in later clinical examples, the basic differences between a specific case and the Standards of the associated chronologic ages that relate to the anatomic sizes presented.

The following chapters give first a brief résumé of the historical background of the Bolton Study; then enter into a discussion of cephalometric technique and records; next present an interpretation of the rationale of the development of the Bolton Standards; then give a series of clinical cases to allow the user of the Standards to become more familiar with their application; and, finally, offer a look at skeletal age as it may assist in overall clinical evaluation.

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CHAPTER 2

Bolton history

To review briefly the history of anthropometry and cephalometry in the Bolton Study of the Laboratory of Anatomy at Case Western Reserve University, we must go back to 1920, when the interest of Dr. B. Holly Broadbent, Sr. (Fig. 2-1) in the study of the face of the growing child was kindled by his instruction under Dr. Edward H. Angle and later encouraged and directed by the contagious enthusiasm and ability of Dr. T. Wingate Todd (Fig. 2-2), then Chairman of the Department of Anatomy of Western Reserve University (prior to the consolidation of Case Institute of Technology and Western Reserve University) School of Medicine.

In the early 1920s, Dr. Todd's rapidly expanding collection of human skulls, which subsequently became the basis for the Hamann Museum, provided an opportunity that existed nowhere else to study and measure the human face with the use of the Todd craniostat.

In 1924 the addition by Dr. Broadbent of a metric scale to the Todd craniostat (Fig. 2-3) converted it into a craniometer[1]; and with it a series of skulls of Caucasian adults, mostly of Middle-European extraction, was used to measure dentofacial relationships. The published results of some of these studies were confined principally to the relation of the dentition to the Frankfort and orbital planes and the key ridges. (Additional interest in this particular study was stimulated by Simon's[8] publication in 1924 relative to the "law of the canines.")

About that time Dr. Todd emphasized his belief that, if researchers were really to learn much about the normal growth of the face during childhood, investigations must be performed on healthy living children rather than on skeletal material, which is usually a record of defective growth processes.

During these years of skeletal study, lateral jaw and craniofacial radiographs (Fig. 2-4), made both by him and by the radiologic firm of Hill and Thomas, were used on a selected basis for diagnosis in Dr. Broadbent's private orthodontic practice.

As a matter of general interest, x-ray films of the face and head taken as early as 1896 can be found by reading Rowland[7] (Fig. 2-5); much later, in 1919, Ketcham and Ellis published their results; and in 1921 Percy Brown designed a head holder for taking angular radiographic pictures of the face. In 1922 Pacini[6] published an accurate method for taking x-ray films of the skull in the lateral aspect and stated that the radiographic technique, at that time, was not adequate for taking frontal views.

In the same year, at the Angle College of Orthodontia, Dr. Spencer R. Atkinson displayed lateral x-ray films of the face that were intended to reveal the relationship of the upper first molars to the key ridges on the lateral surface of the maxillary bone. Besides this relationship these pictures revealed some of the soft tissue areas as well as the relation of the jaws to the rest of the face and the cranial base. It occurred to Dr. Broadbent that superimposing these facial pictures on base lines established by connecting such points as the sella turcica and nasion as well as the auditory canal and orbit would disclose more clearly the changes in the

Fig. 2-1. B. Holly Broadbent, Sr., Director of the Bolton Study.

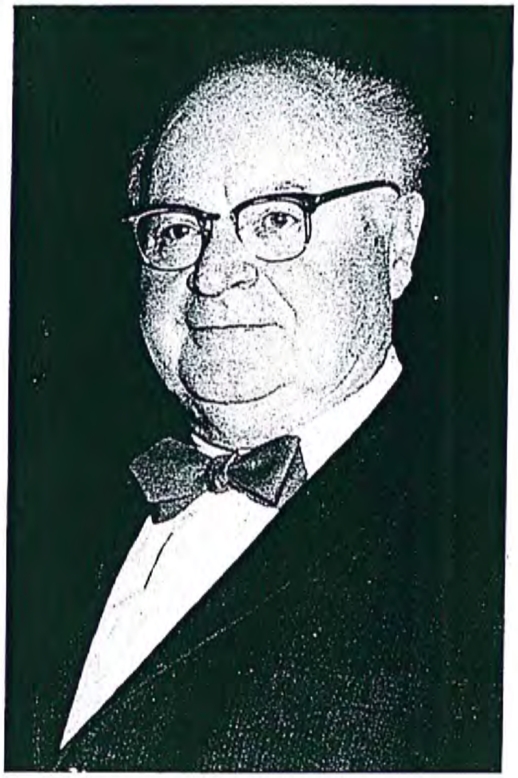


Fig. 2-2. T. Wingate Todd, Chairman of the Department of Anatomy, Western Reserve University School of Medicine, and Director of the Charles F. Brush Foundation Developmental Health Inquiry. (Photograph by Geoffrey Landesman, 1937.)

teeth and jaws during orthodontic treatment. The foregoing indicates that the original impetus to carry on the study of the development of the faces of living children did not stem from pure research but was actually a matter of clinical need.

The experience of using radiographic pictures made by a commercial laboratory indicated that their technique was not sufficiently standardized to secure two identical films or subsequent pictures with the same relationship of the film to the source of the x rays. These observations pointed to the value and necessity of a standardized technique to measure the

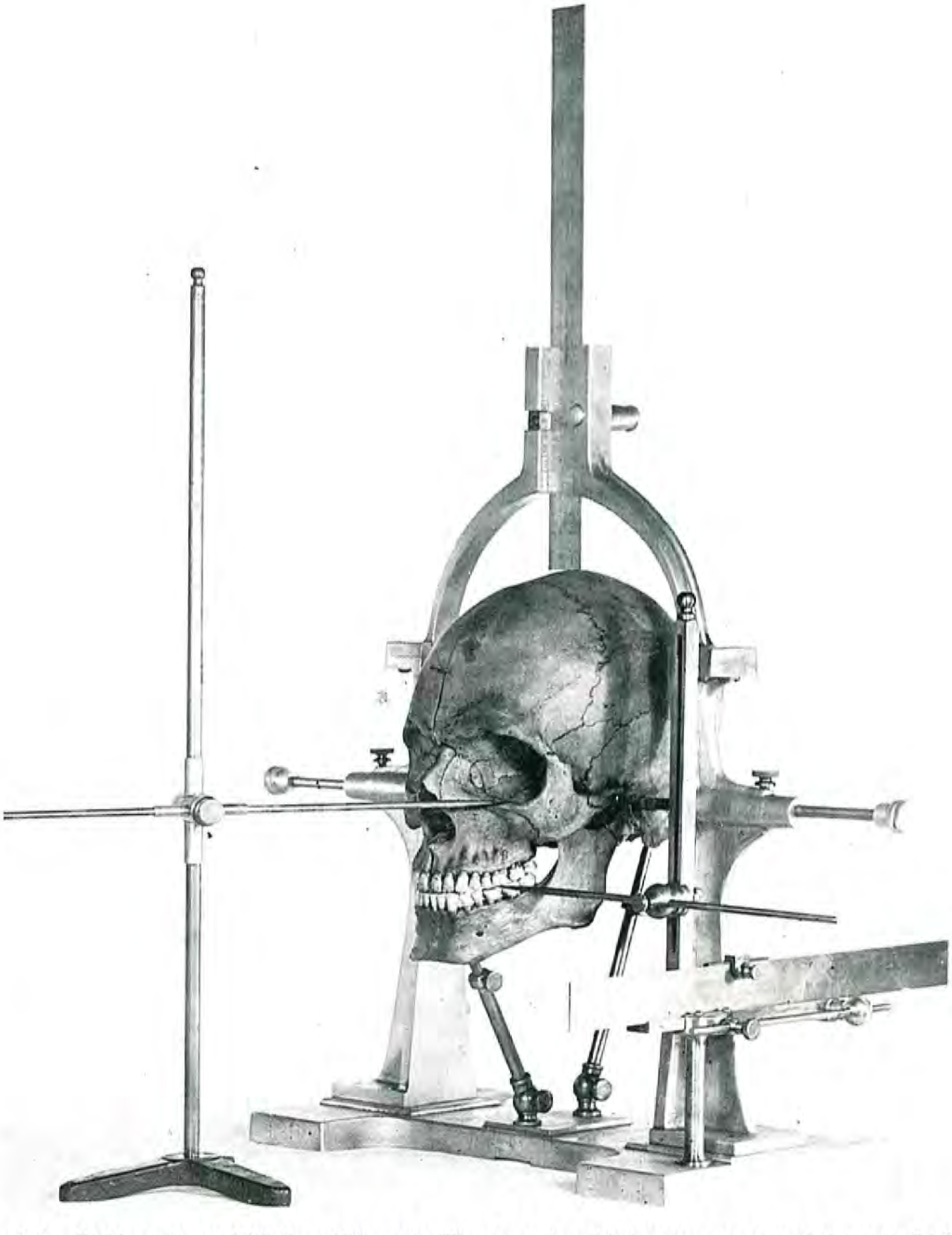
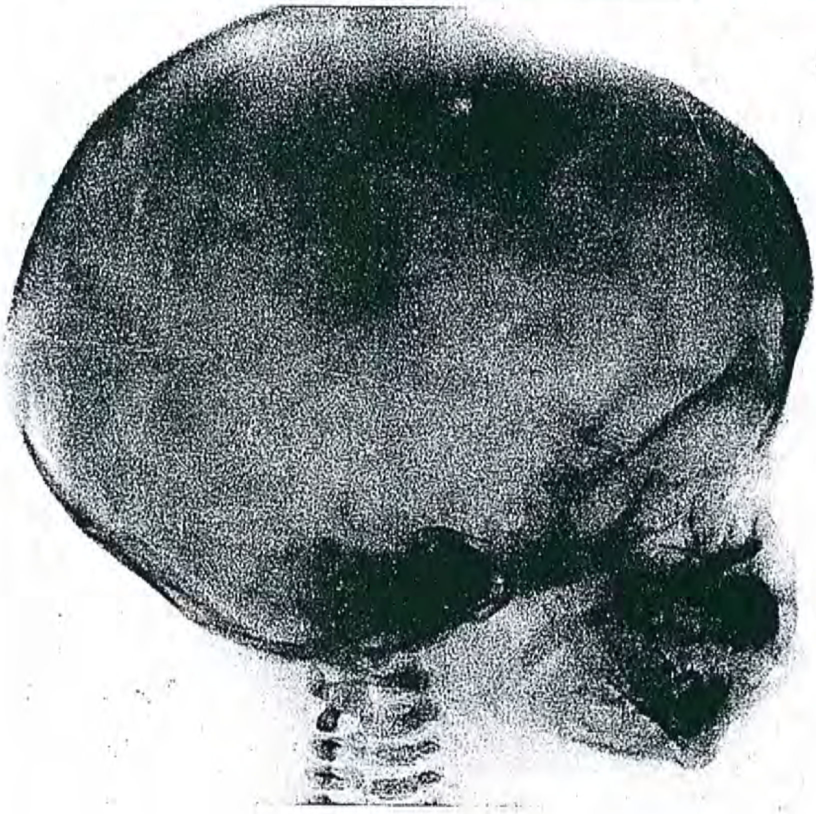


Fig. 2-3. Todd craniostat. With the addition of millimeter scales, this instrument was used to survey the Todd skeletal collection and investigate dentofacial relationships. (From Broadbent, B. H., Sr.: Dent. Cosmos **69:** 797-805, 1927.)

Fig. 2-4. Lateral radiograph. One of the initial craniofacial radiographs taken by Dr. B. Holly Broadbent, Sr., in 1921 for use in his clinical orthodontic practice.

Fig. 2-5. First recorded x-ray film of the living head taken by Sydney Rowland in 1896.



living head as accurately as the anthropologist surveys the dead skull. This led in 1925 to the design of the radiographic craniometer (Fig. 2-6).

The results of experiments with this new instrument indicated that dry-skull profile radiographs could be made that were so precise that different operators could produce identical lateral pictures. This, of course, significantly influenced the design of the head holder for the living head. Since the single view registered but two dimensions, the machine had to be redesigned so that it permitted not only the production of a standardized lateral radiograph but also a complementary frontal film. These were oriented so that they were in fact orthodiagraphic maps of the cranium and face, recording in the three-dimensional areas of space most of the internal, as well as the external, landmarks useful for measuring facial developmental growth and orthodontic changes.

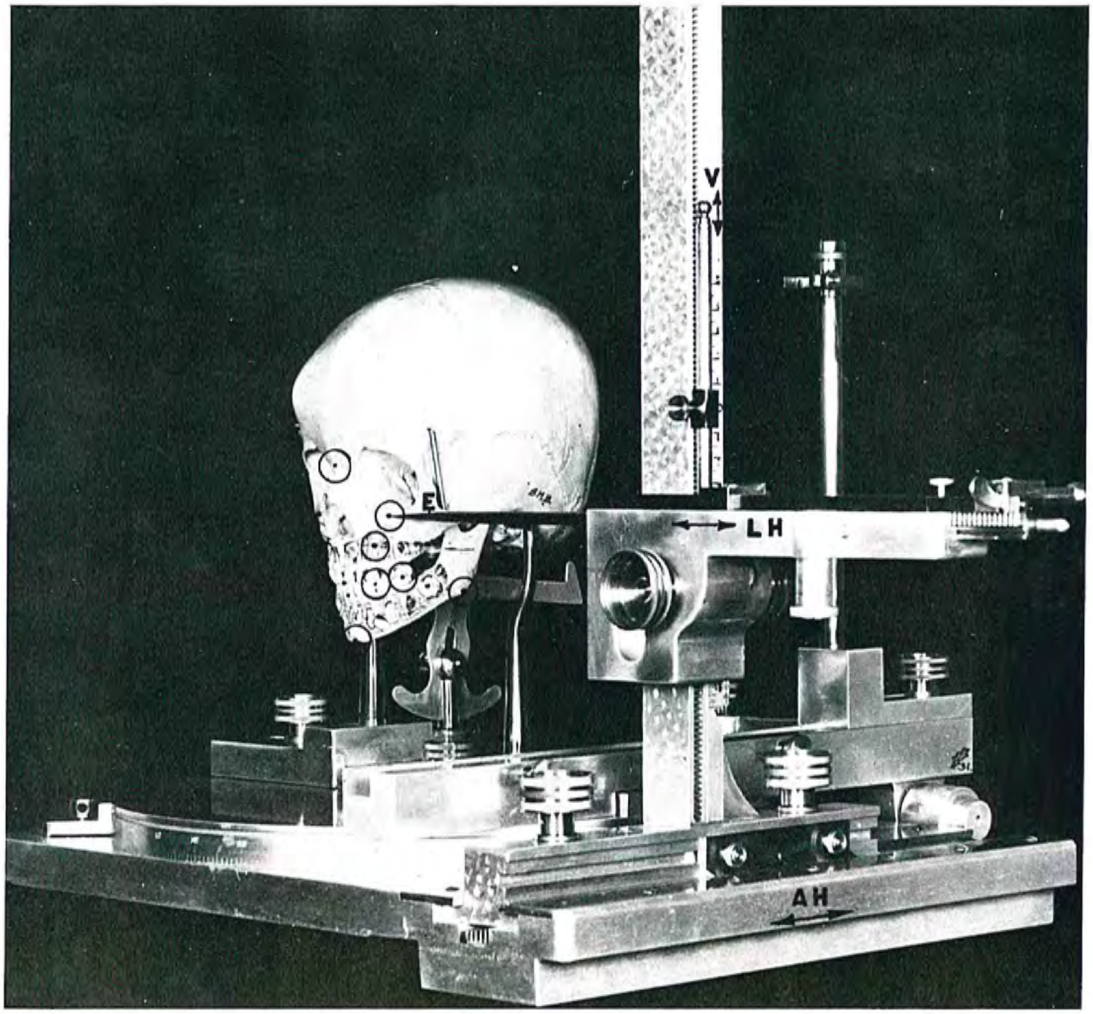


Fig. 2-6. Radiographic craniometer, equipped with a channel for supporting a film cassette in precise relationship to the skull for taking standardized x-ray films.

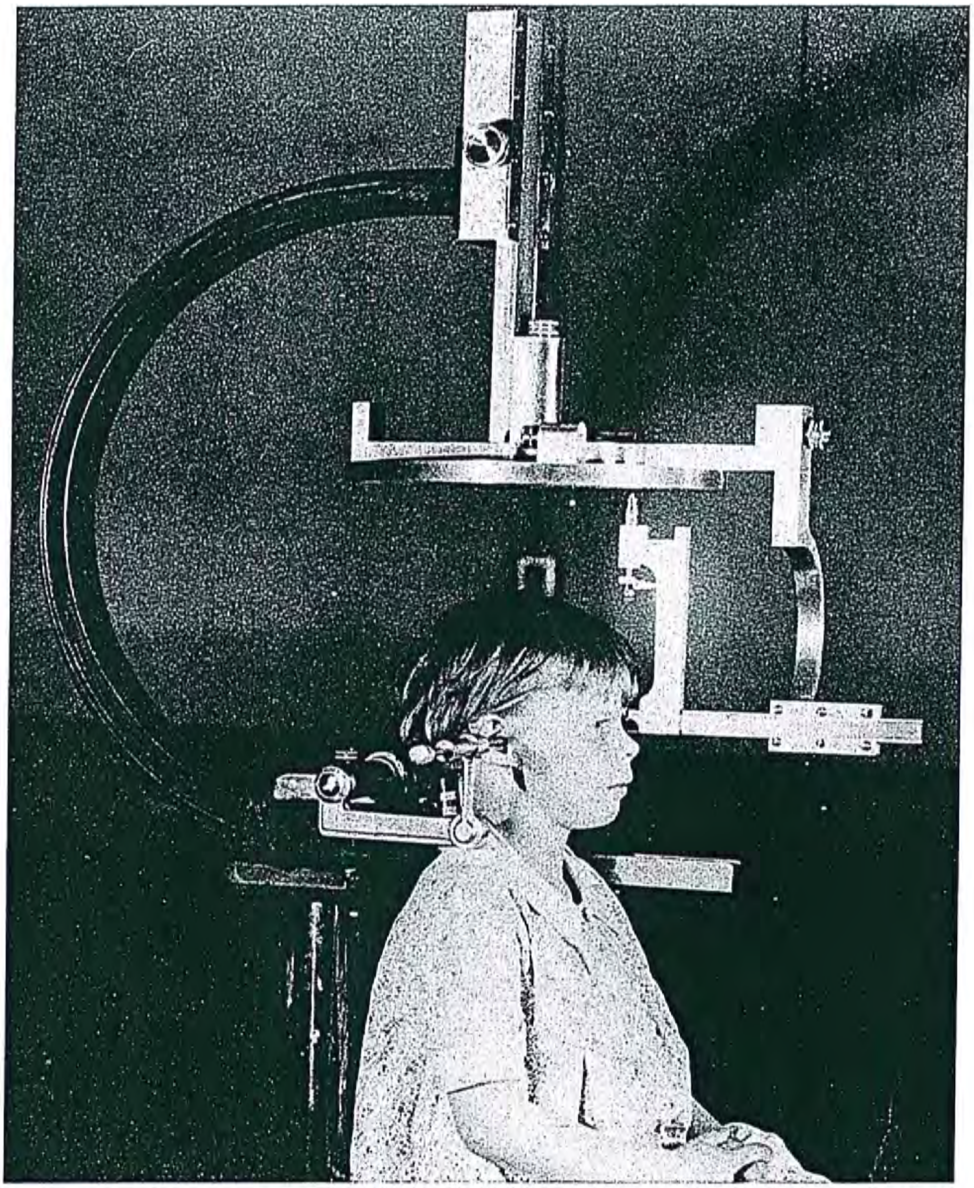


Fig. 2-7. First Broadbent cephalometer, which was designed to hold the living head in a manner similar to the radiographic craniometer.

In 1925 and 1926, experiments with the original head holder (Fig. 2-7) made possible confirmation of the probability that suitably oriented radiographs of the living head and face could be taken and that the results would equal those taken of the dry skulls in the craniometer. Also in 1926 a discussion of the study of normal growth of the teeth and jaws in healthy living children elicited the enthusiastic interest of the Honorable Frances P. Bolton (Fig. 2-8). She had always held a deep personal concern for the betterment of human health with her basic interests specifically oriented toward nursing. Her philanthropies in this area have been monumental; through her dedicated interest and generosity, the Frances Payne Bolton School of Nursing is an integral part of the Health Science Center at Case Western Reserve University in Cleveland.

Fig. 2-8. Frances P. Bolton, congresswoman, philanthropist, and humanitarian.

Experiments were continued, and the then-perfected radiographic cephalometer (Fig. 2-9) was produced to provide a technique suitable for a long-term longitudinal study of the face of the growing child. Early in 1928 former Representative Bolton, while her son, Charles, was undergoing orthodontic treatment, confirmed her keen interest in the study by offering to initiate a fund for the financial support of these investigations.

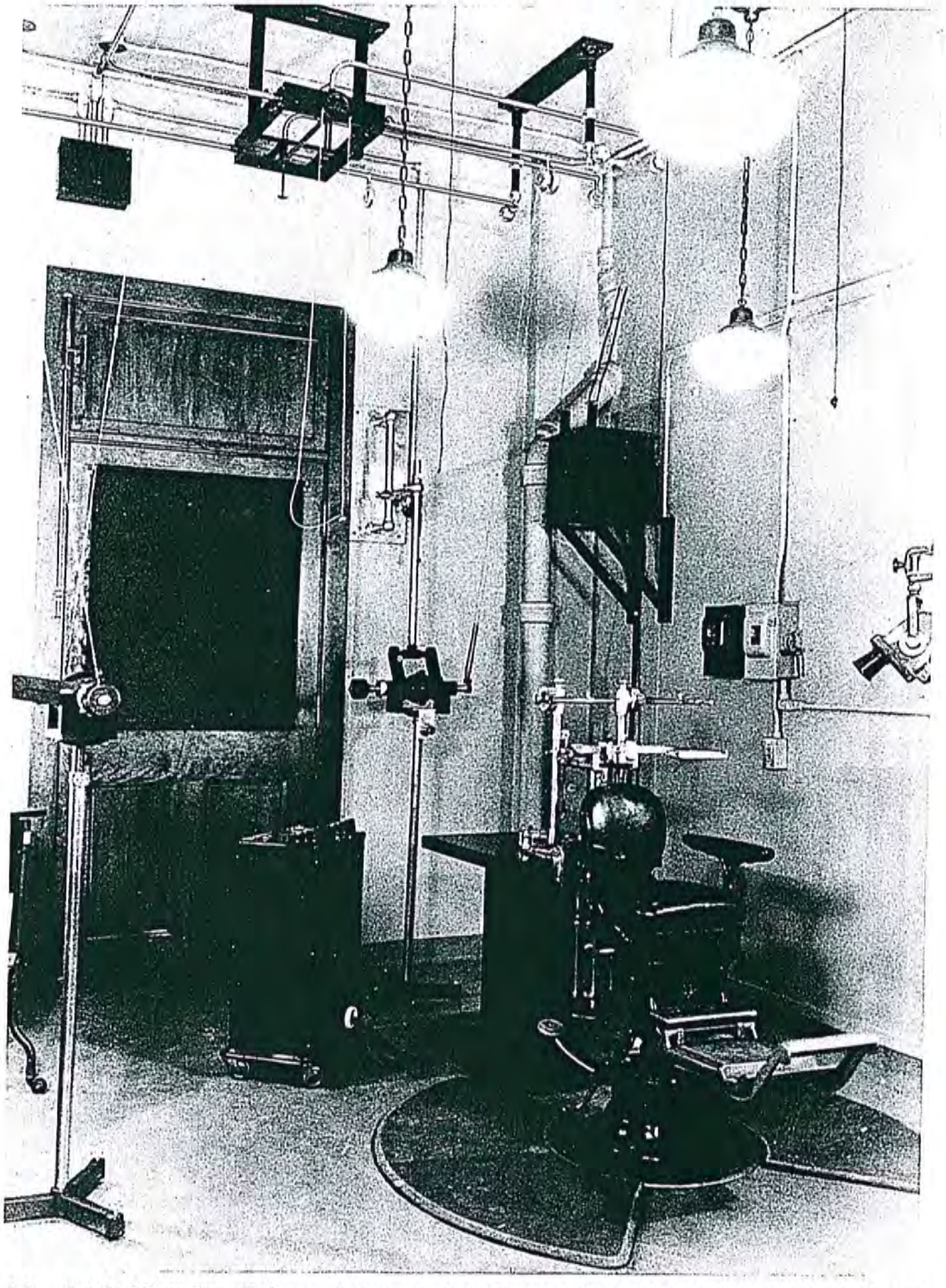


Fig. 2-9. Original Broadbent-Bolton cephalometer, completed in 1929 and designed for taking complementary frontal and lateral cephalometric radiographs. It is the head holder that was used to begin the long-term radiographic study of the growing child.

In October, 1928, the Developmental Health Inquiry by the Charles Francis Brush Foundation under Dr. T. Wingate Todd's direction was initiated; at that time the Charles Bingham Bolton Fund, through the patronage of Mrs. Bolton, was established for a five-year program as an independent, but coordinated, investigation.

In May, 1929, Dr. Broadbent presented a paper before the Eastern Association of Angle Graduates and, with the help of his lifelong friend Dr. Allan G. Brodie, demonstrated the radiographic cephalometer for the production of complementary lateral and frontal radiographs to study and measure developmental growth of the head.

In October, 1930, at the Conference on Adolescence, held in Cleveland, a paper, published in the proceedings of that meeting, was presented, describing the Bolton Study of the developing face of the growing child, utilizing x rays for accurate correlation of first and subsequent observations.[2] Again that year the Bolton technique was presented in the Report of the White House Conference on Child Health and Protection.[3] These papers and several presentations before orthodontic groups antedate the publication of "A New X-ray Technique and Its Application to Orthodontia."[4]

In 1931 Hofrath,[5] in Germany, published an excellent article on what he termed

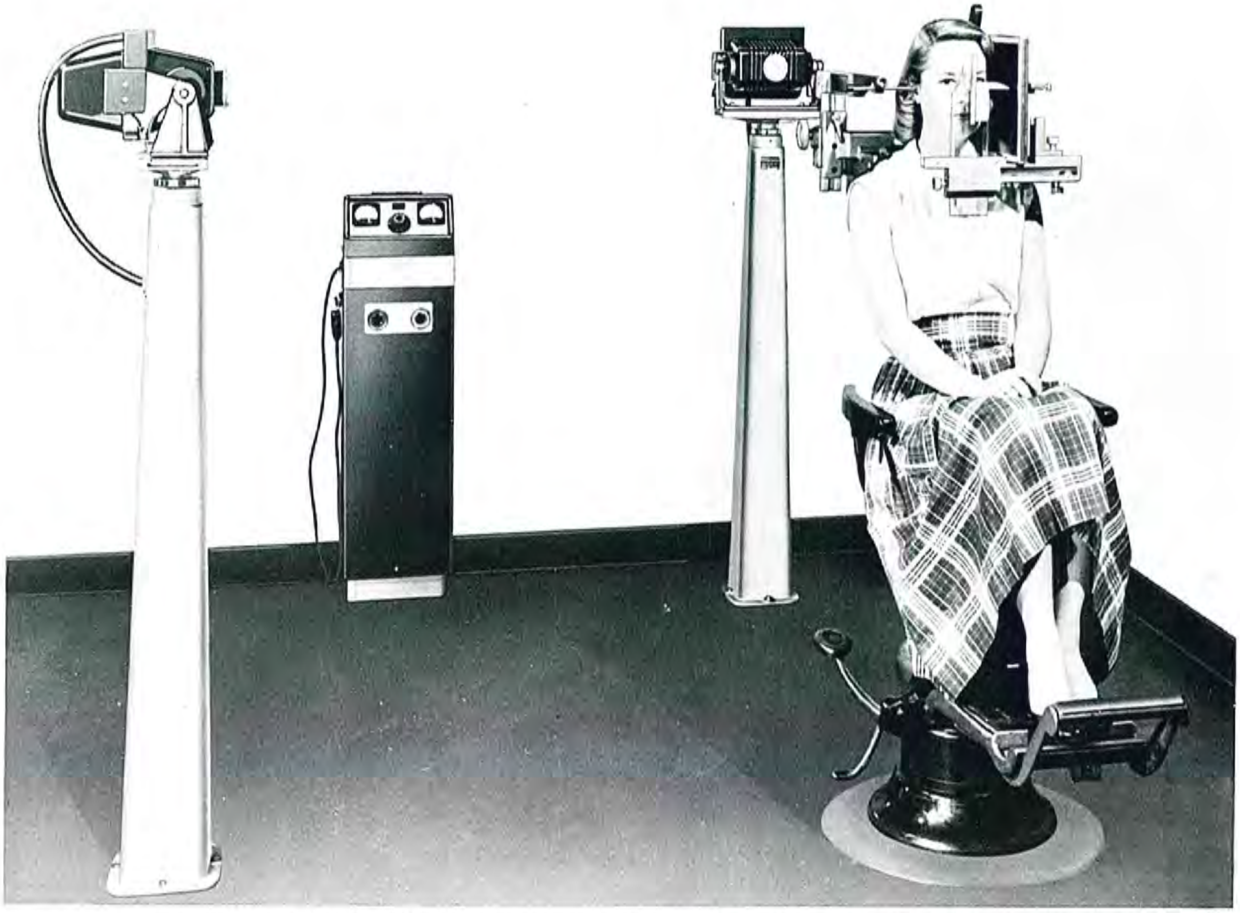


Fig. 2-10. Broadbent-Bolton radiographic cephalometer as it is currently used in the Bolton Study, Case Western Reserve University, Cleveland, Ohio.

teleroentgenography, describing a method for taking lateral head x-ray films in a fixed manner. It included representative photographs of craniofacial radiographs with polygonal patterns depicting the relationship of maxillary and mandibular components.

The period of the initial five-year program passed rapidly, and the Bolton family has continued to finance this long-term study since 1929. Frances P. Bolton and her son, Charles Bingham Bolton, have contributed an inestimable amount not only of their personal support, financial and physical, but also of their scientific knowledge and business acumen to the ongoing work of the Study. In addition, since 1932 they have made possible the provision of precision cephalometric equipment (Fig. 2-10), either as gifts or at less than the cost of manufacture to some forty other institutions and researchers, both in the United States and abroad. This was done to encourage similar investigations with a comparable technique to utilize to the best advantage the results of these studies of child growth and development, particularly as they related to the faces of children in other localities.

The animated motion-picture studies *Normal Dentofacial Growth* developed by the Bolton Study with the active participation of Charles Bingham Bolton (Fig. 2-11) have been unique in their graphic representation of the changes that occur during childhood and have become an integral part of the teaching of dentofacial developmental growth in many dental institutions.

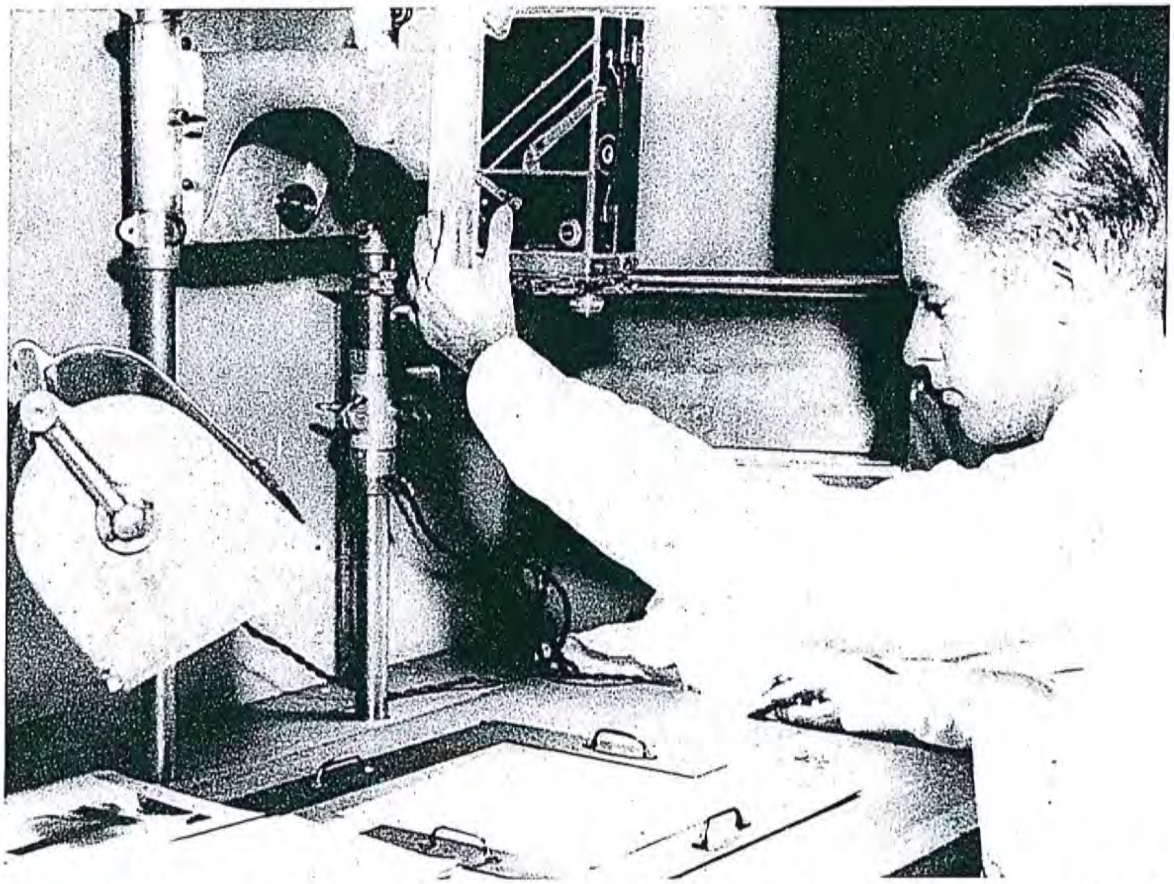


Fig. 2-11. Charles Bingham Bolton photographing cephalometric dentofacial tracings for the production of animated motion pictures on normal facial developmental growth.

In 1959 it was deemed advisable to gradually discontinue the collection of Bolton serial records to devote more time to study and correlation of the information collected. Since the embryonic completion of the male and female Standards in 1963, numerous changes and revisions have been executed as they were tested in routine clinical orthodontic practice. Literally thousands of tracings have gone into this refinement process, and the results are the combined frontal and lateral Standards presented in this atlas. The Standards themselves represent the interpolation of some 2,174 initial and averaged tracings.

The Bolton Study originally had the good fortune to be physically associated with the Department of Anatomy of the School of Medicine at Western Reserve University and more recently has been located in excellent facilities in the new School of Dentistry of the Health Science Center of Case Western Reserve University in the Bolton Dental Building. This was made possible in large part by the leadership and philanthropy of Charles B. Bolton (Fig. 2-12).

The close association of the Bolton Study with the Department of Anatomy continued after Dr. Todd's death under the able chairmanship of Dr. Normand L. Hoerr; and, as time progressed, the Brush inquiry records came under the general supervision and care of the Bolton Study. Through the cooperation of Dr. David R. Weir, Chairman of the Board of Managers of the Brush Foundation, a coalescence developed between the two collections of data, and from this relationship the Bolton-Brush Growth Study Center continues to carry on research in developmental growth. Over the years many students of child maturation and dentofacial development have utilized the records, and those involved in the Bolton Study have been pleased to have seen the emergence of a multitude of excellent research works based on the Bolton collected data.

Fig. 2-12. Charles Bingham Bolton. The dental building at Case Western Reserve University bears his name in testimony to his lifelong service to education in general and to dentistry in particular. (Photograph by Antony Gesù.)

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CHAPTER 3

Bolton radiographic cephalometric technique

CEPHALOMETRIC INSTRUMENT—PHYSICAL RELATIONSHIPS

One of the primary diagnostic procedures in analyzing a patient's dentofacial relationships is the production of high-quality cephalometric radiographs. Basic requirements in their production are a well-made cephalometer properly oriented to an x-ray source or sources and a careful and well-trained cephalometrist. The following discussion is oriented primarily toward the use of the Broadbent-Bolton radiographic cephalometer but has direct application in most instances to the many other cephalometers that are on the market and in use in clinical orthodontic offices. Because some of these instruments vary as to fundamental relationships, such as the target-object or object-film distance (Fig. 3-1), limitations are imposed on the films produced, and users of the Bolton Standards must understand that direct application of the Standards to their particular cephalometric radiographs may not be possible because of differences in technique. This situation will be the exception however. The historical background and basis for the initial standardization of cephalometric technique suggested by Broadbent, Sr.,[1] in 1929, may be found in *The Angle Orthodontist*.

The Broadbent-Bolton radiographic cephalometer is used in the Bolton Study; the instrument and the x-ray sources are positioned in a fixed relation to each other (Fig. 2-10). The anode target of each x-ray tube is placed at exactly 5 feet (1,524 mm.) from the cephalometer's center with the central ray of each tube at a right angle to that of the other (Fig. 3-1, *A*).

This relationship is achieved first by diagraming the tube and instrument positions on the floor and carefully leveling the cephalometer and adjusting the height of the tubes in relation to it. Second, the distance from each tube to the instrument center is carefully set, and the hypotenuse of the triangle formed by the two anodes and the instrument center is checked to ensure the perpendicularity of one central ray to the other.

Once the x-ray equipment is operable, "targeting," which requires the exposure of test films, is necessary for proving the alignment of the x-ray source with the instrument. The posteroanterior (P-A) check is made with a leaded cross hair guide placed on the posterior of the cephalometer. The x-ray beam casts a shadow of these leaded cross hairs on the ear rod shadows to verify correct vertical and horizontal positioning. The lateral beam casts the shadow of two lead rings that are placed one on the left ear rod and one on the right. The concentricity of these rings as seen in the test radiograph reveals either proper alignment or a need for adjustment if the shadows are not concentric. After the final test films are made, the cross hairs and lead rings are removed to be reemployed periodically to monitor the instrument-tube alignment continually. As described, the cephalometer–x-ray tube relation is a critical constant, whereas the distance from the instrument center (object) to the film is the variable.

This distance also may be maintained constant, thereby providing radiographs with uniform enlargement, but this would require an object-film distance great enough to accommodate the largest head that might conceivably be encountered. Thus the percentage of enlargement, although uniform, would be significantly larger in most instances than is necessary or desirable.

The Broadbent-Bolton instrument maintains the head at the instrument center and permits the film to be placed as close to that center as the head size will allow. The enlargement is thereby kept to a minimum.

Because of this enlargement factor, direct comparison *cannot* be made between cephalograms taken on a fixed-maximum object-film–distance machine and those taken on a cephalometer that has a variable distance between object and film surface, depending on head size. This difference may be seen in Fig. 3-2, two superposed records taken of a young woman at 21 and 24 years of age respectively, in whom one would logically assume no change in actual size between these ages. As the tracings of the radiographs indicate, an apparently

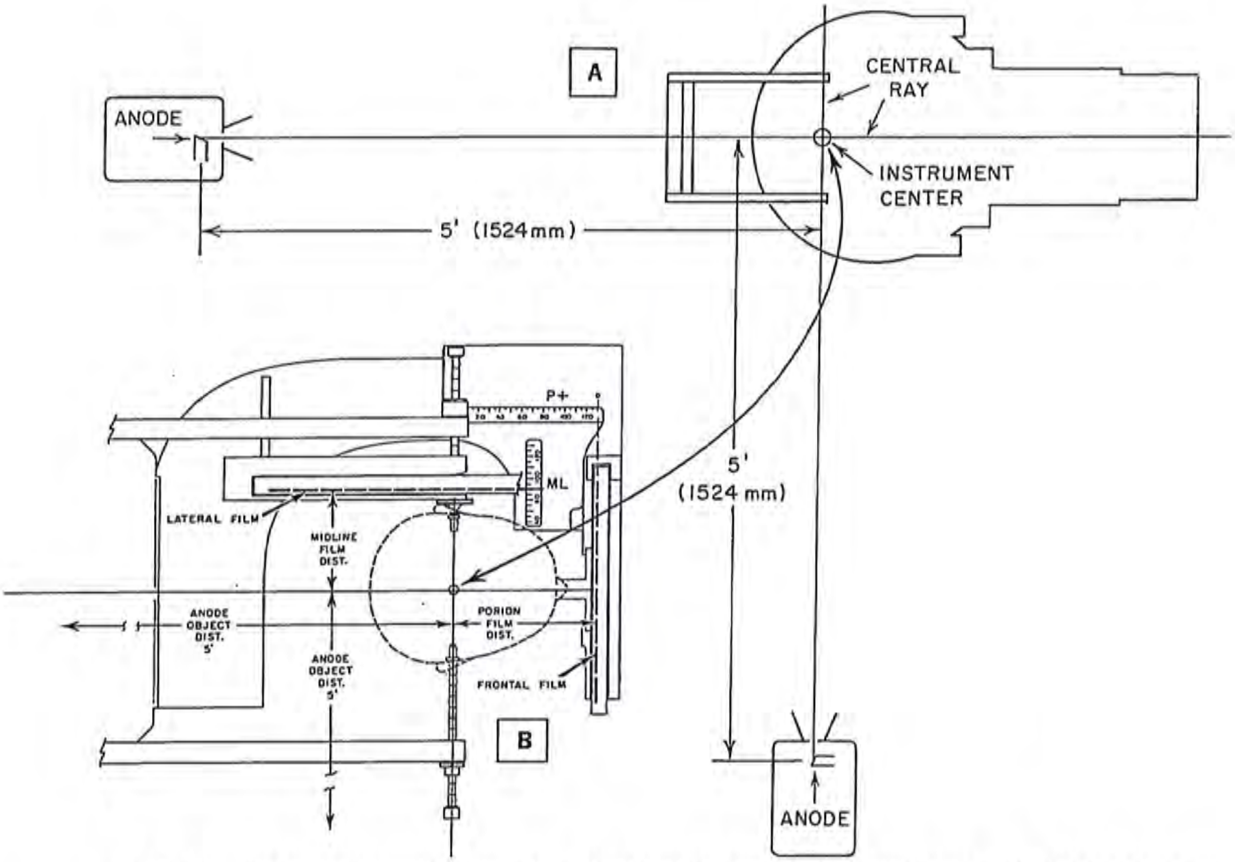

Fig. 3-1. Bolton cephalometric floor plan. **A,** Relation of the anodes, the central rays, and the instrument center. **B,** Relation of the instrument center to the lateral and frontal films and the M.L. and P+ scales.

significant change in size occurred between the first record taken by a fixed-maximum object-film–distance instrument and the second record, which had a variable object-film distance. Comparison obviously indicates that the film surface was closer to the patient's head in the second record taken at 24 years of age, significantly reducing the amount of enlargement and negating the possibility of making linear or size comparisons between the two.

The film distances are indicated on the instrument scales during each positioning and are recorded on the examination sheet. The *ML* is the midline-lateral film distance; the *P+* is the distance from the porionic axis to the frontal (P-A) film. (See Fig. 3-1, *B*.)

Radiographic shadow size relates to object size as anode-film distance relates to anode-object distance. To minimize enlargement of the radiographic shadow, use the maximum anode-object distance and the minimum object-film distance that is practical (Fig. 3-3). Thus the 5-foot anode-object standardization coupled with a variable (minimum) object-film distance has proved most satisfactory. (See p. 56.)

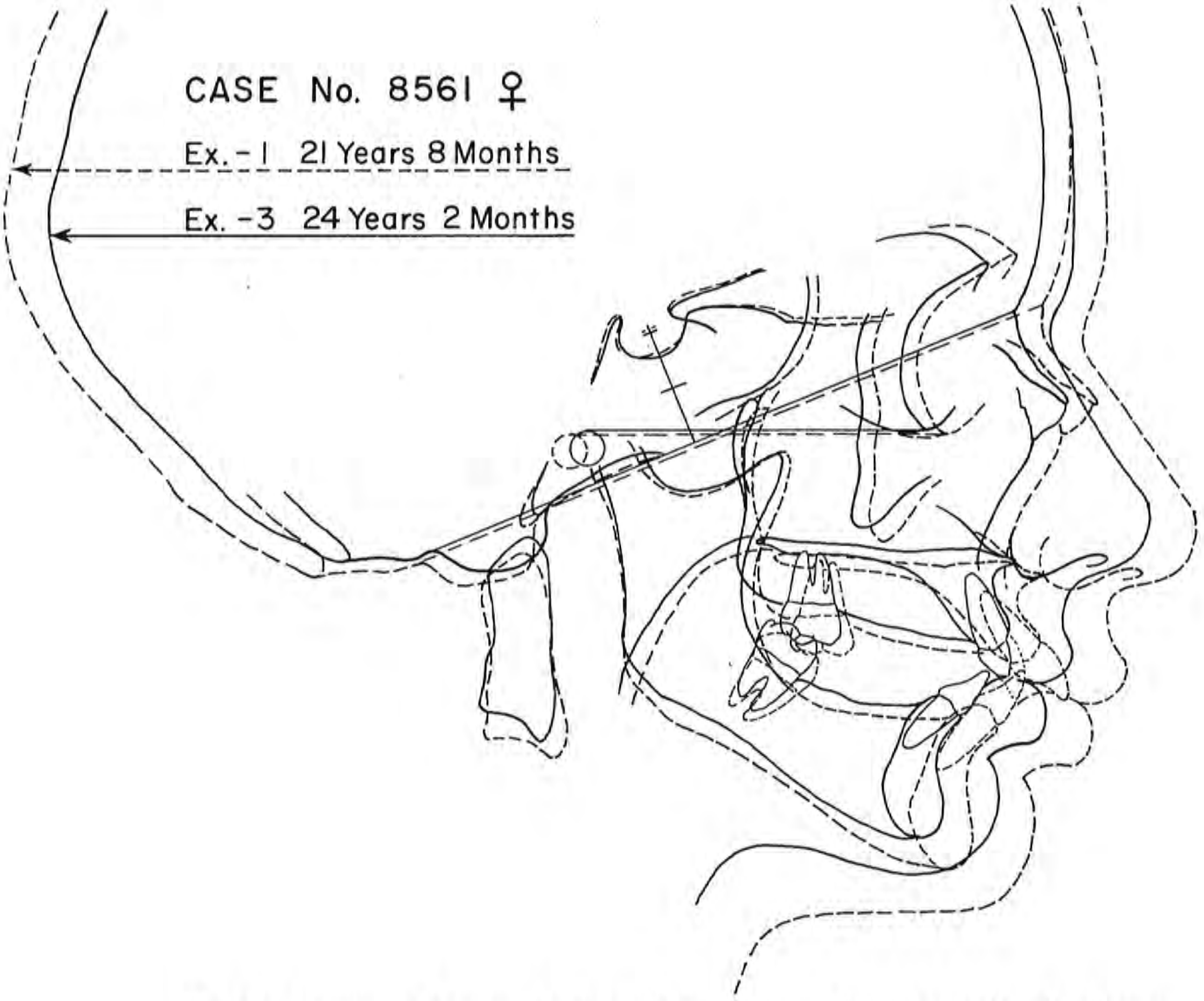

Fig. 3-2. Superposition of tracings. The difference in enlargement is due to varying object-film distances.

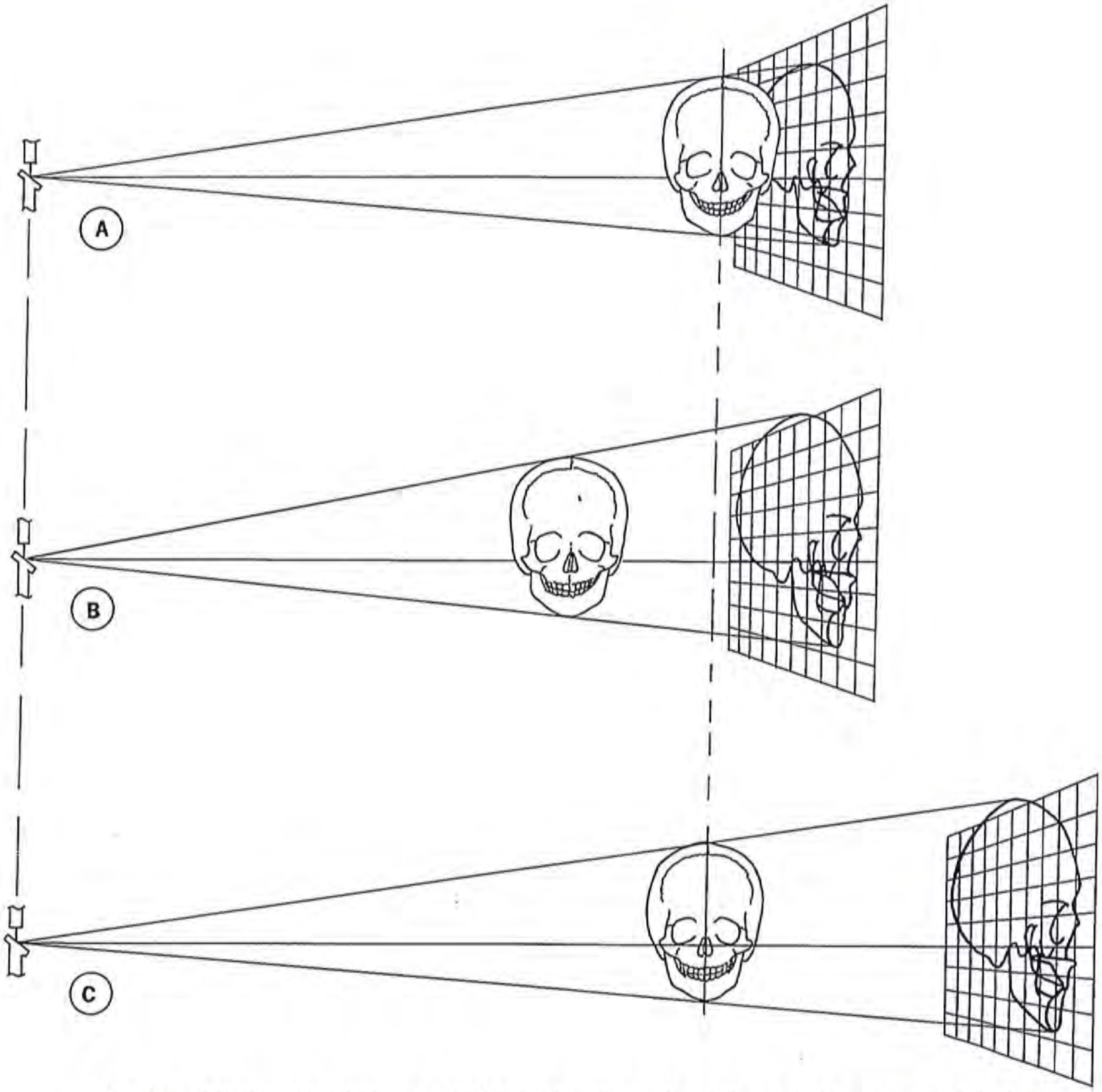

Fig. 3-3. Enlargement of shadow. **A,** Skull distant from the anode and close to the film produces minimal enlargement and a sharp shadow. **B,** Skull situated closer to the anode and more distant from the film produces unnecessary enlargement and less sharpness of the shadow. **C,** Skull far from the anode and also distant from the film produces unnecessary enlargement and less sharpness of the shadow.

FILM EXPOSURE AND PROCESSING

The correct exposure of the cephalometric x-ray film is determined in large measure not only by the type of film that is being used, but also by the density of the individual structures to be radiographed. In almost all instances, one should begin with average exposures and then refine the exposure chart by virtue of the clinical results with the cephalometer being used. In processing films the old adage "if one wants good advice, go to an expert" is well applied. The film manufacturers know the chemistry inherent in their products, and the practitioner, or clinician, is well advised to follow their recommendations unless a specific controlled experiment is being carried on. It is also sound advice to handle the many variables in cephalometric technique in such a manner as to change only one at a time, so that conclusive judgments may be made and changes because of poor results kept to a minimum.

X-ray processing technique is well known to all who deal with radiographic procedures, but a few admonitions bear repeating:

1. Handle all films with care and protect them from fogging, static electricity, physical scarring, and finger marks.
2. In the processing technique, make sure that adequate measures are taken to wash films thoroughly prior to their final drying. For records that will have long-term value, one must wash the films thoroughly, so that chemical change, or "yellowing," does not take place with aging.
3. Films should be carefully guarded against mechanical damage. This includes protection during tracing procedures from excessive heat, which will cause warping, and also protection against pinhole or pencil marks, which will permanently damage the film and adversely affect its future usefulness.
4. The operator is well aware but should be reminded that all necessary protection from x rays should be provided both for the patient and for the operating and nearby personnel.
5. A well-documented record of exposure, milliampere seconds, kilovoltage, and other such factors should be kept of each radiograph taken because this will allow not only for proper correction of exposures if necessary at a later date, but also will provide documentation of the patient's radiographic exposure history. Cephalometric radiography, because of the use of such devices and methods as intensifying screens, diaphragming, double-emulsion films, and relatively high kvp, is an extremely "safe" radiographic diagnostic procedure.

TRACING CEPHALOMETRIC RADIOGRAPHS

To facilitate cephalometric analysis and measurement, the most common method used is the tracing of pertinent detail directly from the film on 3/1,000 inch matte acetate. Tracing presents several advantages: linear and angular measurements may be made accurately and rapidly; any errors in interpretation may be corrected easily and without damage to the film; several tracings may be superimposed to compare individuals or serial records of the same individual; and they may be compared with standards, grids, or untraced cephalometric films. The films themselves cannot be superimposed in the same manner, since the density of each obscures the other. Additionally the overabundance of unessential shadow detail in the film itself tends partially to obscure the more important structures being compared.

The quality of the cephalometric film pairs determine to a great degree the amount of usable information that can be derived from each. This depends on the care and skill of the cephalometric technician, positioning of the patient in the cephalometer, taking of both a lateral and a P-A view while the patient is immobilized, use of the proper exposure, and recording of the distance from the instrument center to the film. The importance of this last may be judged by once again comparing the superimposed tracings in Fig. 3-2. The object-film distance factors involved in the production of complementary lateral and frontal cephalometric radiographs must be known so that the necessary mathematical corrections and direct correlations may be made.

Most cephalometric equipment requires that the patient be turned, or rotated, 90 degrees between the lateral and P-A exposures. Care should be exercised in this procedure, for, if the head moves relative to the film plane, orientation of the two films will be more difficult.

Whether or not one traces and compares frontal (P-A) views, a two-dimensional lateral film does not contain sufficient information to depict the three-dimensional head. Even if only the lateral film is routinely traced, the P-A view is important as an aid in the interpretation of the lateral. The anterior teeth and their apexes can be seen much more distinctly in the P-A view, and this type of information can, by orientation or other means, be applied to the lateral view.

The tracing trainee should have or acquire a general knowledge of the anatomy of the head, particularly the skull, as well as having basic artistic ability and an understanding of perspective. A gradual introduction to cephalometric film tracing has the advantage of familiarizing beginners with the basic dental units and facial structures before they are confronted with, and possibly overwhelmed by, the many alien bilateral forms. A good fundamental approach is to start with the tracing of periapical dental films to gain familiarity with the radiographic images of individual teeth. The next step is the tracing of a radiograph of a half skull, prepared by sectioning along the midsagittal plane, since this gives a clearer, unilateral picture. (Use nonscreen film to preserve detail.) Also a pair of three-dimensional films can be made to be used in a stereo x-ray viewer for exceptionally fine appreciation of the related unilateral structures. The half skull itself should be available for examination while being traced, to relate the x-ray shadows directly to the bony structures of the skull.

Tracing materials and equipment

The tracing surface should be of either opal or clear glass backed by milk white diffusing plastic. The latter has the advantage of allowing a black mask to be placed between the glass and plastic to effectively block the extraneous light around the periphery of the film. The hard glass surface also permits the use of a knife to cut the sections of drafting tape that are used in positioning and holding the film without marring the table surface. A sharp-pointed H or 2H drawing pencil is recommended.

The lateral film is placed on the tracing surface facing to the right, so that the tracer's viewpoint simulates the anode position. It is then located in the proper relationship to the mask and taped down firmly at all four corners. Next the matte acetate (3/1,000 inch) is placed on the film with the upper edge ½ inch below the upper edge of the film and the left side of the acetate ½ inch to the right of the left (posterior) edge of the film. Only three corners of the acetate are taped, leaving the lower right corner free to be turned up, exposing the dentofacial parts of the skull. The tape should be placed so that it adheres to the acetate, the film, and the glass surface. The hinge method of taping the acetate to film should not be used, since it allows too much play and may result in poor registration between tracing and film.

Although the operation itself is relatively simple and clear-cut, when the tracing is partially finished, the penciled outline of the dental units already traced tends to obscure the other parts. Therefore for clarity one-half sheet of acetate is taped directly to the dentofacial area of the film under the loose corner of the master-tracing acetate. The dental units that were, in part, hidden by the completed areas of the tracing now afford an unobstructed view and may easily be traced on the half sheet. From this outline they then may be transferred to the final tracing. It is hoped that this method will remove the urge to lift the tracing and mark directly on the film itself.

Lateral anatomic structures traced

An almost unlimited quantity of detail can be traced from cephalometric films, but usually a limited amount of this information is of direct interest to the clinician. The following list

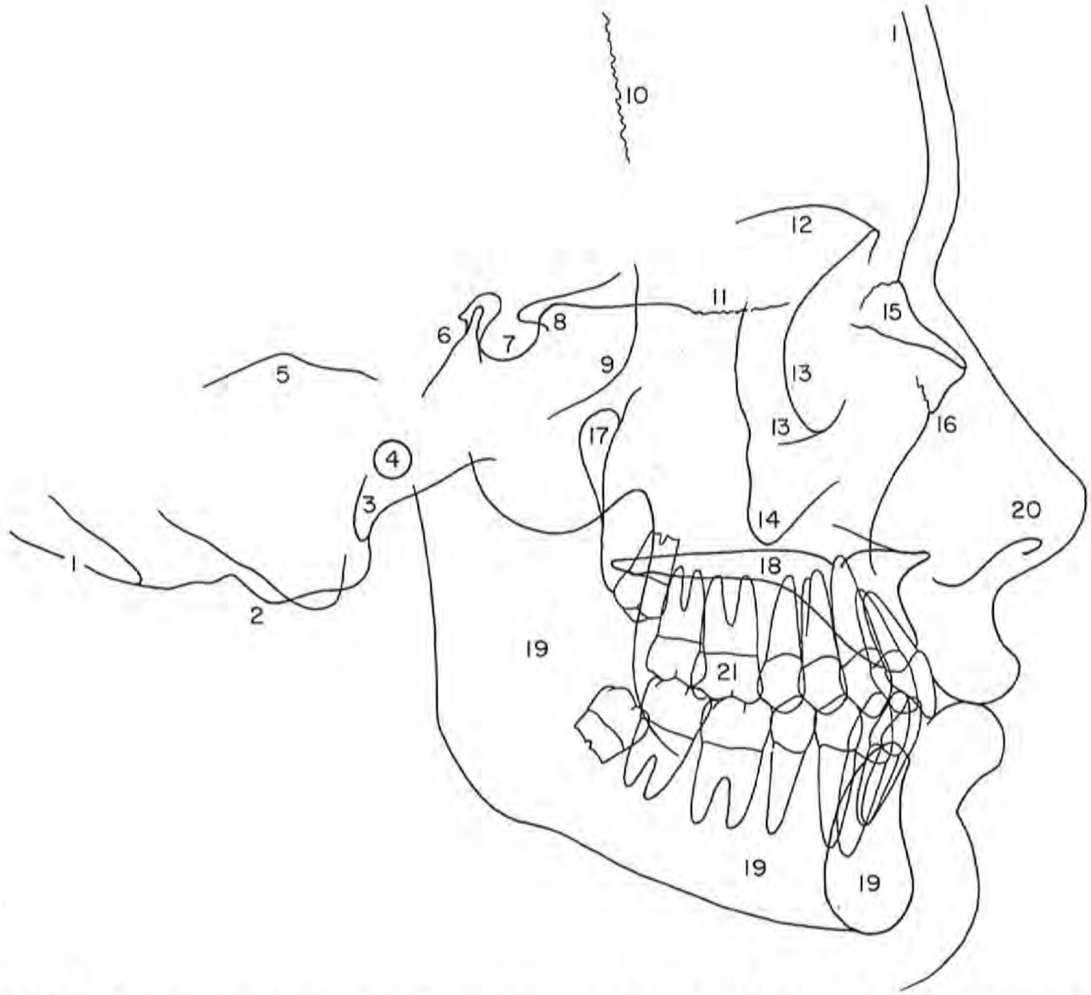

Fig. 3-4. Lateral tracing, showing the outlines more commonly traced. The numbers refer to the description in the text.

briefly describes the lateral structures more commonly traced. The numbers refer to the lateral diagram (Fig. 3-4).

1. Peripheral external surface of the cranium: frontal, parietal when visible, and occipital
2. Occipital condyles, frequently superimposed and appearing as one, the superposed outline being the mastoid process of the temporal bone
3. Cross section of the anterior margin of the foramen magnum, the lowest part of a triangular wedge (i.e., the basal portion of the occipital bone)
4. External auditory meatus, not generally seen because of the ear rod and ear rod support, usually drawn in with the template of the ear rod
5. Arcuate eminence, used chiefly as an aid in orientation, since it is generally seen in both views
6. Posterosuperior surface of the sphenoid bone from the speno-occipital suture up to and including dorsum sella
7. Pituitary fossa, including anterior and posterior clinoid processes, also the middle clinoids when visible
8. Tuberculum sellae, planum, and sphenoethmoidal junction

9. Cerebral surface of the greater wing of the sphenoid bone, which partially forms the middle cranial fossa
10. Coronal suture
11. Superior surface of the cribriform plate of the ethmoid bone, not generally well defined and not to be confused with medial ridges of the orbital plates of the frontal bone
12. Inferior surface of the orbital roof or orbital plate of the frontal bone
13. Orbital margins and orbital floor
14. Key ridge, which is the cross section of the anterior root of the zygomatic arch
15. Nasal bones and nasofrontal suture
16. Anterior edge of maxillary and nasal bones, which form the lateral limits of the nasal aperture
17. Pterygomaxillary fissure down to and including the tuberosity of the maxilla
18. Hard palate, generally seen as a single outline representing the roof of the mouth and the floor of the nasal passage and occasionally as two palates when the heights of the right and left sides are different, confirmed by inspection of the P-A film
19. Mandible, the ascending ramus, including the coronoid processes, the body, and the symphysis
20. Soft tissue profile
21. Complete dentition or selected units

Complete skull, lateral, and P-A films

The next logical step after having satisfactorily mastered the tracing of a half skull is, of course, to trace the complete skull. At this point one must introduce the P-A film, which is included not solely for its own practical value but also for its significant assistance in the interpretation of the lateral.

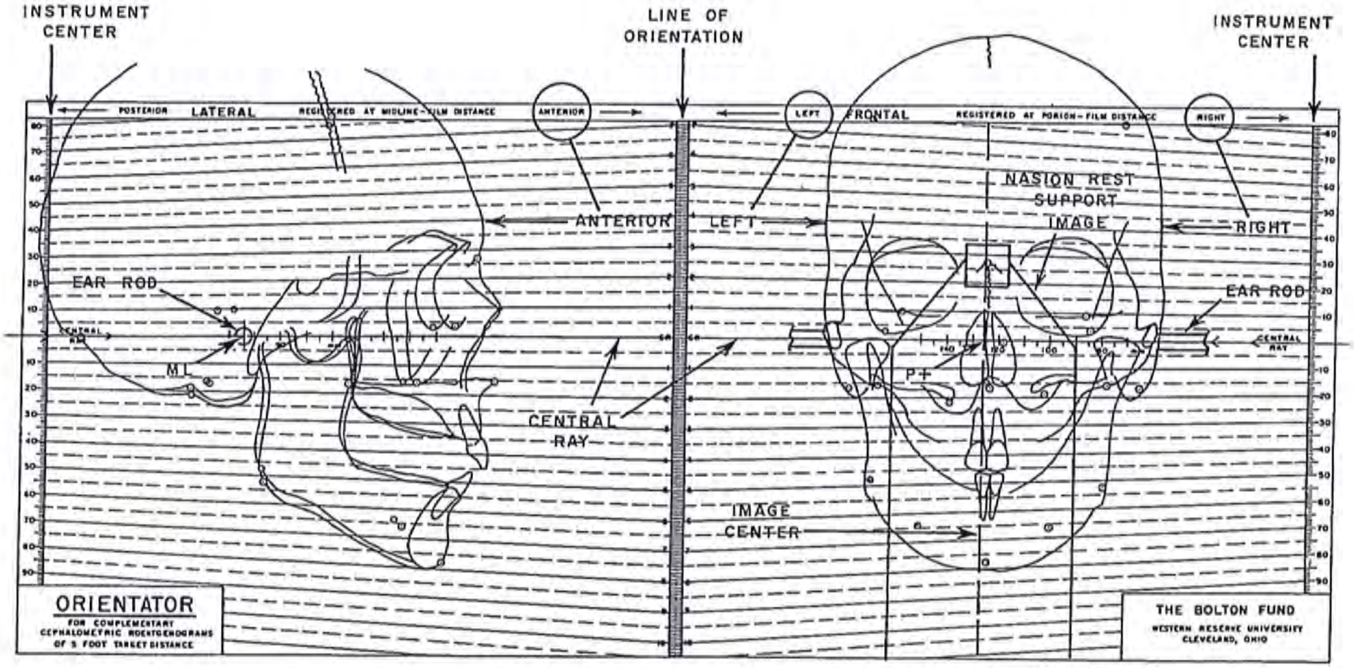

Fig. 3-5. Bolton Orientator with lateral and frontal tracings in position.

Before describing the structures traced in the P-A film, however, we must digress briefly to understand a few additional factors that enter into the proper interpretation and tracing of both the lateral and frontal films.

Direct correlation of the two films is possible through the design and use of the Bolton Orientator, which relates the lateral to the frontal views as they were related during the projection of the image of the head by the radiographic beam at the time that the films were taken (Fig. 3-5). The following is a brief discussion of the Orientator, which will be more fully developed later, and also a short description of enlargement, perspective, and averaging techniques, which will precede the description of the P-A film and how it is traced.

BOLTON ORIENTATOR

The Orientator is a rectangular sheet of transparent material approximately 20 inches wide and 8 inches high. The ends of the sheet are marked with vertical lines that represent the center of the cephalometer (Fig. 3-5). The Orientator is divided at its midsection by a vertical line that represents *both* the lateral and P-A films (line of orientation). It is traversed at about half its height by a straight horizontal line that diagrammatically represents the central ray of the x-ray beam. Along the ends of the sheet at 5 mm. intervals both above and below the central ray are additional lines that simulate the ray lines and diverge as they approach the center of the Orientator at the line of orientation. The divergence, or angulation, of these lines is based on a radius of 5 feet from the end of the sheet, which as noted represents the instrument center. These divergent lines correspond to the path of the radiation beam of x rays that initially cast the head or skull shadows on the films.

The central ray line is scaled in centimeters and millimeters, so that the films may be located at their appropriate object-film distances. The accurate recording of this distance at the time that the cephalometric films are exposed is necessary for this procedure. When the films are properly placed on the Orientator and their attitude, or relation to each other, is established, the exact height of an object in either the lateral or P-A view may be projected to the complementary film. As mentioned before, the Bolton Orientator and its uses will be explained more thoroughly later.

Enlargement perspective and distortion

Because the functioning of the Orientator is dependent on the mechanical relationships of the image projected by the x-ray beam, a short discussion of these factors will help to clarify the concepts involved in direct comparison of frontal with lateral structures.

Enlargement may be considered comparable to perspective in many ways when the viewpoint, or x-ray anode source, is situated at a practical (5-foot) distance from the object in relation to its size. If, however, the viewpoint, or anode, is located too close to the object, the perspective and enlargement will be altered to such a degree that the image will appear to be distorted because the structures of one side will be enlarged to a much greater degree than those of the other. Most cephalometric pairs of films are exposed at a 5-foot (60-inch) anode-object distance, and this then minimizes differential enlargement. The sagittal and frontal planes of the head, as well as the film planes within the cassettes, must be maintained in a position perpendicular to the central ray to avoid distortion because of foreshortening by head tilt and elongation by the film tilt (Fig. 3-6, *B*).

The lateral film of a true cephalometric pair will show moderate enlargement of all shadows with the right-hand structures enlarged to a greater degree than those on the left hand. (Remember that the Bolton radiographic cephalogram is produced with the left side of the

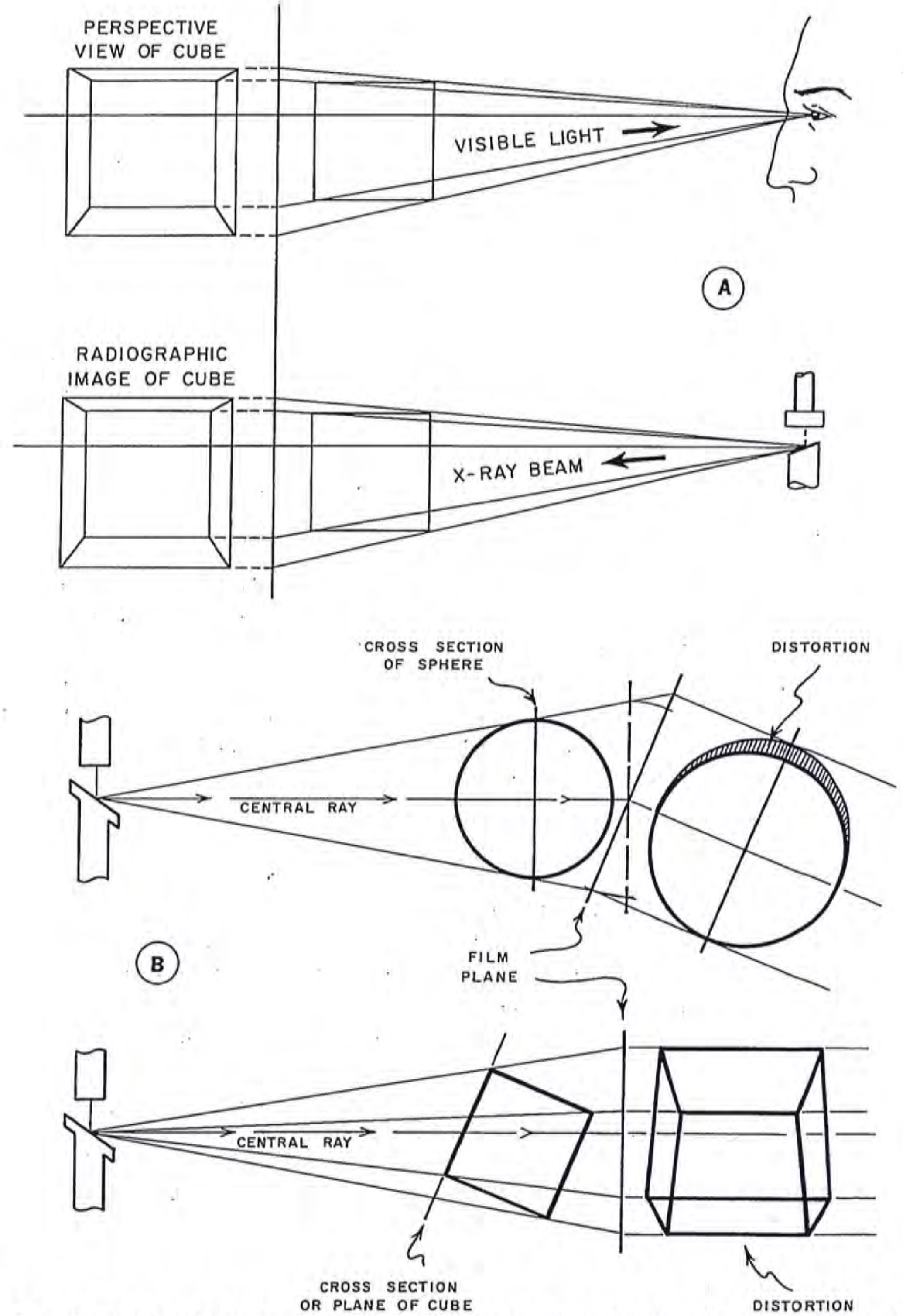

Fig. 3-6. Perspective and distortion. **A,** Similarity of perspective view and radiographic image. **B,** Distortion because of lack of parallelism between cross section of object and film plane.

head toward the film.) With a symmetrical skull properly positioned in the cephalometer, the lateral x-ray film will show the shadow of the right-hand structure of a bilateral pair to be the farthest from the ear rod image; for example, the lower borders of the mandible are displaced from one another in the lateral projection, and, with a symmetrical subject, the right mandibular border will be projected lower on the film than the left.

The size, location, and relationship of various right and left structures as seen in the lateral film are similar to what would be seen from a viewpoint 5 feet distant from the same object if it were transparent. The lateral headplate with its inherent enlargement can be viewed as a two-dimensional picture containing simple linear perspective.

In one facet of this comparison, the x-ray film image and the direct view differ, and that is the clarity, or distinctness, of image of the opposing sides. In direct viewing, the near side would obviously be more distinct and detailed except perhaps to a hypermetropic person. On the other hand, in the radiograph the far side will appear a little more sharply defined because of its greater proximity to the film during exposure (Fig. 3-6, *A*).

Paired structure averaging in tracing

The x-ray shadows of anatomic structures are enlarged to varying degrees, depending on their distance from the film. Within a single plane, any and every object or dimension that is perpendicular to the central ray and parallel to the film will be enlarged to the same degree regardless of proximity to, or distance from, the central ray. This enlargement factor, if not properly manipulated, can introduce error into either linear or angular measurements.

As an example, assume that the vertical distance of three points is being measured below the Frankfort plane. The points are right gonion, left gonion, and gnathion. The right gonion, being the farthest from the film, will have its distance below the Frankfort plane increased by the greatest percent of enlargement; the gnathion, situated in the sagittal plane, will be displaced downward by a smaller percent of enlargement; and the left gonion, situated nearest the film, will be displaced the least. The vertical distance therefore from the Frankfort plane to each of these points has changed to a different degree. If the Frankfort-mandibular plane angle is measured, it too then will be changed. The mandibular plane, drawn from the gnathion to either the right or left gonion, will obviously have its angular relation to the Frankfort plane changed by this unequal displacement of these three points.

Probably the most expedient method of coping with this obvious disparity, as it relates to differential enlargement, is the averaging of all bilateral structures in the tracing. The averaged tracing, as it will be described, may be treated as a midline structure, and thus being a single plane, the enlargement factor is the same throughout.

Note, however, that a minute (negligible) error is involved in this method; for example (Fig. 3-7), with a 60-inch anode-object distance, a 90 mm. object-film distance, and two landmarks (right and left gonion) located 60 mm. below the central ray and 80 mm. apart, the error involved in averaging the two points would be 0.044 mm. This is less than the width of a thin pencil line and so minimal as to be inconsequential in the light of the overall accuracy obtainable by the tracing method.

The technique of averaging bilateral structures is a straightforward and relatively simple operation. The tracer must average anatomically similar portions of the structures point by point, not simply the adjacent portions.

As a good exercise in averaging, a few irregular structures may be traced on acetate—for example, the lateral view of an orbit, one side of the mandible, and the key ridge. Having completed the first outlines, retrace each of them on another sheet of acetate. Now place one

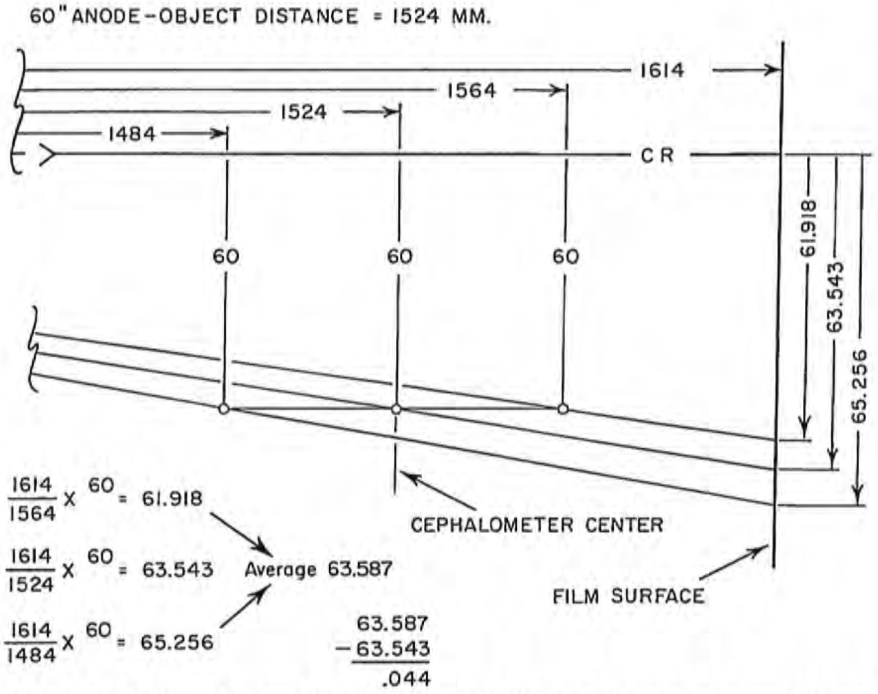

Fig. 3-7. Average and midline. Diagram illustrates the slight difference between an averaged point and a true midline point.

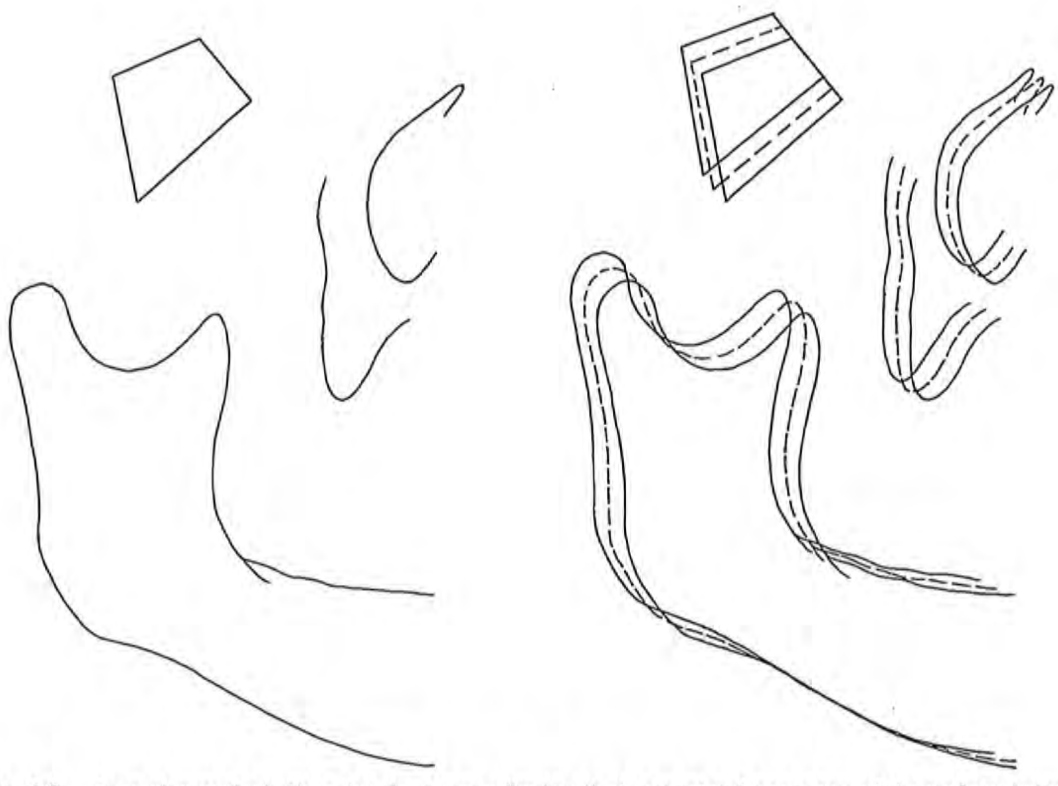

Fig. 3-8. Averaging method. Note that the average (broken line) maintains the contours of the surfaces being averaged. The average depicts identical facets of right and left structures and not simply adjacent structures.

of these tracings over the other, and offset the similar outlines by 3 or 4 mm. (Fig. 3-8). An average may now be traced for each of these pairs. On completion reregister the two originals with the average, and they should all be identical. If not, the averaging was done incorrectly.

Tracing suggestions (frontal structures)

Using the Bolton Orientator in tracing complementary lateral and P-A films will enable one to project the height of objects seen in one film to the other, in which their locations may be questionable. This procedure will also be of significant assistance to the beginner in the anatomic interpretation of the films.

When they are oriented to each other, place a tracing acetate over the lateral film, as previously directed, and then place tracing acetate over the P-A view of the skull about ½ inch below the top of the film. Tape the acetate down at the upper corners so that the tape adheres to acetate, radiograph, and glass tabletop. Tape the sides of acetate down firmly near the level of the central ray, leaving the lower portion free, so that it may be turned up to expose the dental area. An additional one-fourth sheet of acetate should be taped beneath this directly to the radiograph, covering only the dental area. This will be used as a work sheet under the master tracing.

As in the half-skull tracing procedure, a complete skull, as well as a three-dimensional (stereo) lateral and P-A radiographic film pair, will prove invaluable in helping to recognize the closely associated shadows of the many anatomic parts.

To begin one may trace the midline structures seen in the lateral film: the occipital, parietal, frontal, and nasal bones, the maxilla, the sphenoid bone, and the symphysis of the mandible. The films on the Orientator, traced as a complementary pair, aid each in the interpretation of the other. The following structures are basic to the tracing of the P-A film, and the numbers refer to the P-A diagram in Fig. 3-9. Other structures, of course, may be added or deleted to suit the needs of the investigator.

1. External peripheral cranial bone surfaces
2. Midsagittal and coronal sutures
3. Mastoid processes
4. Occipital condyles and basion when visible
5. Planum of sphenoid and superior surface of the floor of the pituitary fossa
6. Nasal septum, crista galli, and floor of the nose
7. Orbital outline and inferior surface of the orbital plate of the frontal bone
8. Oblique line formed by the external surface of the greater wing of the sphenoid in the area of the temporal fossa
9. Arcuate eminence
10. Lateral surface of the frontosphenoidal process of the zygoma and the zygomatic arch down to and including the key ridge
11. Cross section of the zygomatic arch
12. Infratemporal surface of the maxilla in the area of the tuberosity, which is seen lateral to the lower reaches of the key ridge after the eruption of the first permanent molars
13. Body of the mandible, the ascending rami, coronoid processes, and the mandibular condyles when visible
14. Complete dentition or selected dental units

Again the greatest amount of information from a pair of cephalometric films may be gleaned by working from one to the other. Trace a structure in one view; then locate the corresponding object in the other film.

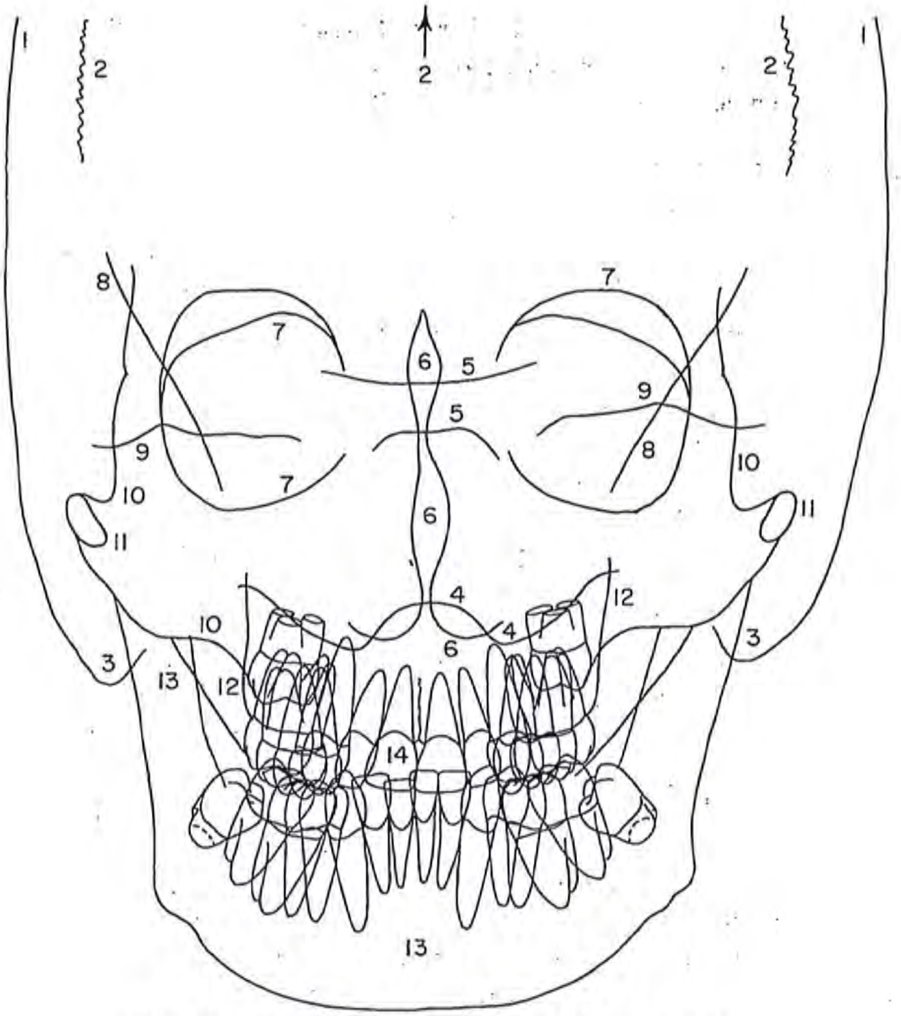

Fig. 3-9. P-A tracing. Numbers refer to description in text.

Most of the anatomic features of interest in the P-A film may be traced directly on the master-tracing acetate, since no averaging is required in this view. Care should be exercised that the lines of the tracing represent accurately the surface of the anatomic area of interest to the examiner. As an example, a line representing the orbital surface of the orbital plate of the frontal bone should remain on the orbital surface and not become, a little farther on, the cerebral surface of the same bone plate. As another example, in the lateral view, part of the upper surface of the sphenoid bone forms the pituitary fossa: tracing the inferior surface of this same bone plate would outline the upper reaches of the sphenoidal sinus.

The bilateral shadows in the lateral radiograph are traced separately on the half work sheet and then averaged on the master, or final, tracing. This method of tracing each object below and averaging on the top sheet is slightly more time-consuming but considerably more accurate. It overcomes the difficulties encountered in trying to identify clearly the perimeter of two generally similar, but offset, shadows and averaging them all in the same operation.

From the P-A film, several dental units may be traced directly on the master tracing. When, however, their outlines begin to obscure the untraced teeth, simply turn back the master tracing, and outline additional teeth on the one-fourth work sheet. Then turn down the tracing again and transfer the new outlines from the work sheet to the final tracing. Return to the work sheet, erase the teeth, which now have been transferred, and draw the remaining units in a similar manner.

The dentition in the lateral view may be managed in the same way as other bilateral structures. Teeth that are separate from each other are traced in pairs on the work sheet. The average of each of these pairs is traced on the final tracing.

If done correctly, this tracing technique should not diminish the size of the teeth below the average of the measured shadows seen in the radiograph. It should also not diminish the shadow overlap of adjacent units. Because of overexposure or underexposure of the film or simply the superabundance of shadow detail, the location of a particular tooth may be obscure; so on occasion, rather than attempting to locate the shadow of a complete tooth in toto, it may be expedient to locate it bit by bit.

In the P-A view, one may start by picking up the mesial surface of the incisors and the lingual surface of the cuspid, bicuspids, and molars, accounting for each along the way, while marking the location of that surface for the questionable tooth. The same method is followed with the distal surface of the central incisors and the buccal surface of the cuspid, bicuspids, and molars, each again being accounted for and the one sought being marked.

The vertical location of the crowns, cusps, and root apexes may be projected from the lateral view via the Orientator lines.

The combination of these two methods will largely establish the location of the questionable tooth.

Description of the Bolton Orientator

As mentioned earlier in a cursory manner, the Orientator is a device produced primarily, as the name implies, for the orientation of one film to another. It is intended to relate the two films of a cephalometric pair that have a 5-foot anode-object distance. The cephalometric pair generally consists of a lateral and a frontal film but may be any that present planes at right angles to each other. Accurate correction of film shadow dimensions may also be accomplished on the Orientator. Its greatest value is in accurately relating two views of the same object and thereby aiding in proper location, interpretation, and identification of shadows.

The Orientator halves are designated to accept lateral and frontal films; these halves, in turn, indicate left and right for the frontal and anterior and posterior for the lateral (Fig. 3-5). The central ray line (CR) carries a millimeter scale that, on the lateral half, represents the recorded midline–lateral film distance (ML) and, on the frontal portion, represents the recorded porion-film distance (P+), both these dimensions having been noted at the time that the films were exposed.

The vertical scales at the right and left ends of the Orientator represent lines perpendicular to the central ray and located exactly 5 feet from the points of origin of the radiating lines. In other words, the scales represent the instrument center. The vertical scale at the Orientator's center represents the line of junction or orientation for the two films.

The lateral cephalogram shadow of the ear rod is placed on the CR at the appropriate ML distance on the scale because the lateral cephalogram has been enlarged in projection over that distance or to that degree.

In the P-A cephalogram, the center of the nasion rest support image is placed on the CR at the P+ distance, since it too is an enlarged shadow. In the positioning of this film, the vertical centering of the ear rod shadows on the CR is also maintained.

The posterior of the skull was nearest to the source of radiation and farthest from the film during the P-A exposure and was therefore enlarged to a greater degree. The right side of the skull was nearest the source of radiation and farthest from the film during the lateral exposure and therefore was enlarged to a greater degree.

In placing the cephalograms on the Orientator, this relationship must be maintained, the posterior of the lateral skull view and the right side of the P-A film each toward the ray sources.

Bolton Orientator setup

First, attach the Orientator to the x-ray illuminator with drafting tape so that the axis of the CR is horizontal.

Position the frontal film on the Orientator as though viewing the head from the back with the right side to the right and the center of the ear rod axis registered on the CR. The midline center of the instrument is determined by the x-ray shadow of the nasion rest. Shift the film to the right or left until the instrument center is located at the appropriate P+ location on the metric scale of the Orientator. Fix in place with drafting tape.

Place the complementary lateral view on the left half of the Orientator with the facial profile toward the frontal view and the center of the image of the ear rod registered on the CR at the point on the metric scale that corresponds to the ML distance at which this record was made.

Fix in this position temporarily with drafting tape. Now note the relation of one or two midline anatomic or dental landmarks (i.e., the pituitary base or the edge of an incisor) to the nearest Orientator x-ray line. If necessary, rotate the lateral film around its ear rod axis until its relation to the lines corresponds to the frontal record. Project a few anterior points that can be definitely established in both films to be certain that they are oriented correctly.

The vertical height of any object seen on either film may now be projected by means of the Orientator lines to the other film. In addition, graphically constructed points or those which are seen in only one view may be projected to the other. Some of the constructed points are R (registration), S (sella center), S′ (S prime), Gn (gnathion), and Bo (Bolton point). Some of the anatomic points seen in only one view include zygion, Na (nasion), ANS, PNS, inion, A, B, and PGo.

Reduction of images to actual size

Midline points (Fig. 3-10). The film image is composed of shadows, all of which are enlarged to some degree. The shadows of structures in any one plane of the skull situated at a right angle to the central ray are enlarged on the film to the same degree. Thus all the shadows of objects in the midsagittal plane have been enlarged in the lateral film to the same extent.

The cephalometric pair of films is placed on the Orientator in the usual manner with acetate affixed as for tracing. A line is drawn on the lateral, perpendicular to the CR at the ear rod center *(LC)*. This line, labeled *L*, represents the edge view of the lateral film plane and is the same distance from the left Orientator scale as the film plane was from the sagittal plane of the skull. Point *LC* on the lateral film represents the point through which the CR passed, and therefore all enlargement progressed outward from this point; conversely all reduction to normal size is in the opposite direction toward this point. Point *FC* represents a similar location in the frontal. The vertical line *F* is drawn perpendicular to and through the CR at the instrument center *(FC)* as seen in the frontal view. The line *F* represents the frontal film plane to which right and left side points may be projected from their frontal locations and then handled as midline points.

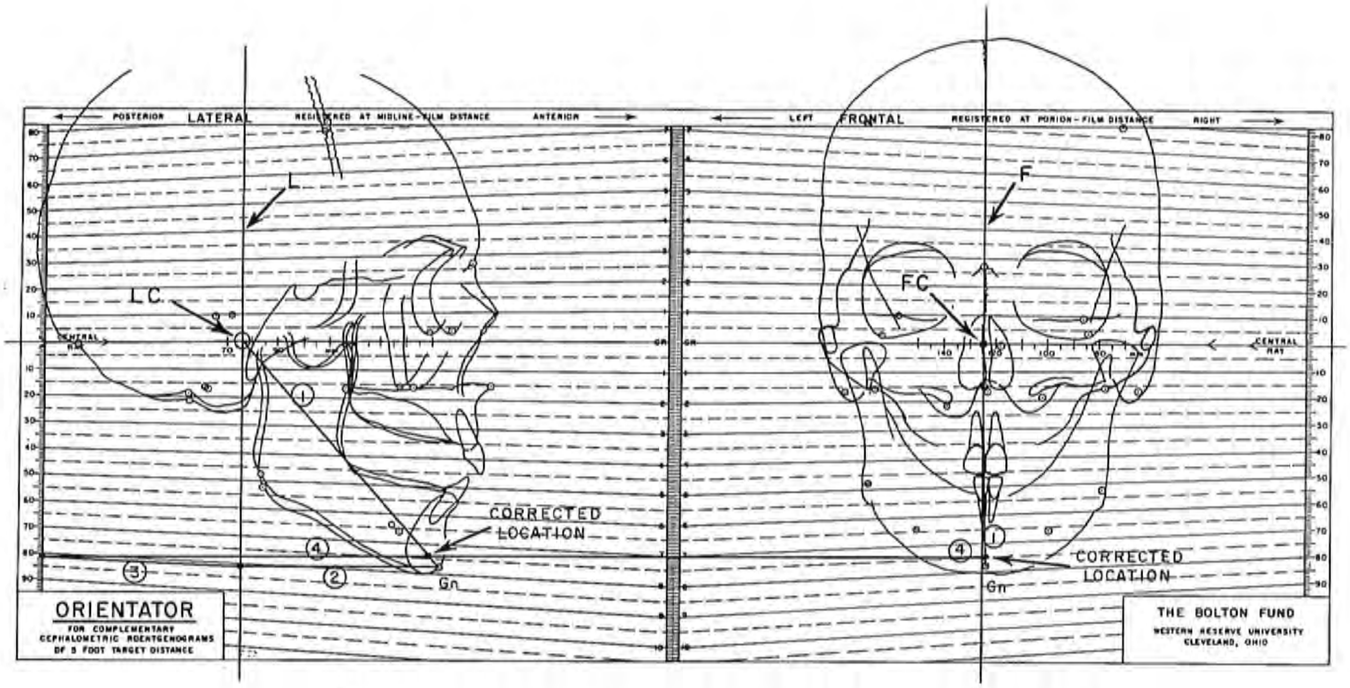

Fig. 3-10. Orientator. Directions for correcting the location of midline points.

1. A line is drawn from point *LC* in the lateral and *FC* in the frontal to the point location being corrected in each film—in this instance *Gn*. The corrected location of *Gn* will eventually fall on this line *(1)*.
2. Point *Gn* on the lateral is carried *horizontally* to line *L*, maintaining its distance below the *CR*.
3. The new point is then carried *along* the *lateral Orientator lines* back to the normal scale. This location on the scale represents the true distance below the *CR*.
4. This point on the scale is finally carried *horizontally* and *parallel to the CR* across the Orientator until it intersects line *1* on the lateral and P-A views. This intersection is the corrected point location on both views.

Points located to the left or right of the midsagittal plane (Fig. 3-11)

1. The preliminary steps are the same as for midline points up to and including step 1.
2. The point *R Go* of the frontal film is projected *horizontally* to line *F* at the midline.
3. This midline point is carried along the *Orientator lines* to a point of junction with line *1* of the lateral view. This would be its location had it been a midline point originally.
4. This lateral point is carried *horizontally* to line *L*.
5. From this junction the *Orientator lines* are followed to the normal scale. This, then, is its true distance below the *CR*.
6. A *horizontal line* is next projected from this location on the scale to line *1* on both views. This final junction of lines *6* and *1* is the corrected position for the point *R Go* as seen in the lateral and frontal films.

Points located to the left or right of the midsagittal plane and on or near the central ray (Fig. 3-12). The correction of point locations so far has been accomplished by correcting the vertical dimension and applying this correction to line *1*, which radiates to the point shadow. When this point is located near the *CR*, the line radiating to this point shadow and the central

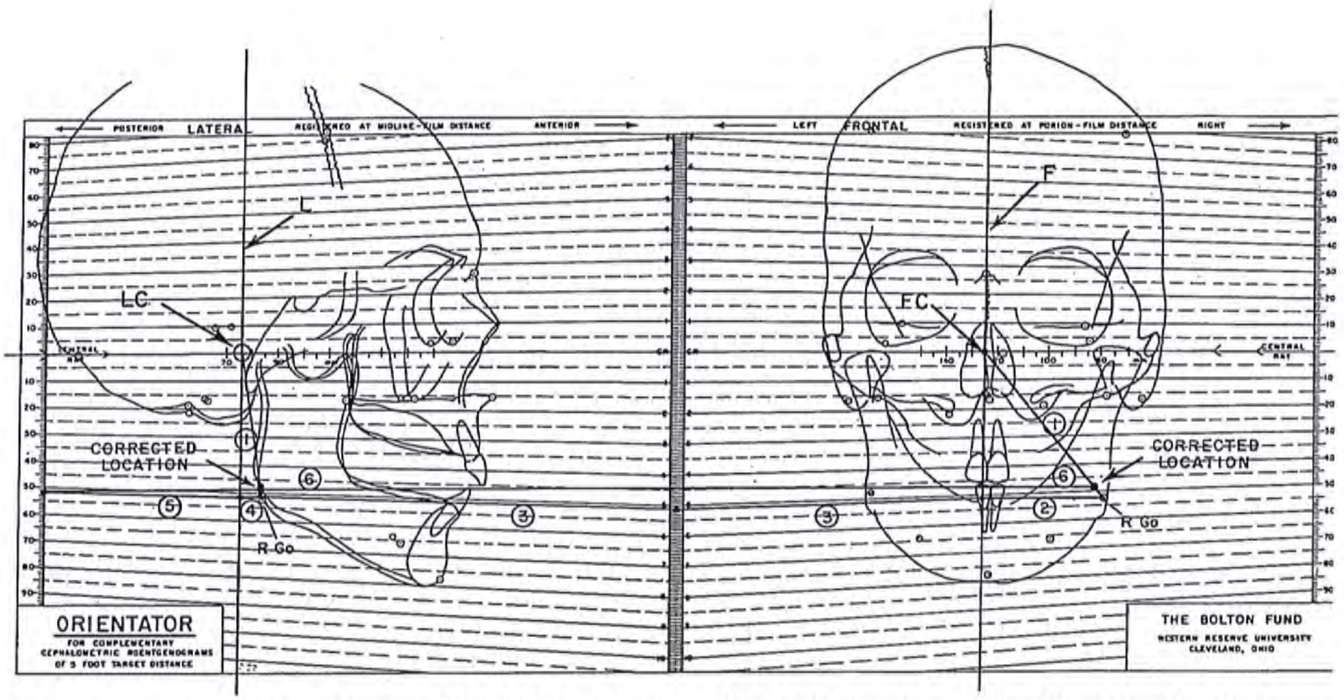

Fig. 3-11. Orientator. Directions for correcting the location of points left or right of the midsaggital plane.

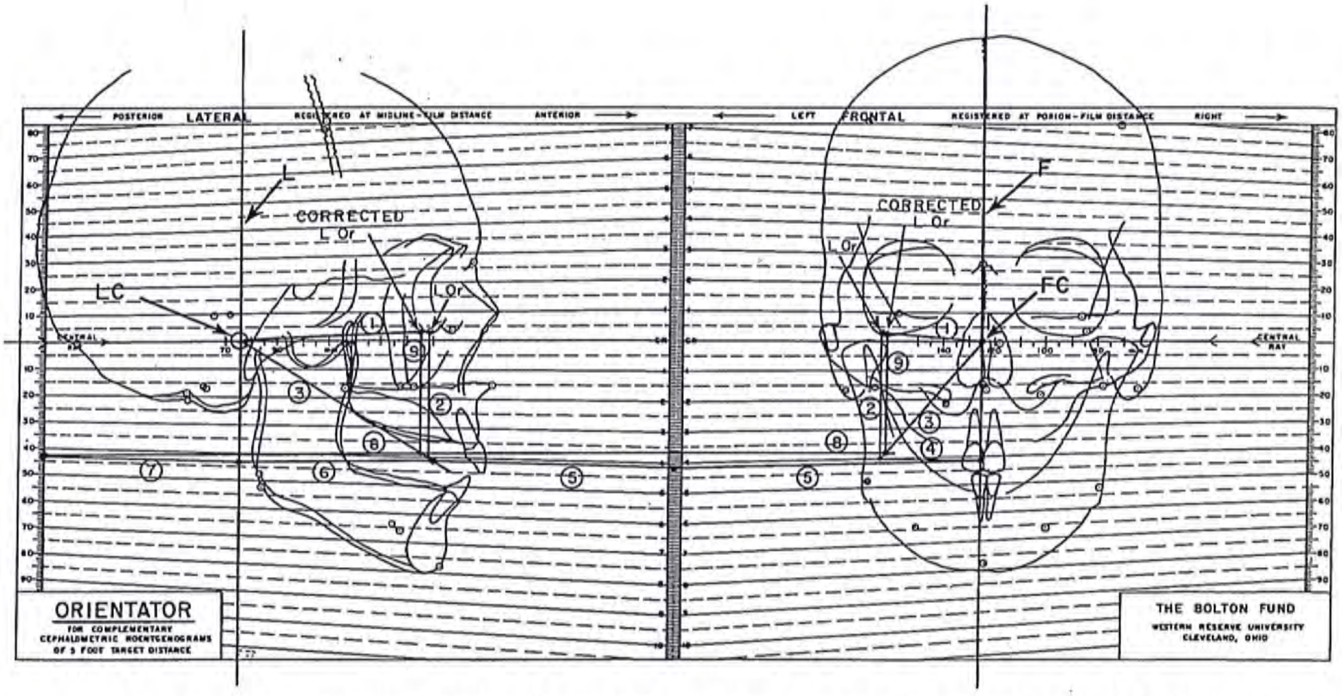

Fig. 3-12. Orientator. Directions for correcting the location of points left or right of the midsaggital plane and on or near the central ray.

ray are nearly the same. The point must temporarily be displaced, corrected, and then replaced.

The left orbital point *(L Or)* may be used for demonstration, since it falls close to the central ray:

1. A line is drawn first from *LC* to *L Or* in the lateral film and then from *FC* to the same point in the frontal. The corrected point will eventually be situated on this line in each view.
2. The lateral and frontal point locations are moved up or down by means of lines *perpendicular to the CR* to convenient locations on *one of the Orientator lines.*
3. Radiating lines from *LC* and *FC* are drawn through these locations.
4. This location, or point, in the frontal view is carried *horizontally* to the midsagittal plane.
5. From there it is carried *via Orientator lines* to a junction with line *3* of the lateral film.
6. From that junction it is carried *horizontally* to line *L.*
7. From there it is moved along the *Orientator line* to the scale.
8. The point on the scale is projected *horizontally* to a junction with lines *3* of the lateral and frontal views.
9. The points of junction are now returned to the *CR* or line *1* by lines that are *perpendicular to the CR.*

The method described will enable one to correct dimensions in three planes of space.

Correction of dimensions on an averaged lateral tracing (Figs. 3-13 and 3-14)

The lateral tracing on which the bilateral structures have been averaged may be corrected dimensionally with little difficulty. A description of two of the easiest and quickest means follows.

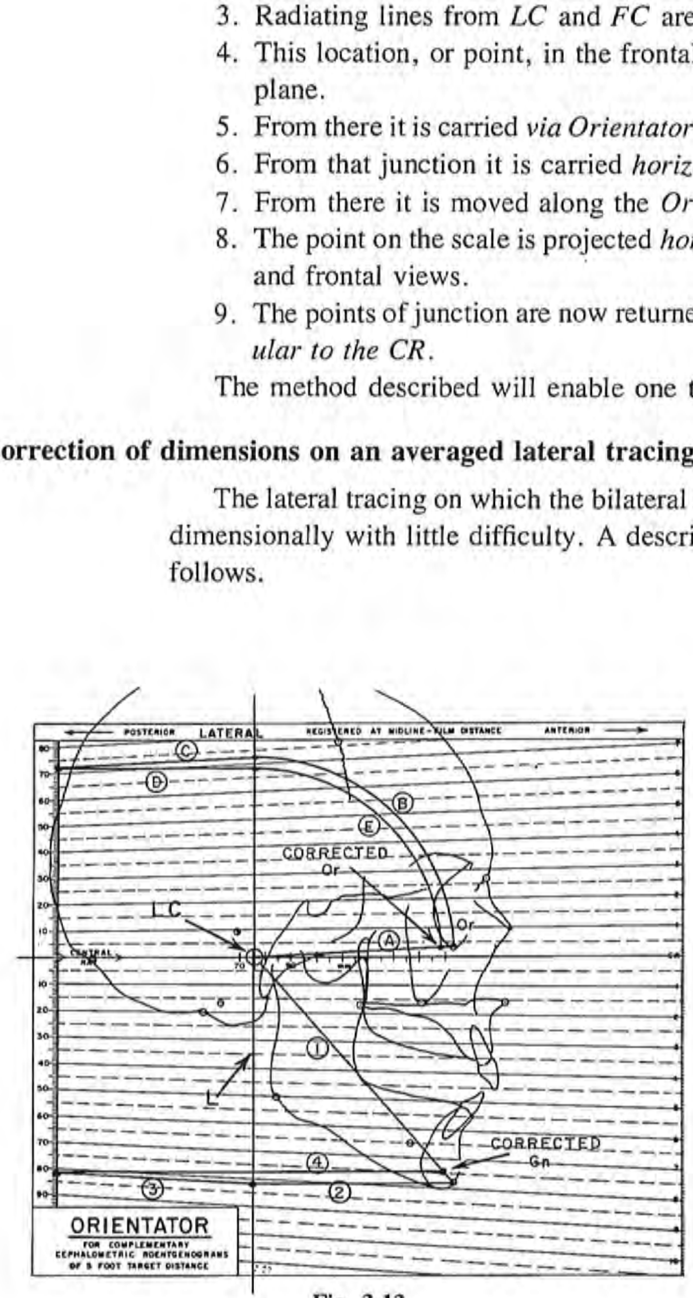

Fig. 3-13

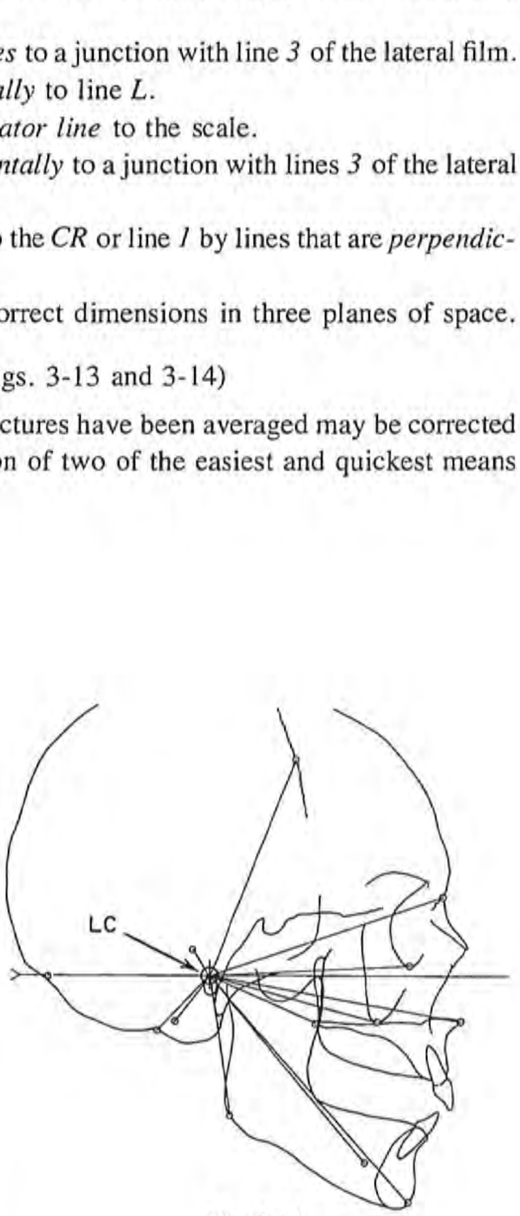

Fig. 3-14

Fig. 3-13. Left half of Orientator. Directions for correcting the location of points on an averaged lateral tracing.
Fig. 3-14. Averaged lateral tracing. Mathematical correction of dimensions.

As in preceding methods, draw lines radiating from the point through which the *CR* passed, the ear rod image center *(LC)*, to the points' shadows that are to be relocated or corrected. As previously mentioned, since enlargement took place in the direction of these lines, the corrected point locations will also fall on the same lines but closer to the central ray point.

One technique is to use the lateral side of the Orientator only and follow the directions for the correction of *midline points*. Since the bilateral points or structures have been *averaged*, they may now be handled as *midline points*.

The points that fall on the *CR* may be handled simply as in Fig. 3-13, *A* to *E:*

1. Draw a line to connect *LC* and the average orbital point *(A)*.
2. Using a compass, the pivot of which is located at *LC*, carry the orbital point to line *L (B)*.
3. Move the point to the left-hand scale along the *Orientator* lines. Incidentally the measurement reading on the scale indicates the true distance of the orbital point from *LC (C)*.
4. Carry the point *horizontally* back to line *L (D)*.
5. By means of the compass, pivot at *LC* and return the point to line *A*. This is the corrected location of the averaged orbital point *(E)*.

The second technique is simply a matter of measuring the distance on the tracing from point LC to the *averaged point* and then of reducing that distance mathematically to normal size. At an ML distance of 90 mm. with a 5-foot anode-object distance, the enlargement is 5.9%; so the averaged point must be moved 5.9% closer to point *LC* along this line (Fig. 3-14):

Anode-object distance (5 feet) = 1,524 mm.
Object-film distance = 90 mm.
Anode-film distance (1,524 + 90) = 1,614 mm.

$$\frac{1{,}614 \text{ A-F}}{1{,}524 \text{ A-O}} \times 100 = \frac{161{,}400}{1{,}524} = 105.9$$

SKULL WIRING

Having reached a satisfactory state of proficiency in skull tracing, averaging, and orientation, technicians may wish to prove to their own satisfaction that they can pinpoint the anatomic structures casting the shadows that they have been tracing.

This can be accomplished by overlaying selected bone surfaces and contours of a dry skull with 1 amp. lead fuse wire. This wire, besides being radiopaque, has a dead-soft quality that lends itself well to following and maintaining contact with the bone contours. The wire may be held in contact with the bone by way of small strips of drafting tape, which is almost completely radiolucent. The tape strips need be no larger than ½ inch by $^{1}/_{16}$ inch, and they will leave no undesirable deposits of glue on the bone surfaces if removed within a reasonable time.

If a dry skull is not available, a well-detailed plastic skull kit, carried in many model or scientific supply stores, will serve satisfactorily. Models of this type, naturally, do not provide the quantity or quality of anatomic structures to be found in the human skull, but they are nevertheless useful. Many surfaces are faithfully reproduced and will give a radiographic shadow similar to a genuine skull. The x-ray exposure used for the plastic skull is minimal, since the plastic is almost radiolucent.

Many cephalometric landmarks currently in use are simply an adaption of earlier craniometric landmarks, and it is important to understand fully the definitions used, since some of those most commonly referred to may have as many as six or eight varying definitions. Relating one to the other can provide an interesting and occasionally surprising exercise. The individual landmarks may be located on the skull by careful inspection and then pinpointed for radiographic recording by marking them with a small steel bearing or lead shot. A round object is preferable to one of an irregular shape, since it is easier to define the center of such an object in the radiographic image, regardless of the direction of the view. The bearing should not be less than $^5/_{64}$ inch in diameter because a smaller object may be lost to view in the radiograph from the penumbral effect of anode size, scattered radiation, or poor radiographic detail.

Wired-skull films, oriented to each other and showing anatomic detail, as well as cephalometric-craniometric landmarks, can be of considerable future value as a reference or discussion aid.

SERIAL CEPHALOMETRIC FILMS

A complementary pair of cephalometric films provides three-dimensional information, but the series of cephalometric pairs provides yet another dimension—time. The individual is seen, not only in the present, but also at various stages of developmental growth progress.

The purpose of this discussion is not to delineate the applications or potential use of these series but rather to deal with some of their interpretations. At first glance the film of a living individual will appear somewhat more complicated and less sharp than the films of the dry skull. This impression is natural and correct. In the living head, considerable soft tissue detail is superimposed on the already complicated skeletal forms.

Furthermore, nonscreen film was used in radiographing the skull, since quantity of radiation was not an important consideration. In the living individual, radiation dosage is of the utmost importance and must be kept to a minimum. To accomplish this, ''screen film'' with intensifying screens is used. The characteristic of screen film is that it necessitates only a fraction of the radiation (approximately one twenty-fifth with par-speed screens) required by nonscreen, but, at the same time, it lacks the fine detail obtainable with nonscreen film. At times, however, an overabundance of detail may be somewhat misleading, since one may trace many nonexistent objects by connecting the overlapping shadows of various unrelated structures.

In cephalometric tracing take advantage of every aid available. Study all dental, lateral jaw, oblique, or panoramic films. Also review intraoral and facial photographs, study models, and dental charts, as well as any cephalometric films that may have been taken before or after the pair being traced.

In tracing serial films, one may either start with the youngest pair and, through the tracings, follow the child toward maturity or start at the most mature stage and work backward. Working through time forward or backward affords the tracer an opportunity to observe gradual morphologic changes. The advantage of sequential progression or regression is forfeited if the pairs are not traced in order.

The radiograph depicts what appears to be the image of a transparent object, and this, to the untrained eye, may be a source of much confusion because of the number of structures involved as well as several aspects of each. The tracer may, by judicious selections of shadow outlines, pick out of each structure the facet most useful in a particular situation. One of the essential values of tracing is to locate the outlines of interest precisely and to eliminate the confusing unusable detail.

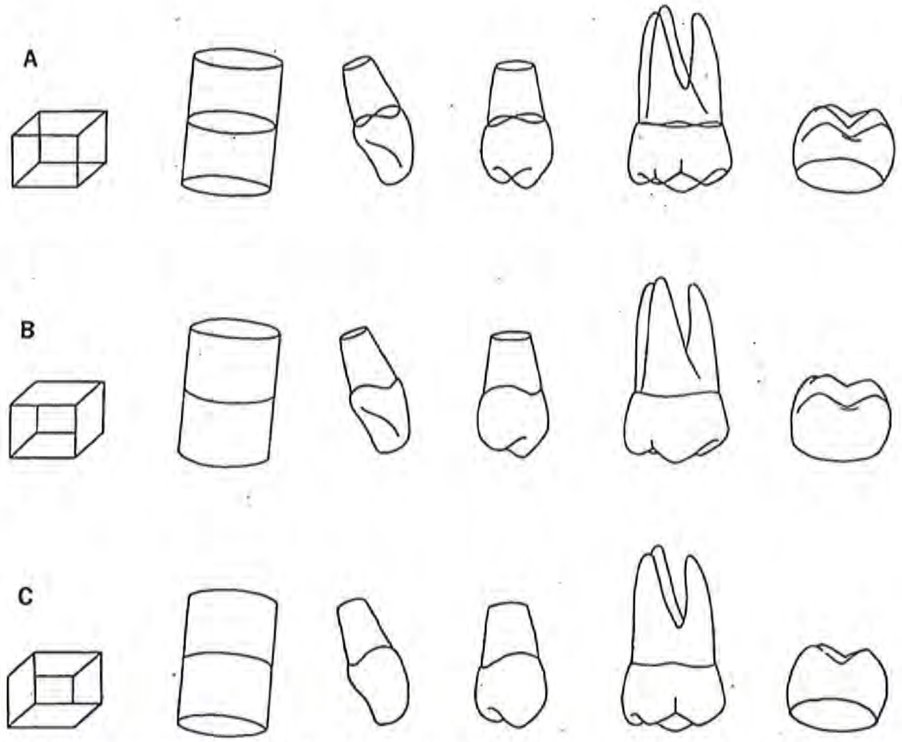

Fig. 3-15. Cube, drum, and teeth. A, Drawing depicts all information available in the radiographic image. B, Objects drawn or traced as though solid and seen from one side. C, Objects drawn as though solid and seen from the other side.

Fig. 3-15, *A*, shows the complete shadow; *B*, only the detail seen from one side had the object been opaque; and *C*, only the detail seen from the other side. Some of the outlines from *A* have been deleted in *B*, and others have been omitted in *C*, but none have been added.

When all the required cephalometric films in a series have been traced, they may then be superimposed to provide ample information relative to either growth or orthodontic or surgical changes as well as an excellent demonstration of tracing accuracy or mistakes.

The registration of the series should be varied, since many relationships are of value: sella-nasion (S-Na), Bolton-nasion (Bo-Na), porion-orbitale (Po-Or), posterior nasal spine-anterior nasal spine (PNS-ANS), gonion-gnathion (Go-Gn), Bolton relation, or simply the relating of the craniofacial or single bone contours. Several registrations must be used in checking the serial cephalometric tracings. If a single registration were used, an error in one or more cephalometric landmarks could prejudice the entire morphologic appraisal.

When subjected to numerous methods of registration, a cephalometric series will generally show a growth pattern that is fairly regular and consistent in direction, even though this direction occasionally describes a curve as individual points are plotted serially. A more erratic pattern usually indicates tracing inconsistencies.

SELECTED CEPHALOMETRIC LANDMARKS, DEFINITIONS, AND AIDS FOR ANATOMIC IDENTIFICATION

As mentioned earlier in this chapter, an infinite number of landmarks, anatomic areas, and morphologic interpretations might be used, producing a usable cephalometric tracing. Next we have attempted to distill this material and present those basic landmarks and anatomic

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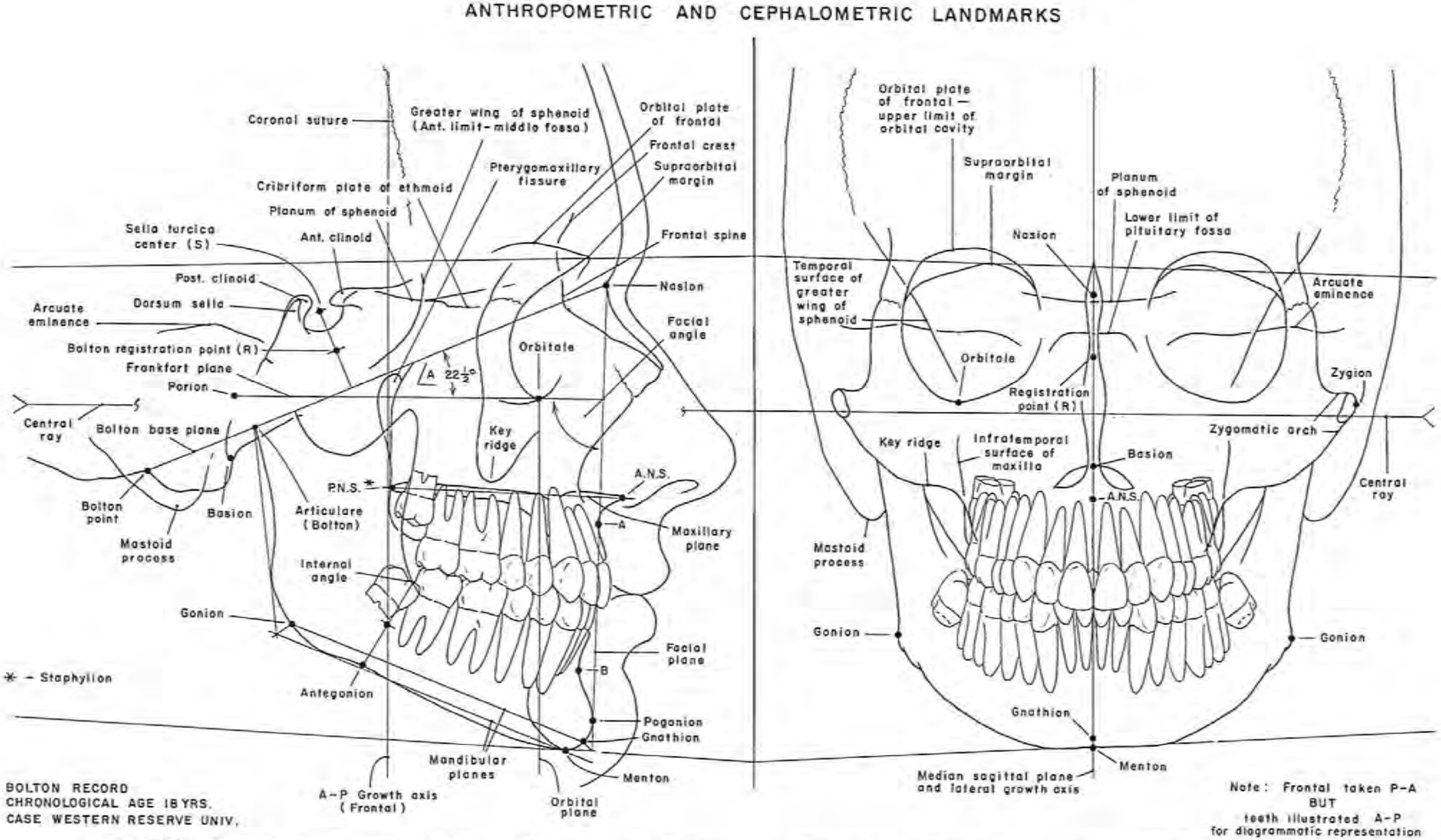


Fig. 3-16. Lateral and P-A tracings of 18-year Bolton record. The structures, lines, and points that are frequently traced have been labeled.

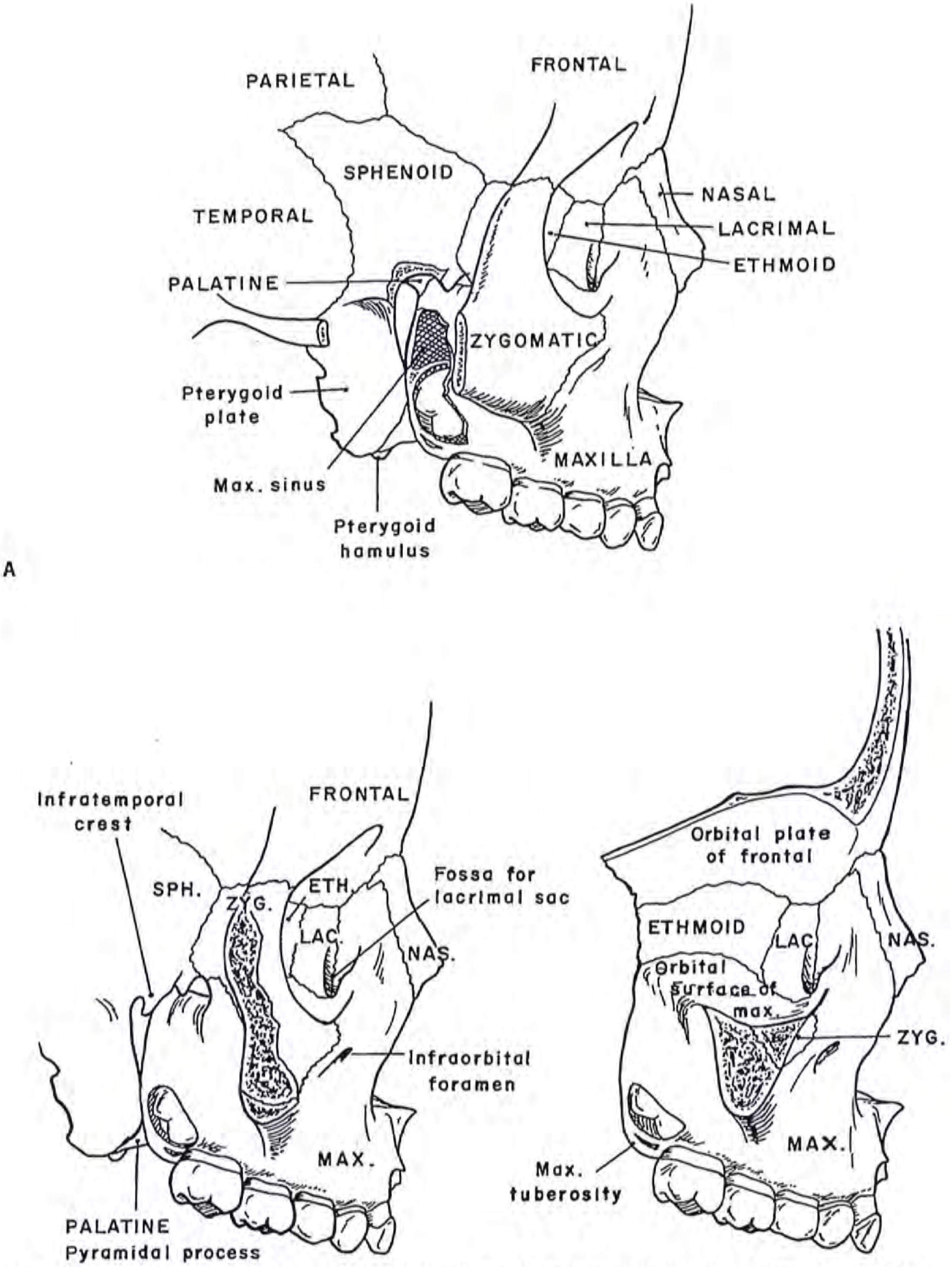
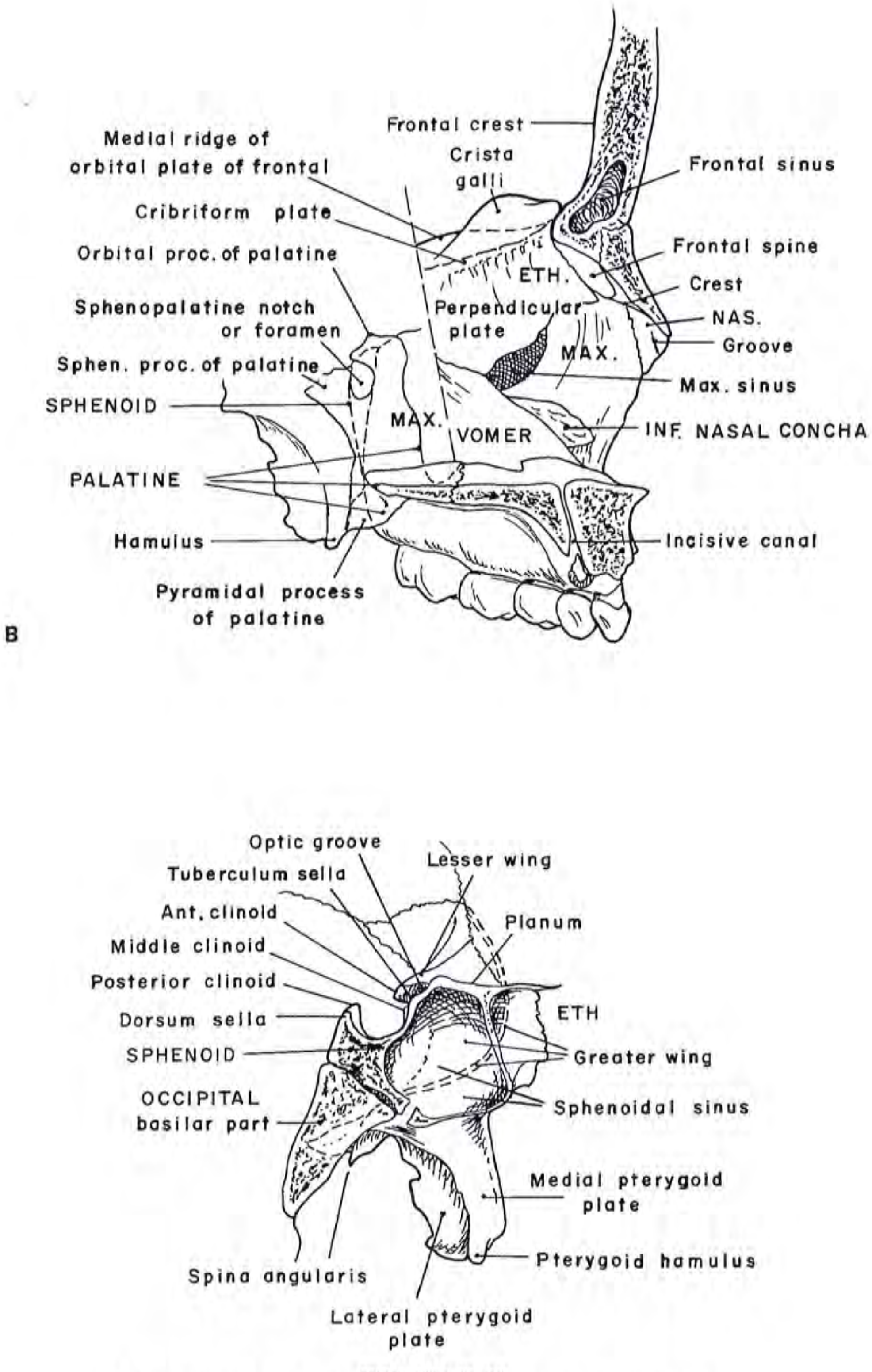


Fig. 3-17. Cephalometric anatomy. Anatomic drawings of facial bones, skull 1249. **A,** Viewed from right side with cutaway.



BOLTON SKULL NO. 1249

Fig. 3-17, cont'd. **B,** Viewed from midsaggital plane with cutaway.

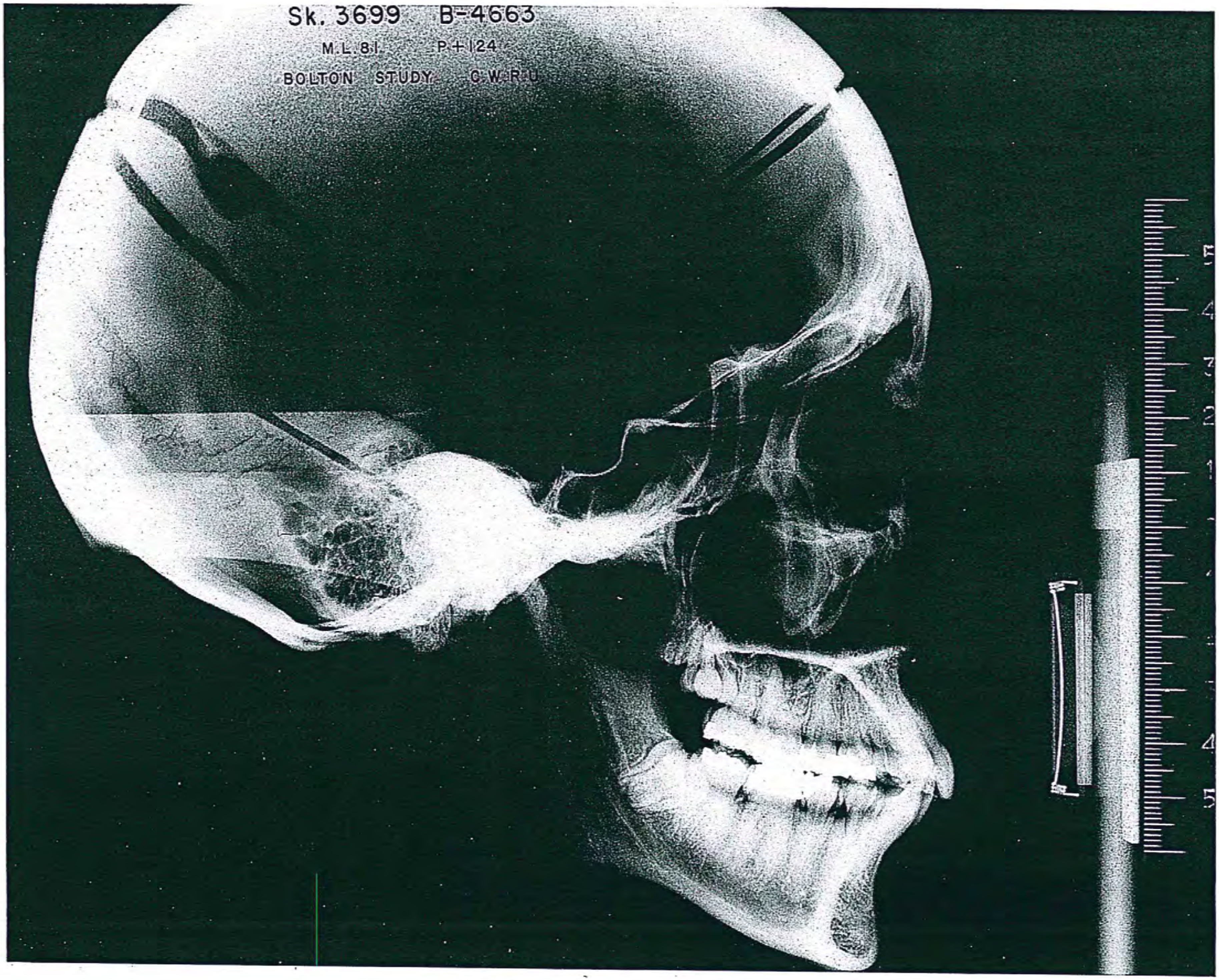


Fig. 3-18. Lateral cephalogram, skull 3699.

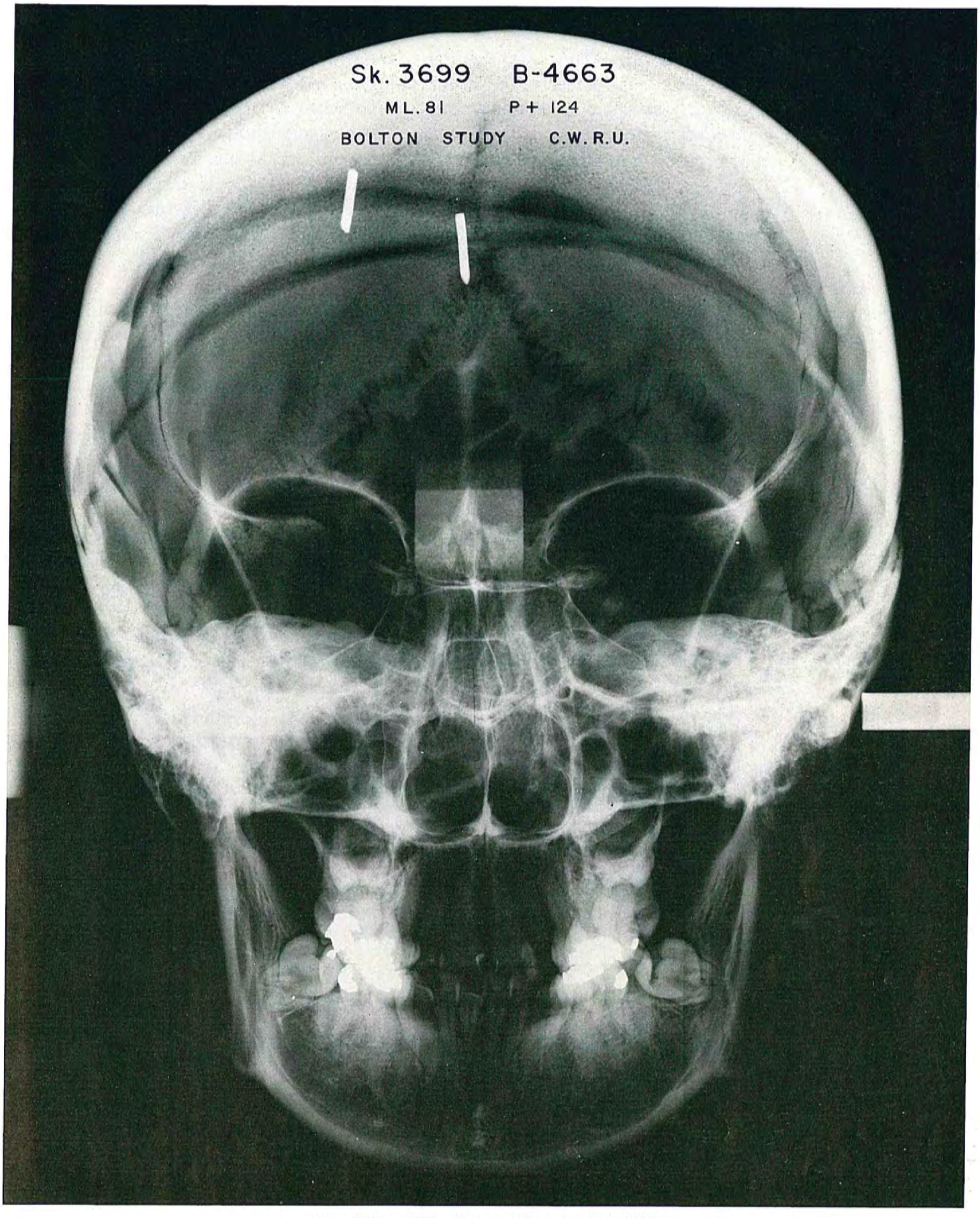


Fig. 3-18, cont'd. P-A cephalogram, skull 3699.

descriptions that are fundamental to most tracing techniques. When no general agreement exists on tracing priorities, this list offers a base for the cephalometrist to build on. Fig. 3-16 presents an outline chart of the lateral and frontal cephalometric tracings that enumerates many of the anthropometric and cephalometric landmarks. Note that these drawings are oriented as the cephalometric radiographs are placed on the Bolton Orientator. The outline, as noted in the lower right-hand corner of the diagram, may be slightly confusing, in that the structures are traced as the radiograph is taken from the P-A aspect. Consequently, the left orbital point is located on the left side of the diagram. The confusing element arises in that the dentition has been traced in an anteroposterior manner strictly for diagrammatic representation, since the teeth are viewed from the labial rather than the lingual side in routine observation.

A list of specific definitions of landmarks and anatomic areas that are frequently used can be found in the Appendix. Understand that these definitions may vary slightly or dramatically from those which you have learned, since many variations have been developed either with intent or inadvertently through the writings and interpretations of many different authors. The point to keep in mind is that, whenever a landmark is used, it is identified correctly by definition, so that the viewer or reader knows exactly what the intent of the describer is.

Fig. 3-17 includes anatomic drawings of the midface and cranial base that will prove of assistance in interpreting the many shadows and superposed outlines in this area of the cephalometric radiograph.

Skull 3699 of the Bolton Study material was placed in the cephalometer and radiographed in complementary pairs for the use of the student of cephalometric tracing and anatomy. The first pair includes frontal and lateral cephalograms of the intact skull (Fig. 3-18). The second pair of cephalograms (Fig. 3-19) was taken after the skull had been wired with fine lead fuse wire, outlining the structures most commonly traced from the lateral film. These outlines may also be seen in the frontal film of this pair. For the third pair of cephalograms (Fig. 3-20), the skull was wired, following the anatomic contours normally traced in the frontal film. The complementary lateral film of this pair also shows this aspect of the wiring. Both films of each of these wired pairs are alphabetically labeled, with the labeling explained in the legends.

For information on cephalometric radiographic enlargement, see p. 56.

REFERENCE

1. Broadbent, B. H., Sr.: A new x-ray technique and its application to orthodontia, Angle Orthod. **1**:45-66, April, 1931.

Fig. 3-19. Lateral and P-A cephalograms, skull 3699, wired and labeled to describe structures traced in the lateral view.

A, Nasofrontal suture: external surface

B, Orbit: supraorbital border (frontal bone), lateral border (zygoma), and inferior border (zygoma and maxilla)

C, Orbital roof: highest section of inferior surface of orbital plate of frontal bone

D, Orbital floor: lowest section of superior surface of orbital portion of zygoma and maxilla from orbit to and through inferior orbital fissure into infratemporal fossa

E, Key ridge: anterior limit of temporal and infratemporal fossa, zygomatic process of frontal bone, frontosphenoidal process of zygomatic bone, and zygomatic process of maxilla

F, Anterior cranial fossa: most anterior depression of cerebral surface of frontal bone and medial ridge of orbital plate of frontal bone

G, Anterior clinoid process: lesser wing of sphenoid bone

H, Middle cranial fossa: cerebral surface of greater wing of sphenoid bone

I, Ethmoid and sphenoid bones: superior surface of cribriform plate of ethmoid bone; ethmoid spine, planum, tuberculum, pituitary fossa, and dorsum; and clivus of sphenoid bone

J, Occipital bone: basilar part, superior and inferior surfaces, including anterior margin of foramen magnum (basion)

K, Sphenoid, vomer, palatine, and maxillary bones: inferior surface of sphenoid bone in midline from basilar part of occipital bone to its articulation with vomer bone; posterior edge of vomer bone, posterior nasal spine, and inferior midline surface of palatine bone; inferior surface of palatine portion of maxilla in midline to incisive canal

L, Lateral pterygoid plate: anterior surface up to infratemporal crest

M, Posterior surface of maxilla: down to and including maxillary tuberosity

N, Palatine bone: most anterior point in curve along posterior limit of horizontal part of palatine bone, superior and inferior surfaces of horizontal part of palatine bone on right side at its thinnest area

O, Palatine process of maxilla: deepest portion of nasal floor on right to anterior nasal spine in midline, down midline of maxillary alveolar process, between central incisors, and up posterior surface into incisive canal

P, Petrous portion of temporal bone: superior surfaces including arcuate eminence

Q, Internal acoustic meatus

R, Mastoid process of temporal bone

S, Occipital condyle: inferior edge of foramen magnum; cross section of occipital bone at posterior edge of foramen (opisthion)

T, Coronoid process of mandible

U, Mandibular condyle

V, Posterior border of ramus

W, Inferior border of mandible

X, Posterior, or lingual, surface of mandibular symphysis

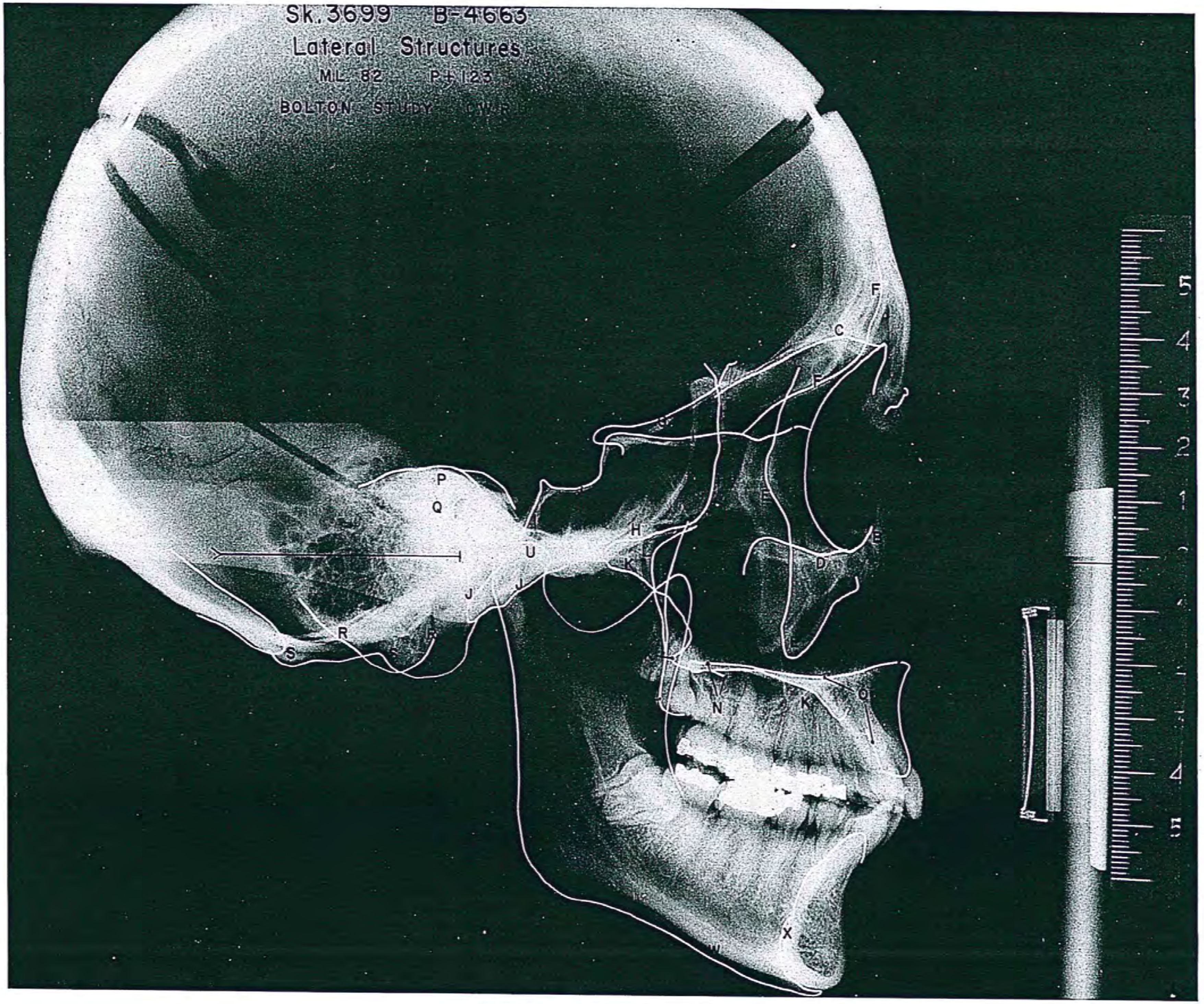


Fig. 3-19. For legend see p. 53.

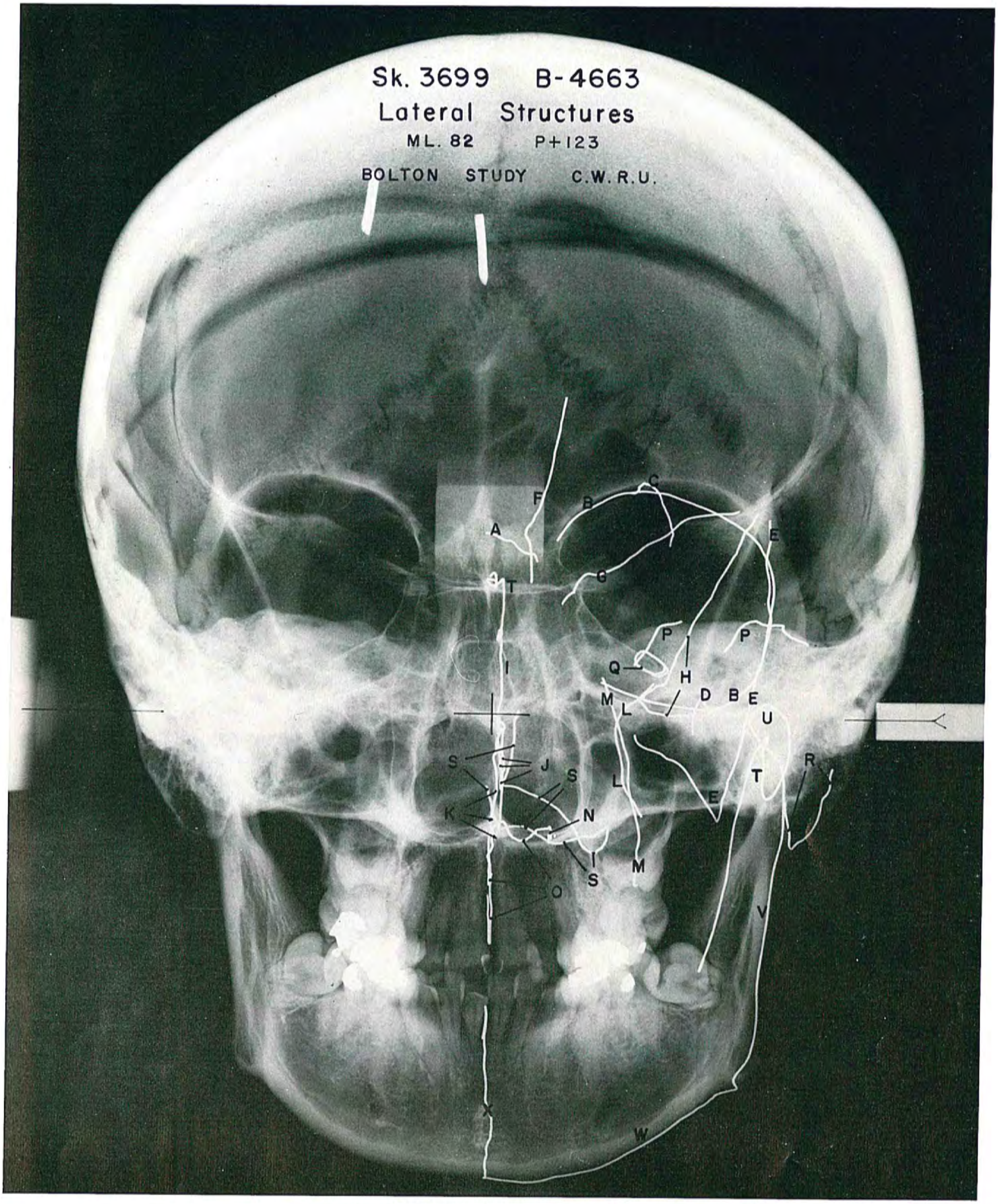


Fig. 3-19, cont'd. For legend see p. 53.

CEPHALOMETRIC RADIOGRAPHIC ENLARGEMENT

The Bolton Standard tracings were made from cephalograms produced by the Bolton cephalometric technique. This method dictates that the anode-object distance of 5 feet be maintained and that the object-film distance be kept to a minimum. The object-film relation in the lateral cephalogram is termed *midline–lateral film distance (ML)*. In the frontal cephalogram, it is designated as *porion-film distance (P+)*. The following chart shows the average ML and P+ distances that were used at each chronologic age and the resultant enlargement inherent in the Bolton Standards. It is important to consider this percentage of enlargement when the Standards are compared to cephalometric films from other sources.

This chart may also be used to obtain a direct reading of enlargement for a specific cephalometric radiograph in which the fundamental technique has been used and the ML or P+ distance is known.

BOLTON STANDARDS

Radiographic enlargement*

Age	ML	% enlargement	P+	% enlargement
1	80.0	5.2	—	—
2	80.0	5.2	—	—
3	80.0	5.2	104.0	6.8
4	81.0	5.3	107.0	7.0
5	82.0	5.4	108.0	7.1
6	83.0	5.4	109.0	7.2
7	84.0	5.5	110.0	7.2
8	84.0	5.5	113.0	7.4
9	85.0	5.6	114.0	7.5
10	86.0	5.6	116.0	7.5
11	87.0	5.7	118.0	7.7
12	88.0	5.8	120.0	7.9
13	89.0	5.8	122.0	8.0
14	89.0	5.8	123.0	8.1
15	90.0	5.9	125.0	8.2
16	90.0	5.9	125.0	8.2
17	90.0	5.9	126.0	8.3
18	90.0	5.9	128.0	8.4

*The columns to the right of the chronologic ages are the ML distance of the lateral film with its percentage of enlargement and the P+ distance of the frontal film with its respective percentage of enlargement. The ML and P+ recordings are made at the time that the films are exposed.

Fig. 3-20. Lateral and P-A cephalograms, skull 3699, wired and labeled to describe structures traced in the P-A view.

A, Crista galli
B, Nasofrontal suture: external surface
C, Orbital roof: most superior area of inferior surface of orbital plate of frontal bone
D, Orbit: superior border (frontal bone), lateral border (zygoma), and inferior border (zygoma and maxillary bones)
E, Lesser wing of sphenoid bone: anterior clinoid process
F, Planum of sphenoid bone: across planum and down through optic foramen
G, Petrous portion of temporal bone: superior surface
H, Greater wing of sphenoid bone: temporal surface and infratemporal crest
I, Maxilla: infratemporal surface down to and including alveolar process in molar area
J, Lateral pterygoid plate and greater wing of sphenoid bone: infratemporal fossa and crest
K, Zygomatic arch: superior surface of the zygomatic process of temporal and malar bones and cross section of zygomatic process of temporal bone at greatest bizygomatic width
L, Zygomatic arch to key ridge: inferior surfaces of malar bone, maxilla, and key ridge
M, Mastoid process
N, Occipital bone: inferior surface of jugular process, condyles, and anterior margin of foramen magnum
O, Occipital bone: posterior border of foramen magnum and most inferior area of lateral part
P, Occipital bone: superior surface of area of greatest depth in posterior fossa (fossa of cerebellum)
Q, Occipital bone: cross section of border of foramen posterior to left occipital condyle
R, Posterior nasal aperture (choana); vomer, sphenoid, and palatine bones, medial pterygoid plate of sphenoid, and horizontal part of palatine bone
S, Sphenoid bone (cross section): floor of pituitary fossa through foramen lacerum across inferior surface of body of sphenoid bone between vomer bone and basilar part of occipital bone
T, Anterior nasal aperture: nasal bone and maxilla
U, Mandible: condyle, neck, lateral border of ramus, and inferior border of body of mandible
V, Coronoid process and mandibular notch
W, Ramus: medial surface of posterior part of ramus

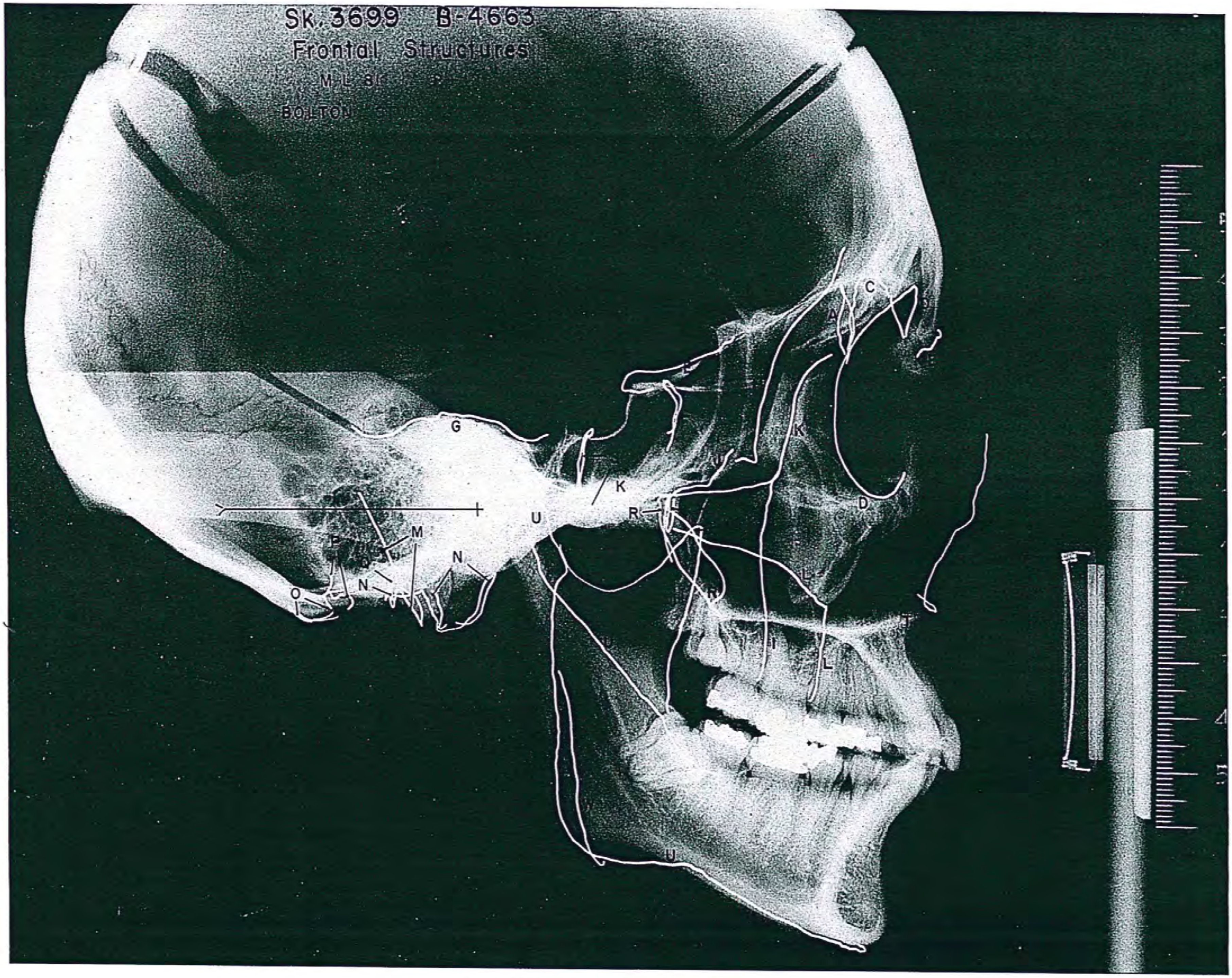


Fig. 3-20. For legend see p. 57.

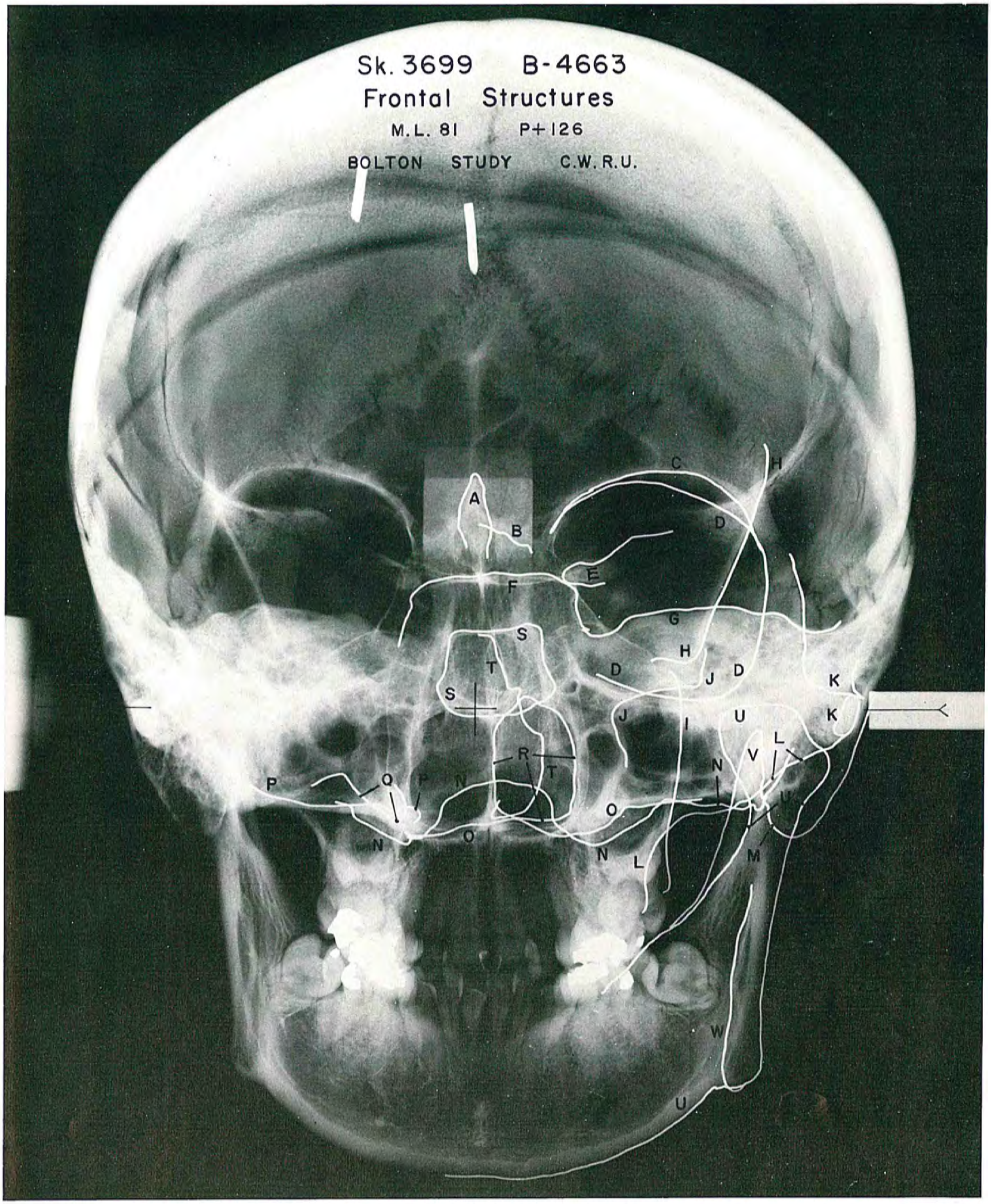


Fig. 3-20, cont'd. For legend see p. 57.

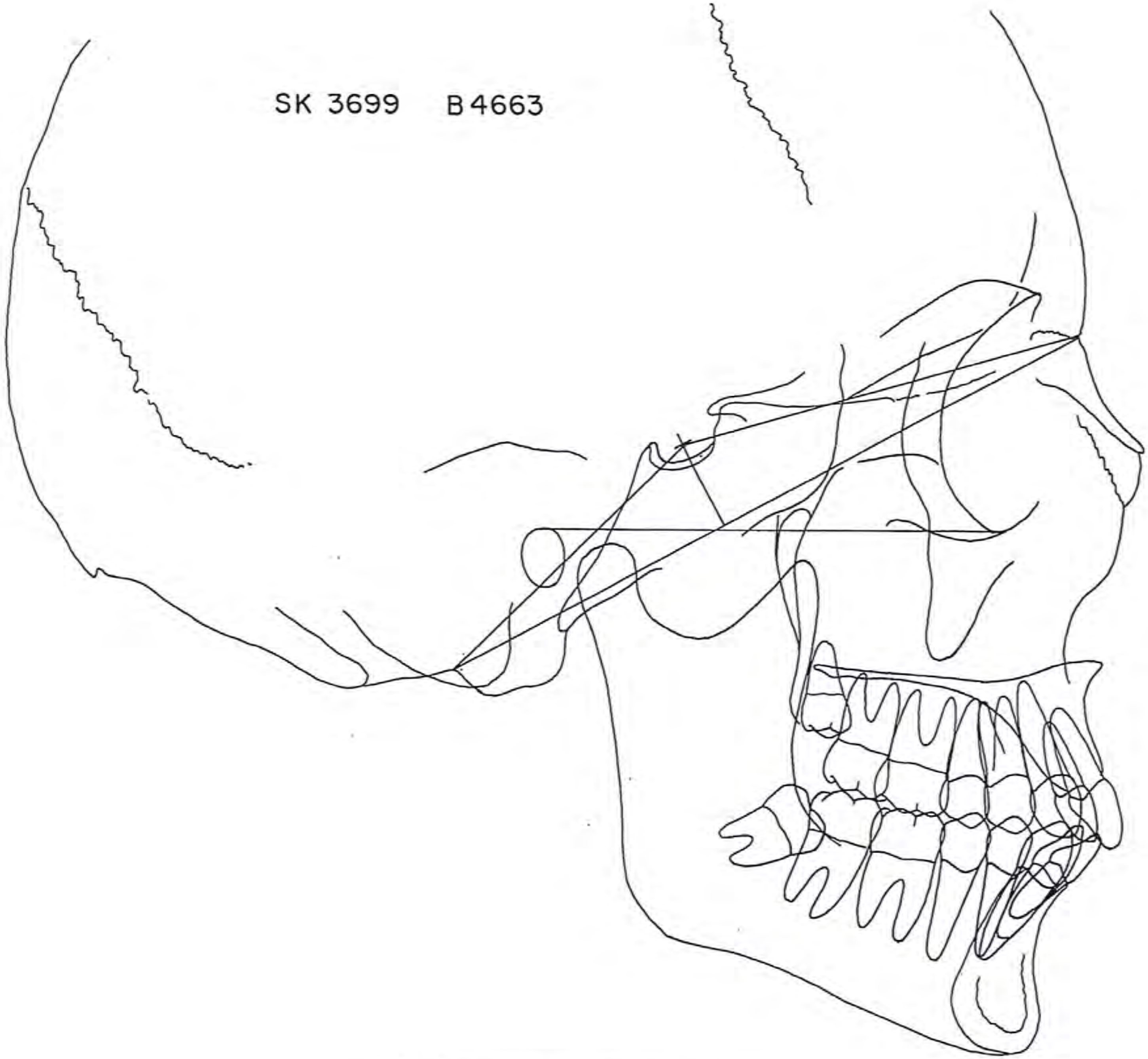


Fig. 3-21. Lateral averaged tracing, skull 3699.

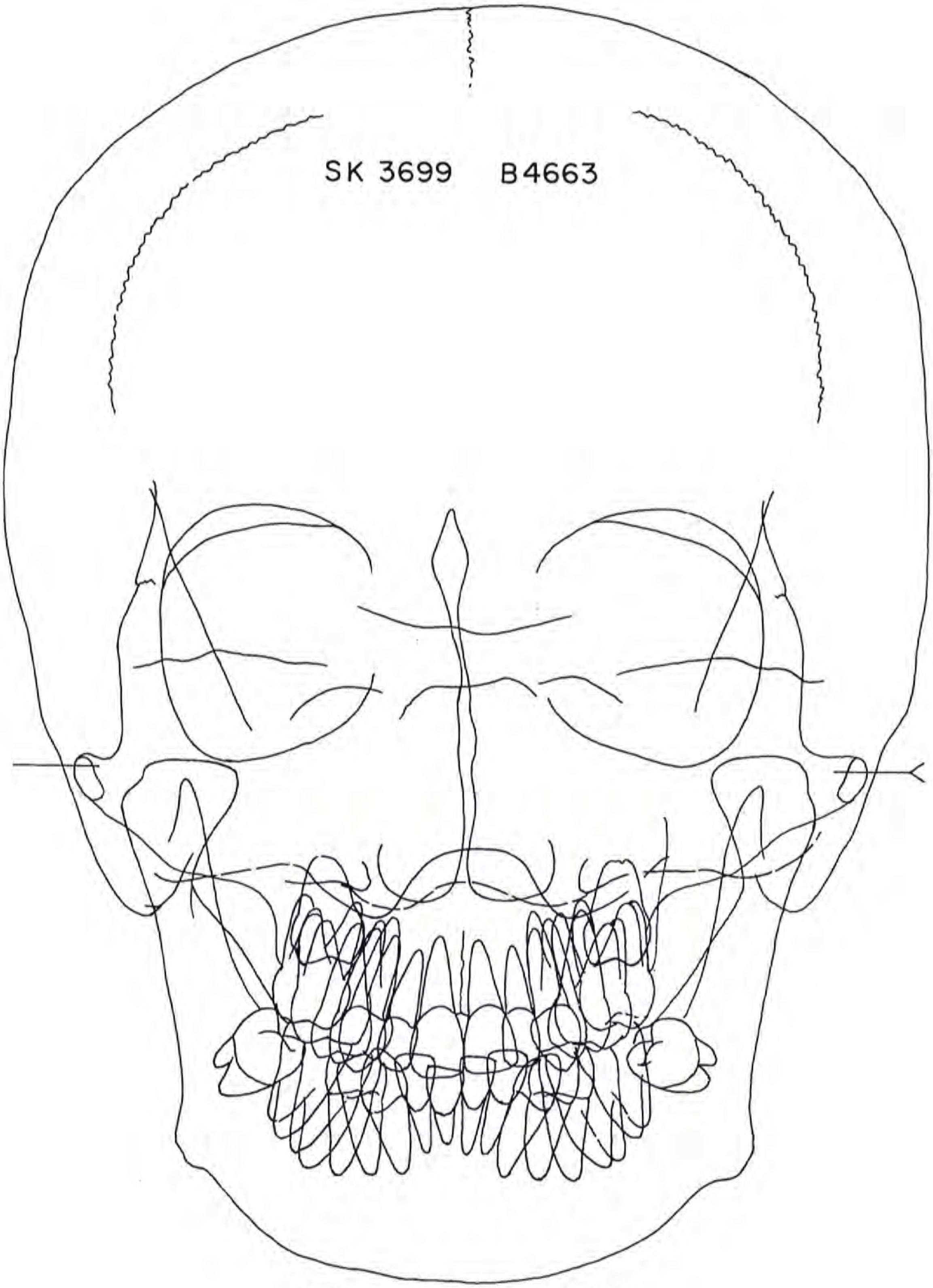


Fig. 3-21, cont'd. P-A tracing, skull 3699.

CHAPTER 4

The Bolton Standards

"Normality," as it is considered in biologic circles, has long been an elusive concept generating active discussion from varying points of view, and this is particularly true of the definition as it relates to the dentofacial complex. Webster gives a number of definitions for *normal,* which include "a state or form regarded as the norm, an archetype standard to which individuals may conform," or "the ordinary or usual condition, quantity or the like, average or mean."[3] Gould gives similar definitions in the medical literature, such as "conforming to natural order or law and having the typical structure."[6]

These gross generalities have led to a feeling on the part of many that no specific entity may be referred to as *the norm,* but rather, because of the range of dimension and morphology that is seen in all the dentofacial structures both anatomically and functionally, the latitude is such that strict regimentation of categorization is unattainable.

Through the years of investigation into dental relationships, many extremes of the concept of normality have been presented. These extend from Johnson's "individual normal"[4] (each person is so unique and complex that no standard or norm can apply), at one end of the spectrum, to viewing such a simple relationship as a specific axial inclination of the lower central incisor to the mandibular plane as a "norm" or goal to be sought in treating patients orthodontically, at the other end.

Our view is that certainly a range must be considered in the discussion of normality in dentofacial developmental growth because of the infinite number of variables to be considered, but we are also firmly convinced that some type of yardstick, or measuring device (Fig. 4-1), must be established to allow accuracy in comparative studies and to categorize information arrived at in a logical, scientific manner. To this end the Bolton Standards, contained herein, are directed; and, through their clinical application and years of comparison and revision, we have arrived at what we believe to be a valuable clinical and research tool.

One of the basic qualifications, which has been stated previously, is that the Bolton Standards are definitely related to general concepts of normality because they are *not* artificial gauges but rather have been derived from actual cases that present a so-called *normal* condition of dentofacial morphology as well as arch alignment. One should point out, however, that, rather than their being a statistical mean drawn at random from the population, they are instead a representation of the "optimum" or, as stated by Webster, "the best or most favorable degree, quantity, number, etc., and most conducive to a given end under fixed conditions."[3]

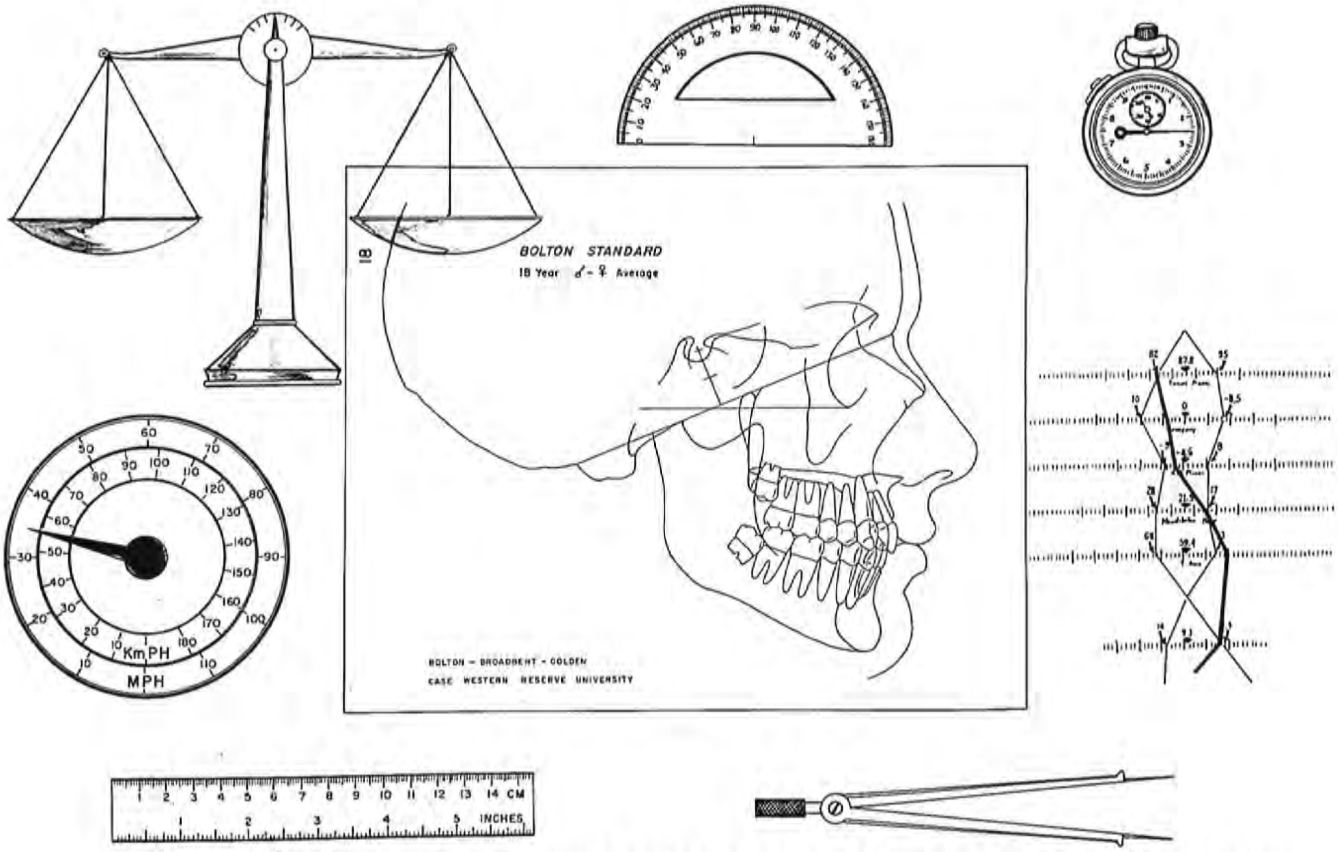


Fig. 4-1. Bolton Standards as a measuring device may be used in a manner analogous to other accepted measuring devices to provide comparative sizes and morphologic patterns, as well as dental eruption stages.

One needs to look at this consideration of optimum versus normal a little more in depth to appreciate fully what the ramifications involved really are. As an example of the approaches that might be taken in defining *dentofacial normality,* Krogman and Sassouni[5] have clearly and simply divided the possibilities into four general categories. They state that normality may be defined statistically, anatomically, functionally, or aesthetically and that generally all the approaches that have been developed to date relate themselves in the broad sense to these four categorizations. Looking at the statistical norm as it relates to population samples, everyone is well aware that the population has a limited number of so-called Class III skeletal faces and a preponderance of both Class I and Class II skeletal relationships. In formulating a mean, or average, norm of the population through statistics, one finds, therefore, that the Class II influence, because of its magnitude, imparts to the norm a Class II morphologic pattern. As an example of this, Fig. 4-2 is a comparison of the 10-year *female* Bolton Standard with a 10-year female average derived by Walker and Krogman from the Philadelphia Center for Research in Child Growth. Note that the mid and upper facial structures are similar in both morphology and size. The major difference, as viewed here in Bolton relation, is at the chin point,

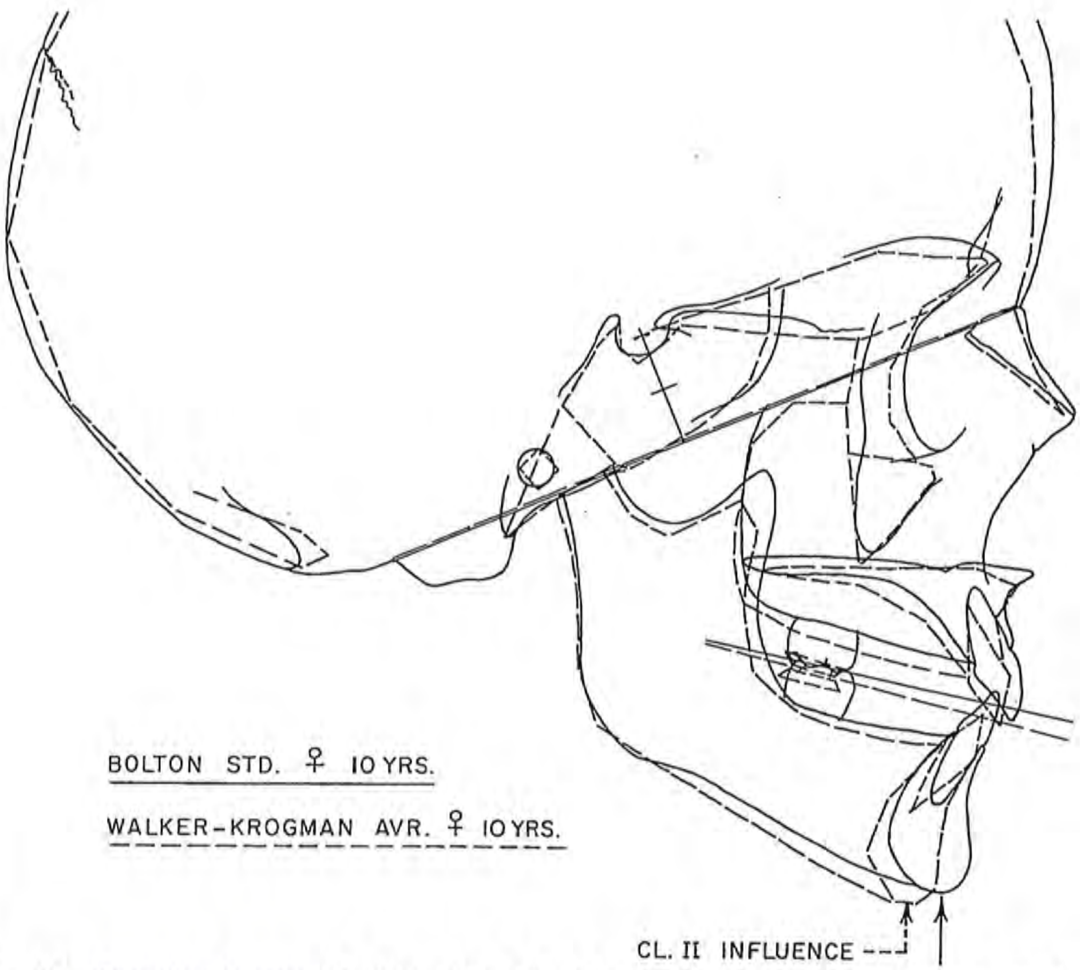


Fig. 4-2. Comparison of norms. The Bolton 10-year female Standard is superposed on a computer-derived 10-year female average of Walker and Krogman to illustrate the difference between optimum facial patterns and a cross-sectional statistical mean.

where the Class II influence of the Philadelphia population sample has made an obvious difference in the size of the mandible. This is not to disparage in the least the fine work that has been done in serial cephalometric study by Krogman and Walker but rather to substantiate our point that, to have a so-called *normal* standard, one must look to the optimum condition rather than to a statistically derived population mean.

SELECTION OF THE BOLTON FACES

As noted in Chapter 1, the population of the Bolton Study contains records of some 5,000 individuals, many of whom had serial cephalometric recordings made on a six-month basis for the first 4 years of life and thereafter on an annual basis to young adulthood. The Bolton Study is fortunate in being one of the largest longitudinal studies of this nature ever conducted, and, because of the current respect for radiation, it probably will not be duplicated in the foreseeable future. From this group of longitudinal records, individual cases were specifically selected to be what has been termed *Bolton Faces,* which comprise the Bolton Standards (optimums).

The following criteria were established as the framework for the Bolton Face selection process:

1. Excellence of static occlusion as viewed in the dental study casts that were taken at the same time that the serial cephalometric records were made
2. A good health history, which precluded those who had significant debilitating diseases from becoming part of the group
3. Faces that conformed in a favorable manner to the statistically derived mean of craniofacial measurements as seen in Fig. 1-2
4. Aesthetically favorable faces as viewed arbitrarily by us
5. Availability of long-term records, which would mean that the individual case was recorded annually from 1 year to 18 years of age on a longitudinal basis (a necessary qualification being that some of the cases had individual annual records missing, these voids, in the long-term series, being filled by cases of similar size and morphology on a selective basis to complete the longitudinal range)

Some, in minimizing the value of norms, have pointed out that our patients do not all have good health histories or aesthetically pleasing faces and certainly do not have excellence of occlusion. One must realize that we are not attempting to define a mean of the population as it presents itself but rather an arbitrary measuring device that will routinely demonstrate the variations displayed by the case to which it is compared.

AVERAGING FOR CONSOLIDATION

Each of the individuals included in the series of Bolton Faces, at the time that the cephalometric radiographs were exposed, had study casts made as well as records of their height and weight and a hand-wrist x-ray film taken for evaluation of skeletal age. This group was equally divided as to sex—sixteen males and sixteen females, and their cephalometric radiographs were traced in the manner described in Chapter 3. This method, in the tracing of the lateral x-ray film, transfers bilateral structures into a single-outline tracing that is comparable to projection of the right and left structures on the midsagittal plane.

Fig. 4-3 indicates the subsequent step of averaging pairs of tracings to form a composite and then in turn averaging composites to form another single tracing. This method of interpolation was carried on until the sixteen tracings of individuals in the male group were interpolated into one optimum face, and the sixteen tracings of individuals in the female group were interpolated likewise. This process was followed for each chronologic age, and the total constitutes some 2,174 tracings for the resolution of the frontal and lateral examinations.

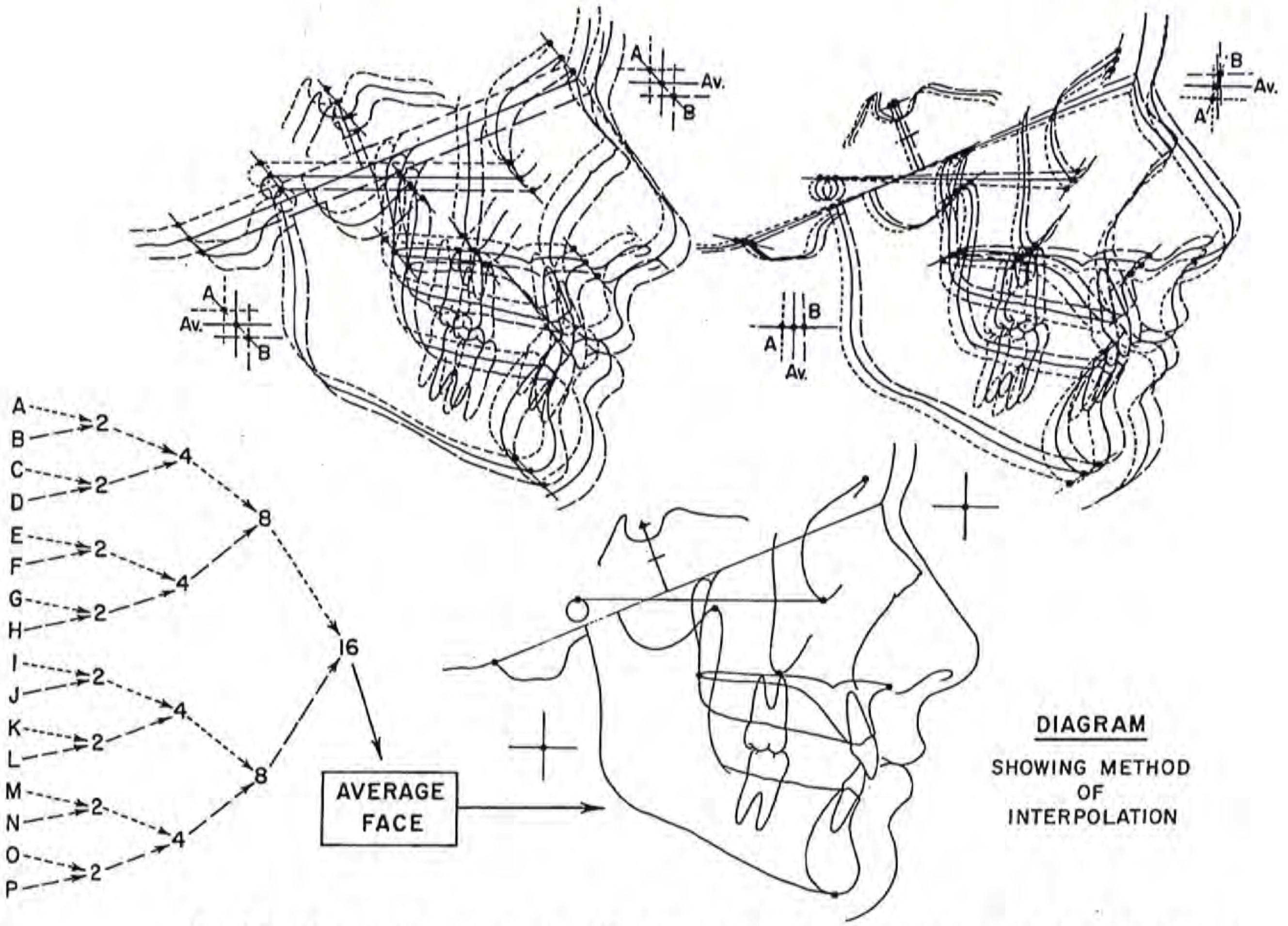


Fig. 4-3. Method of averaging tracings. This diagram shows how two tracings may be averaged, although superposed in different relationships, with the resulting image the same. This method was used to average the group of sixteen males and sixteen females to a single tracing.

The reasons for the selection of sixteen individuals in each sex group are that it afforded a large enough sample to be statistically valid, lent itself numerically to the averaging technique and interpolation, and also constituted a majority of the *optimum* longitudinal records that were available in the Bolton data collection.

Note that the lateral annual Standards extend from 1 year through 18 years of age, whereas the frontals begin at 3 and carry through to 18 years of age. The frontal radiographs were not routinely taken during the first two years because of the difficulty of positioning the infant coupled with the longer exposure time that is necessary to obtain this radiograph. Most of the lateral cephalograms were taken with the child lying down rather than sitting during the first two years of life. Fig. 4-4 presents a composite of the annual tracings of the lateral and frontal Bolton Standards and graphically shows the symmetry and uniformity of morphologic patterns from 1 to 18 years of age. These records are superposed in Bolton relation, as suggested in Chapter 5.

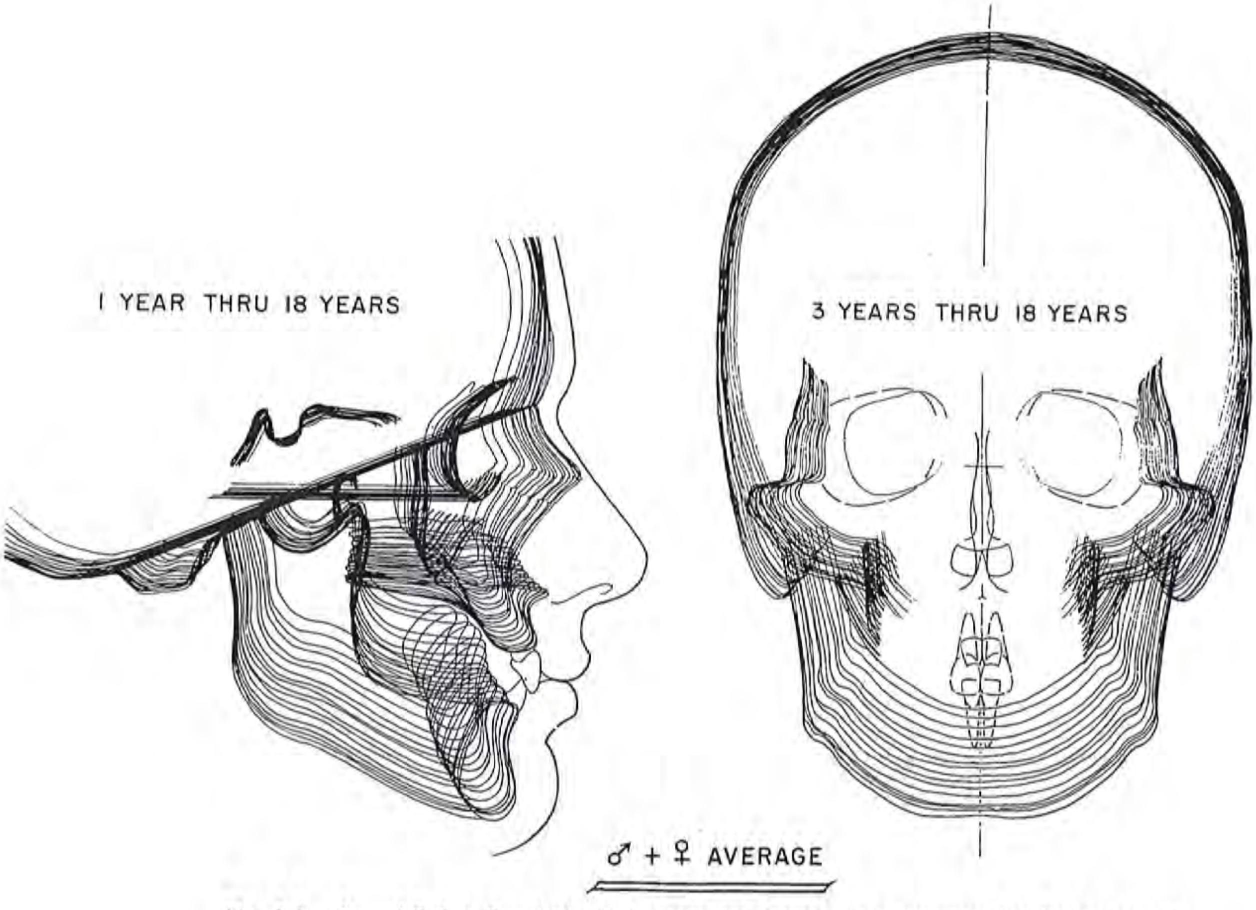


Fig. 4-4. Annual Bolton Standards. Both lateral and frontal views superposed in Bolton relation.

GROWTH SPURTS

It is well known that periods of acceleration and deceleration occur in an individual's developmental progress, particularly in relation to the pubertal growth spurt. However, the occurrence of these changes in velocity takes place at different chronologic ages in different individuals. Consequently, the method of averaging tracings that has been used to resolve the Standards into one outline tracing has obliterated these individual variations, so that the Standards demonstrate an essentially uniform incremental pattern. The point, then, should be constantly kept in mind that, although the Bolton Standards demonstrate almost complete uniformity of progression, the individual is a variable entity and will present changes of growth magnitude at varying times in his or her own developmental growth process.

FRONTAL SYMMETRY

The final frontal tracings that make up the annual Bolton Standards in the P-A projection have been traced with the same method of averaging, or interpolation. However, in addition, to eliminate the often-seen minor asymmetries of the right and left sides, each annual tracing was reversed over itself and a subsequent average completed. This, then, brings the right and left structures into exact symmetry.

Another problem that necessitated correction in the frontal Standards was that of vertical variance, since the head may have been tipped slightly either up or down at the time of x-ray exposure. These corrections were made with the use of the Orientator, so that all structures were correctly related in the horizontal plane.

CEPHALIC AND FACIAL INDICES

Cephalic index, as it has been presented by the anthropologists, is a comparison of the cranial dimensions in the horizontal plane. It relates the lateral dimension of the cranium to the P-A dimension and offers three general categories of this ratio. As seen in Fig. 4-5, facial index draws an analogous relationship between height and width of the face and gives us leptoprosopic, mesoprosopic, and euryprosopic types. The frontal cephalometric tracings of the Bolton Standards fall roughly into the mesoprosopic morphologic pattern and consequently may be used as a lateral gauge, when superposed on the midsagittal plane for determining such measures as the bizygomatic, bigonial, or dental arch widths as they might be differentiated from the two peripheral types.

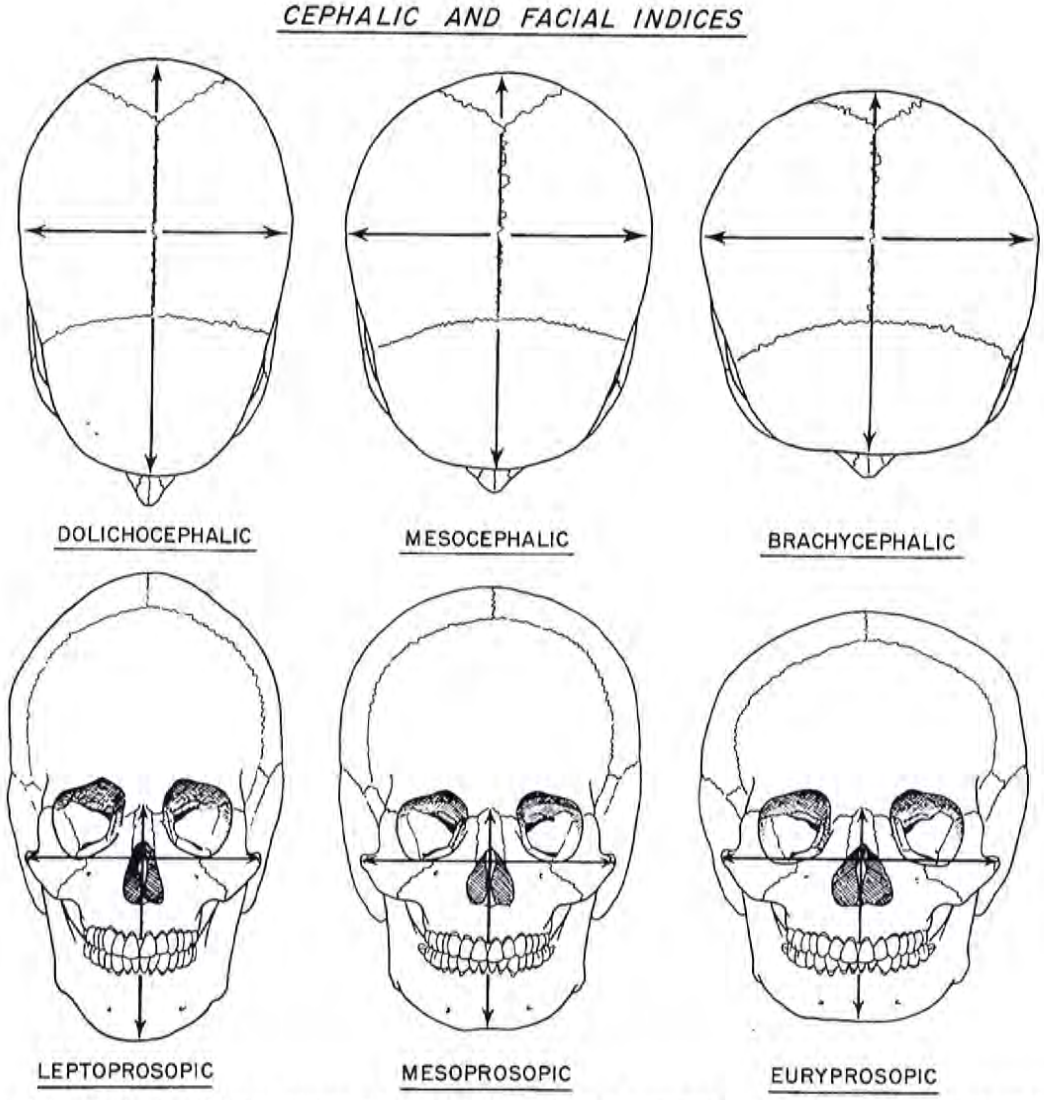


Fig. 4-5. Cephalic and facial indices. Three distinct facial types as related to height, width, and depth of the skull.

CHRONOLOGY OF DENTAL ERUPTION

As one views the maturation of the dental units of the Standards and follows them through to their time of clinical eruption, the overall pattern of the Standards will be noted to be slightly later chronologically than might be suggested by other published statistics[7] of dental eruption times. The overall moderately late eruption times in this optimum group probably are significant, since one may reasonably assume that the longer the face continues to grow dimensionally prior to the eruption of the adult permanent dental units, the greater opportunity Nature has to place them in their proper position in the oral cavity and to bring about a normal alignment.

QUALIFICATIONS IN USE

A reiteration of a previously noted point seems worthwhile at this stage: cephalometric case records, to be utilized properly in a direct comparative manner with the transparent Standards, must be taken originally in the standardized relationships described in Chapter 1—that is, with the proper target-object distance and with a variable cassette location that allows the film holder to be positioned as close to the head as practical during the time of exposure.

An advantage of utilizing transparent Standards will be noted in the fact that they may be superposed over the radiographs directly without the intermediate step of tracing and secondarily that those practitioners who routinely view the face in lateral aspect with the soft tissue features to the left, rather than to the right, will find it simple merely to reverse the

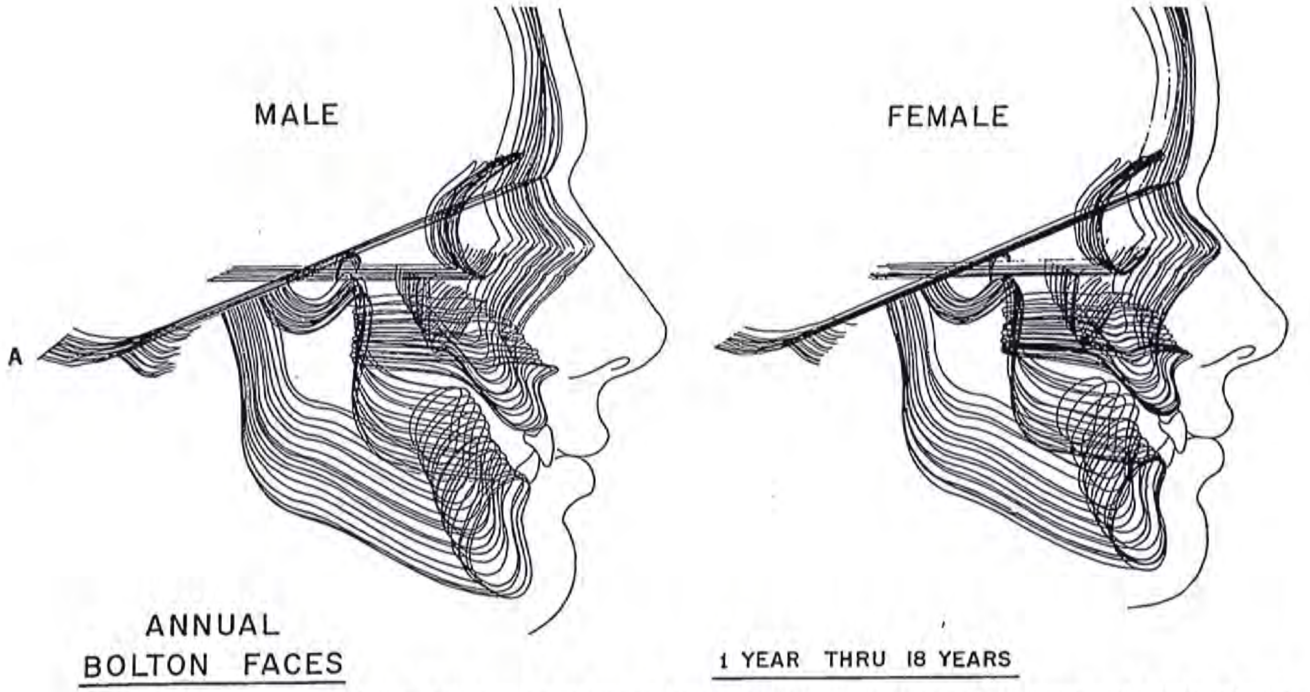


Fig. 4-6. **A,** Bolton male and female annual lateral averages. Both groups are superposed in Bolton relation and depict a strikingly similar morphologic pattern. **B,** Average male and female Bolton Faces superposed in Bolton relation. The similar morphologic pattern is demonstrated with the first significant change in size occurring between 12 and 15 years of age at approximately 14 years.

transparency and superpose it in the manner to which they are accustomed. We wish to stress again that no set pattern of superposing is dictated in the use of the Standards, although some comparisons lend themselves to greater ease of communication. Also we do not wish to imply that individual cases should be metamorphosed into fitting the Standard as a treatment goal. Rather the use of the Standard, in divulging the individual case variations, allows a practical and personalized treatment plan to be developed for the case presented.

MALE VERSUS FEMALE STANDARDS

The resolution of males and female Standards into one has been debated for a long time and, if accepted, must be an arbitrary maneuver. The patterns of the male and female (Fig. 4-6) are essentially the same morphologically, except for a dichotomy in size, beginning in the middle teens, and, of lesser consequence, in secondary sexual characteristics. Sexual dimorphism in size takes place at approximately 14 years of age in the Bolton Faces, but one must realize that everything is not definitive and that a tremendous overlap exists between

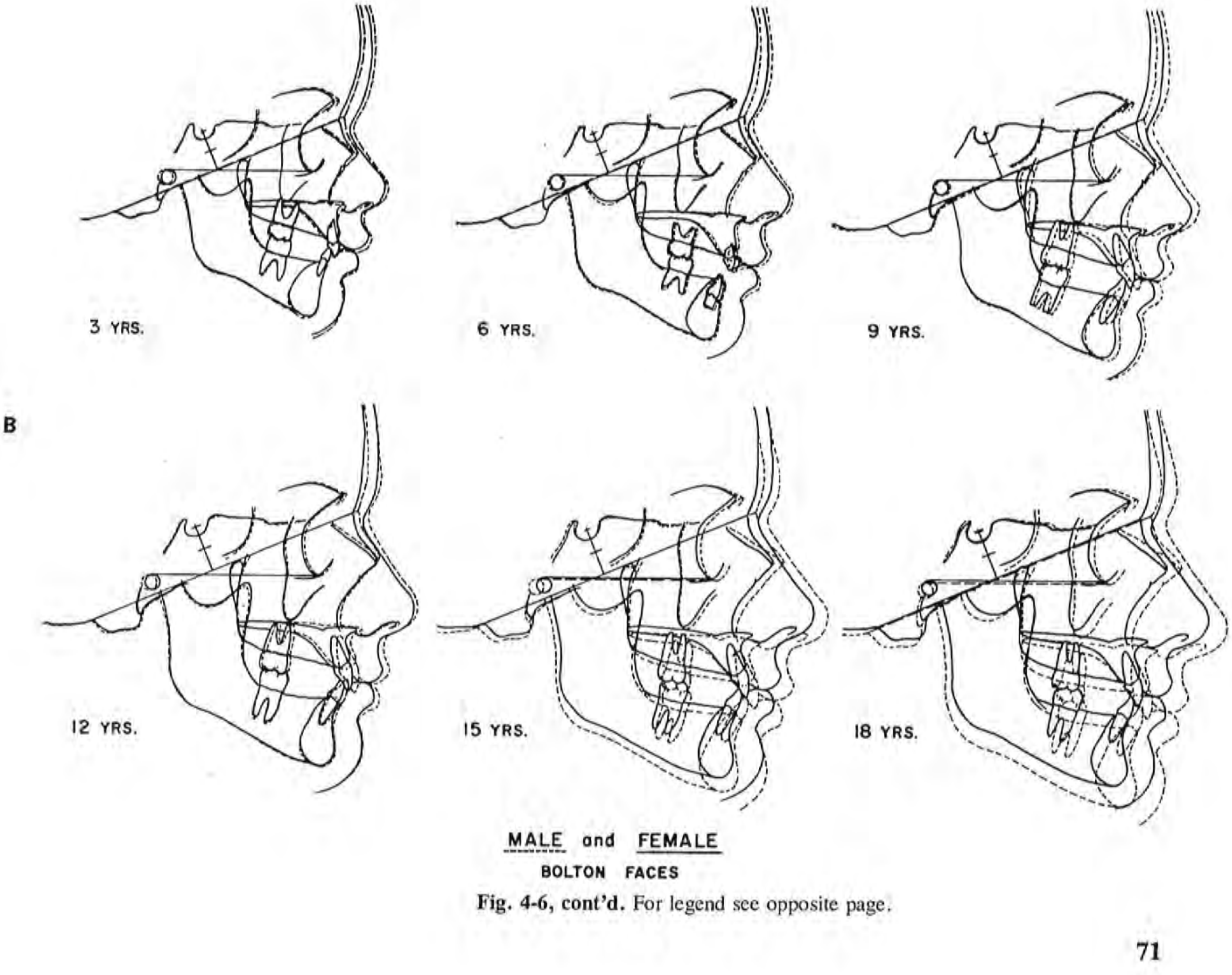


Fig. 4-6, cont'd. For legend see opposite page.

the sexes. As indicated in Bayer and Bayley's[1] diagram of androgyny (Fig. 4-7), the spectrum of individual humans are male-males, female-males, male-females, and female-females. If, in fact, the basic skeletal assembly of males versus females did contribute significantly to a difference in orodental relationships, then this necessarily would have to be taken into consideration; but we have found that the basic facial patterns of the two as they support the dentition are so strikingly similar that they can be coalesced.

In comparing the male and female from a linear standpoint (Fig. 4-8), note that interestingly the faces used in the Bolton Standards have an overlapping of range that throws a large number of both groups into a central band of equality at all ages. This is simply demonstrated by the measurements shown: *Bo-Na, Y Axis,* maxillary and mandibular lengths, and anterior upper face and lower face heights. They present what is referred to as a *continuum;* that is, a critical line cannot be drawn between the two sexes. We believe ourselves thus able to rationalize the use of a single Standard, rather than one for males and another for females.

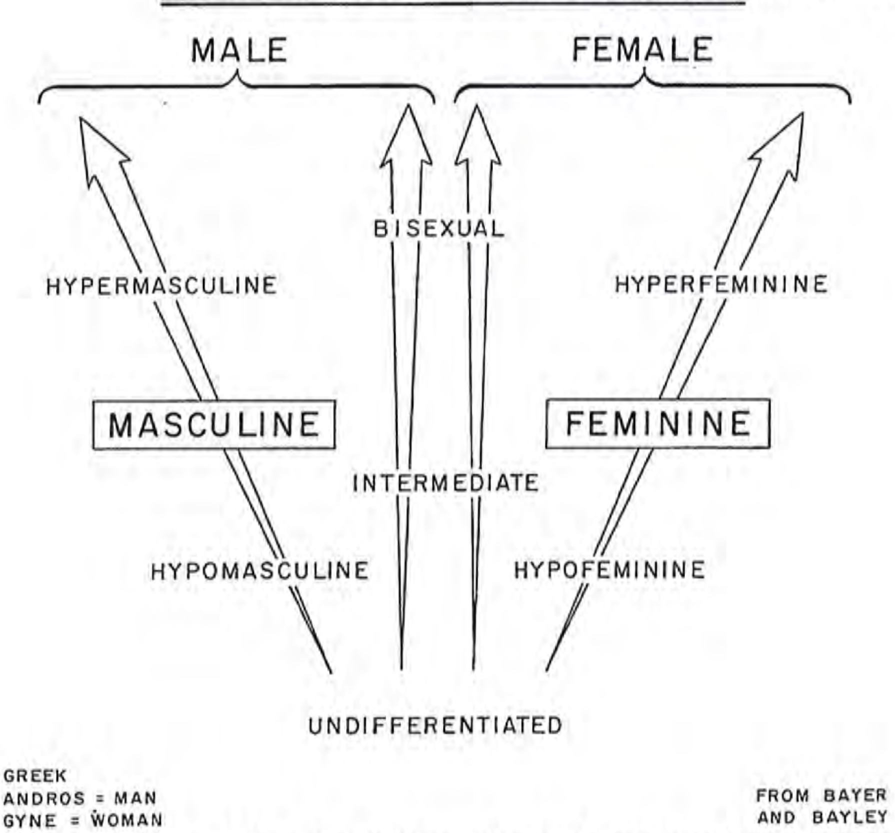


Fig. 4-7. Mosaic of androgyny. Diagrammatic representation of the continuum between hypermasculinity and hyperfemininity. (From Bayer, L. M., and Bayley, N.: Growth diagnosis, Chicago, 1959, University of Chicago Press, © 1959 by the University of Chicago.)

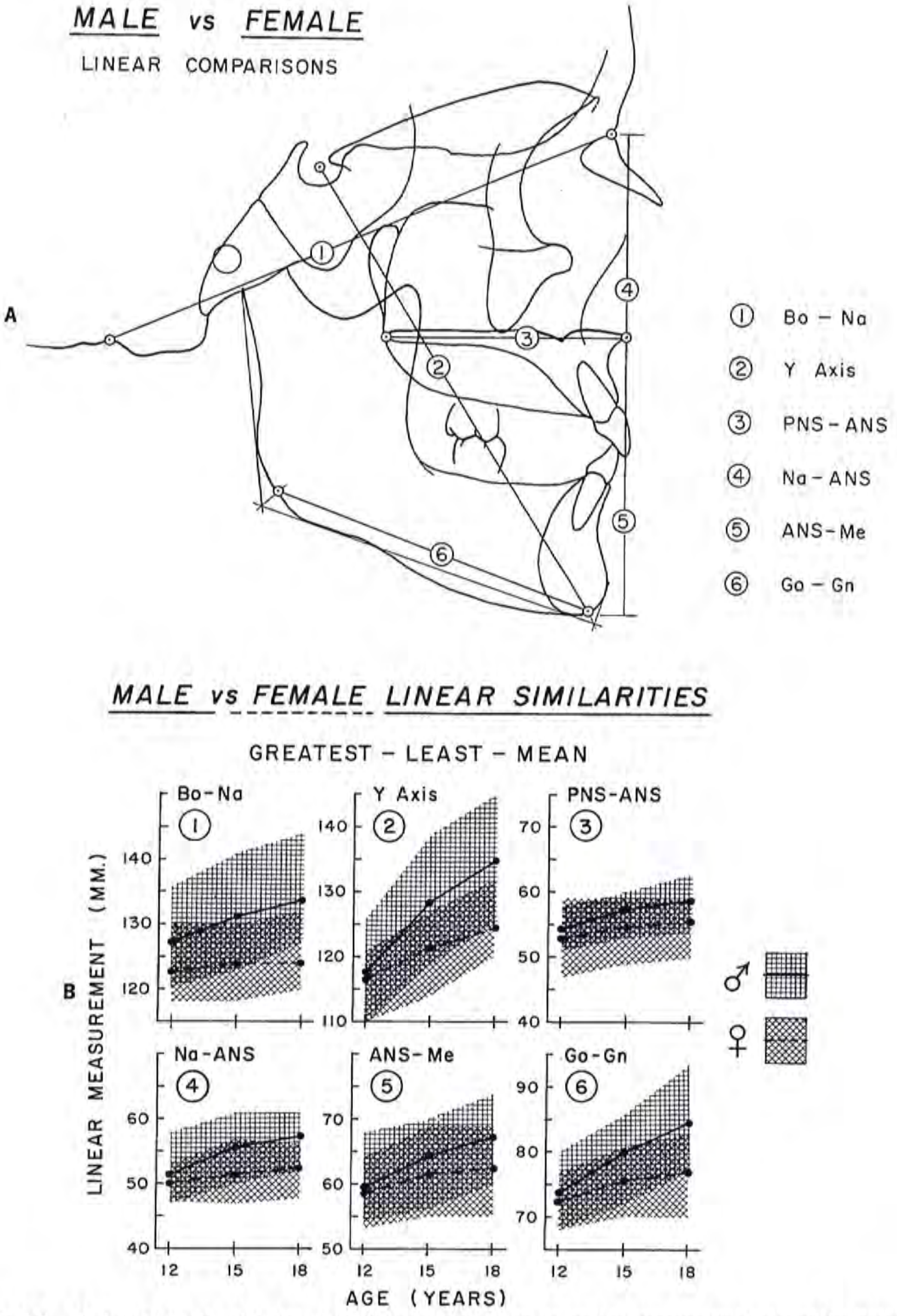


Fig. 4-8. **A,** Lateral tracing showing six basic linear measurements used to compare facial size of the Bolton male and female standards. **B,** Graphs of male and female linear size similarities. Each graph shows the range and mean for the given linear measurements and indicates the continuum that occurs with the overlapping of size of the male and female measurements in all instances.

SEXUAL DIMORPHISM

Looking superficially at the elements that relate to the popular concept of "craniofacial sexual dimorphism" (Table 1), one notes that the phenomenon of the adolescent growth spurt (circumpubertal) is *generally* accepted to occur between the ages of 10 and 12 years in the female and 12 and 14 years in the male and that the termination of active growth takes place in a plateauing of size change in the females at 14 years. However, minimal growth continues on to 18 years of age; whereas the males, in contrast, are observed to continue actively in growth increments to the eighteenth and nineteenth years. Actually sexual dimorphism is in the main an expression of secondary sexual characteristics that occurs after puberty and during the adolescent years. Essentially nine craniofacial areas can be defined as showing notable variability between the male and female (Fig. 4-9). These may, of course, enter into individual treatment planning, but they do not basically alter the skeletal-spatial relationships that, in fact, are the substructure for the proper alignment of the dentition.

The most familiar differences are the larger size of the frontal sinuses and supraorbital ridges of the male versus those of the female and the larger nose and more prominent chin point in the male as contrasted with those of the female. Then of lesser importance is the lipping out of the gonial angle in the male. Of least importance are the differences in occipital condyles and occipital protuberance. Sexual dimorphism of the craniofacial structures, then, is real but of qualified significance.

Table 1. *Sexual dimorphism in craniofacial patterns:* three areas of comparison of males and females that indicate their dissimilarities*

	Females	*Males*
Circumpubertal growth spurt	10 to 12 years	12 to 14 years
Mature size	Growth plateaus approximately 14 years Moderate increase to 16 years	Active to approximately 18 years
Physical characteristics (differences develop in middle to late adolescence)		
Supraorbital ridges (*A*)†	Virtually absent	Well developed
Frontal sinuses (*B*)	Small	Large
Nose (*C*)	Moderate	More massive
Zygomatic prominences (cheekbones) (*D*)	Small	Large
Mandibular symphysis (pogonion) (*E*)	Rounded	Prominent
External mandibular angle (gonion) (*F*)	Rounded	Prominent lipping
Occipital condyles (*G*)	Small	Large
Mastoid processes (*H*)	Small and delicate	Large
Occipital protuberance (inion) (*I*)	Insignificant	Prominent

*These dissimilarities are not significantly related to skeletal balance or malocclusion.

†Letters refer to Fig. 4-9.

SEXUAL DIMORPHISM IN CRANIOFACIAL DEVELOPMENT

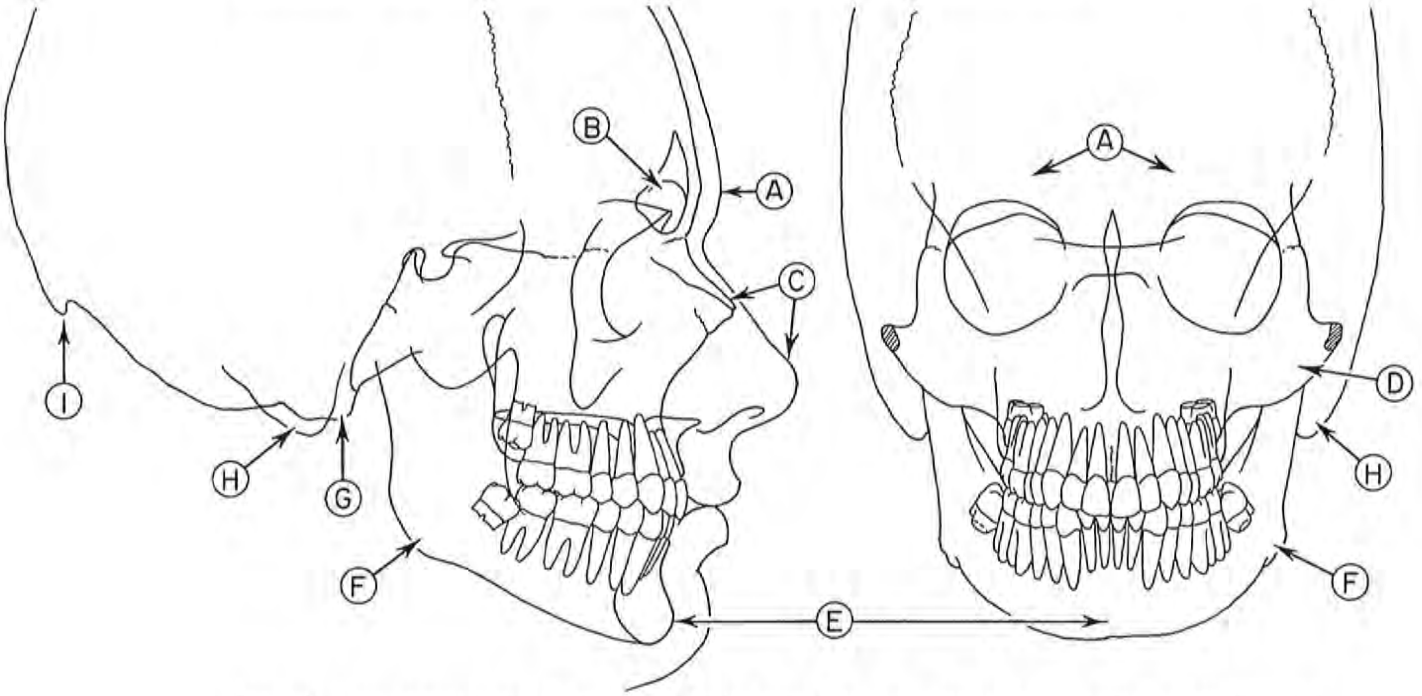


Fig. 4-9. Sexual dimorphism in craniofacial development. Diagram indicates the basic areas of differentiation that occur between males and females in the adolescent years.

RACIAL DIFFERENCES

At least one more important variable must be taken into consideration, and that is the application of a fixed standard to the variations seen in the different human races.

Much discussion still continues among anthropologists about the definition of *race* and exactly which factors are unique to a given racial group. One may accept the division of humankind into three basic races—Caucasian, Negro, and Oriental—or a larger categorization of five[2]—Caucasoid, Negroid, Mongoloid, Australoid, and Capoid—or up to fifty definitive groups. Innumerable studies offer statistical information relative to cranial size or cephalic index as it varies racially, indices of nasal proportions, size of jaws and teeth, hair patterns, eye color, and other factors. The Bolton Standards are Caucasian in derivation, but they can be used as a measuring device to indicate areas of dentofacial racial variability. The obvious limitation on the development of other racially oriented norms is the lack of longitudinal data available.

A use of the Bolton Standards for racial comparison is seen in Fig. 4-10. The example is an 11-year-old Negro boy who has an obvious bimaxillary protrusion, a condition frequently associated with the Negro race. Superposing the 11-year Standard over his tracing in the Bolton relation, one observes a significantly longer cranial base, an anterior position of the midface, and a definite procumbency of the alveolar process and dentition of the mandible. Reorientation of the Standard on nasion and pogonion will give a definitive picture of the extent of the bimaxillary protrusion and its influence on lip position. One can, in this way, use this measuring device as an aid in deciding whether to reduce the procumbency or whether it is a typically Negro pattern and the dental alveolar areas are, in fact, in normal relationship.

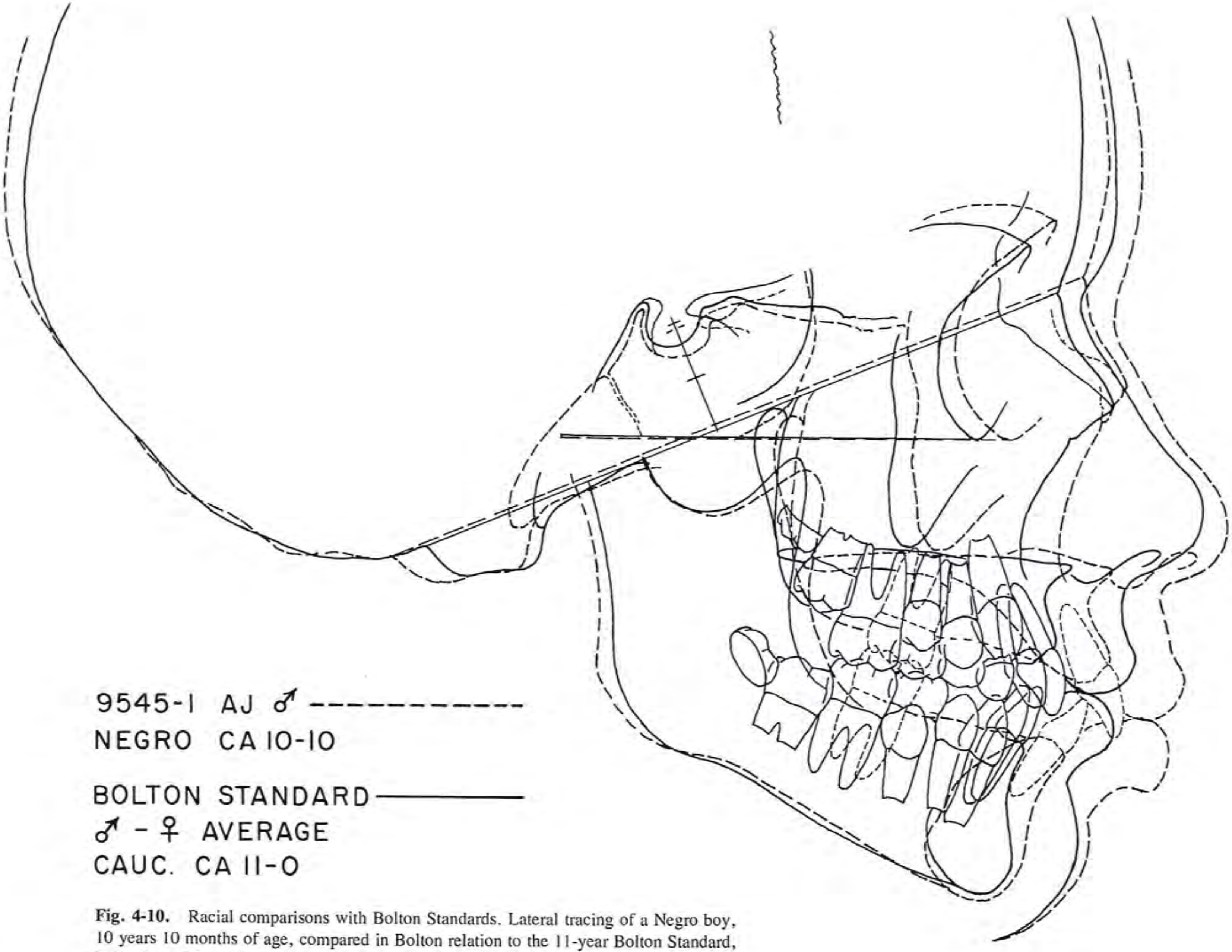


Fig. 4-10. Racial comparisons with Bolton Standards. Lateral tracing of a Negro boy, 10 years 10 months of age, compared in Bolton relation to the 11-year Bolton Standard, indicating a bimaxillary protrusion and basic skeletal variations.

HEIGHT, WEIGHT, AND SKELETAL AGE

Information regarding standing height, weight, and skeletal age is of value in considering an individual's relationship to normal patterns or the maturational process as it relates to peers. Fig. 4-11 shows the mean and range for the developmental progress of these entities in the *Bolton Face* population. The group, as it is used in the entire Bolton Standard, is indicated as males and females pooled, although the mean and range for females and males are each shown separately also. Note that, at approximately 14 years of age, a plateauing of the female increments takes place in both height and weight, whereas the males continue on their moderate upswing to 18 years of age. The few obvious peaks on the high side of the weight range can be related to isolated individuals who were dovetailed into the longitudinal series when a single record of a long-term case was absent.

The skeletal age chart (Fig. 4-11, *C*) demonstrates a significant range of skeletal maturation for each chronologic year but places the mean increment of both the males and females, as well as the pooled group, in a closely related position up to 17 years of age. At that age the females may be seen to have reached "adulthood," whereas the male group is continuing to complete its maturational process.

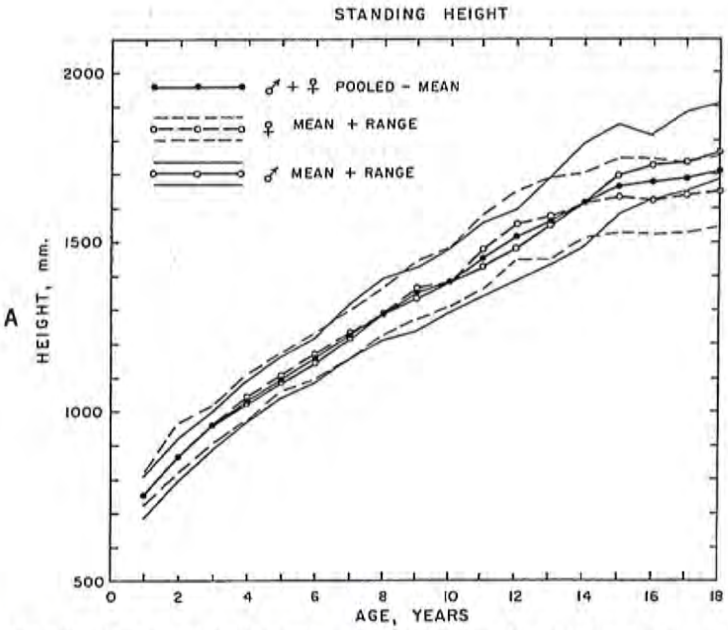
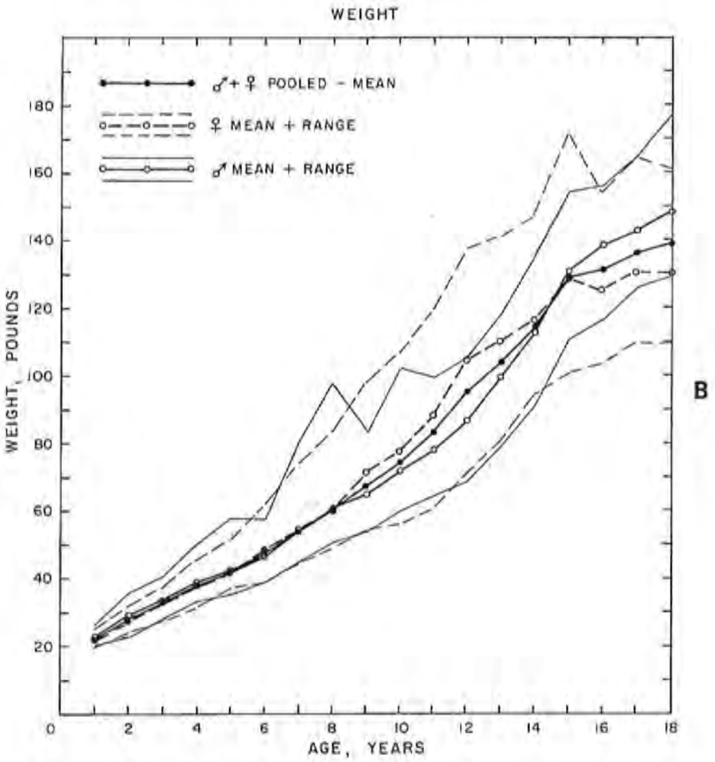


Fig. 4-11. **A,** Standing heights of individuals who make up the Bolton Standards. Male and female ranges and means of height are shown, as well as the mean for the pooled group (the Standards) on a chronologic basis. **B,** Graph indicating weights of Bolton individuals. Ranges and means for the Bolton Standard and the female and male groups are indicated separately on a chronologic basis from 1 to 18 years of age. **C,** Graph of Bolton Standard skeletal ages. Range and mean for skeletal age are indicated on a 1- to 18-year chronologic basis for the females, males, and pooled group, or Standard.



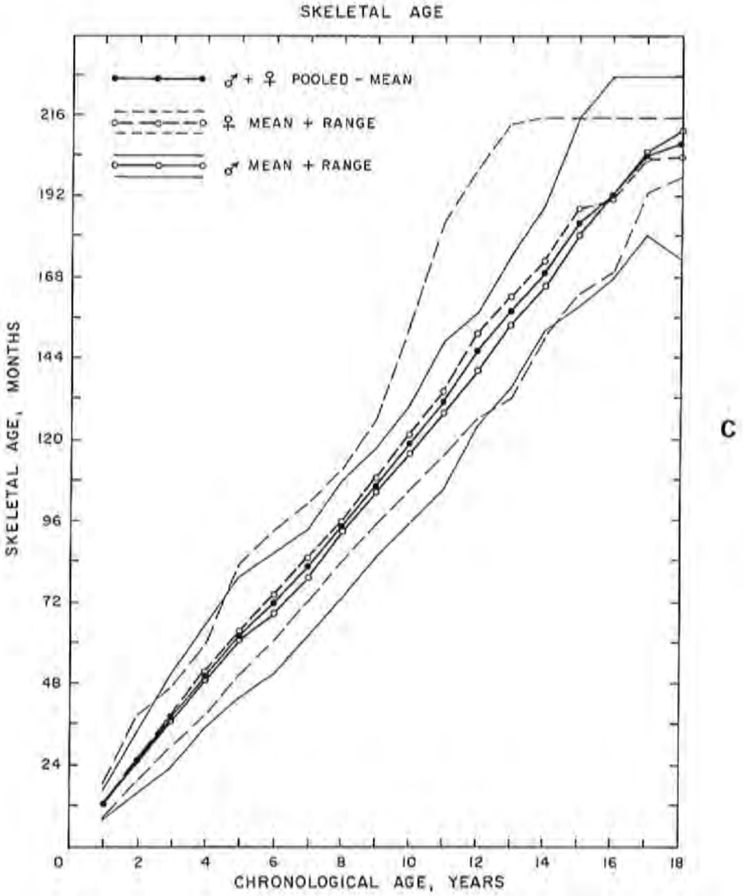


Fig. 4-11, cont'd. For legend see opposite page.

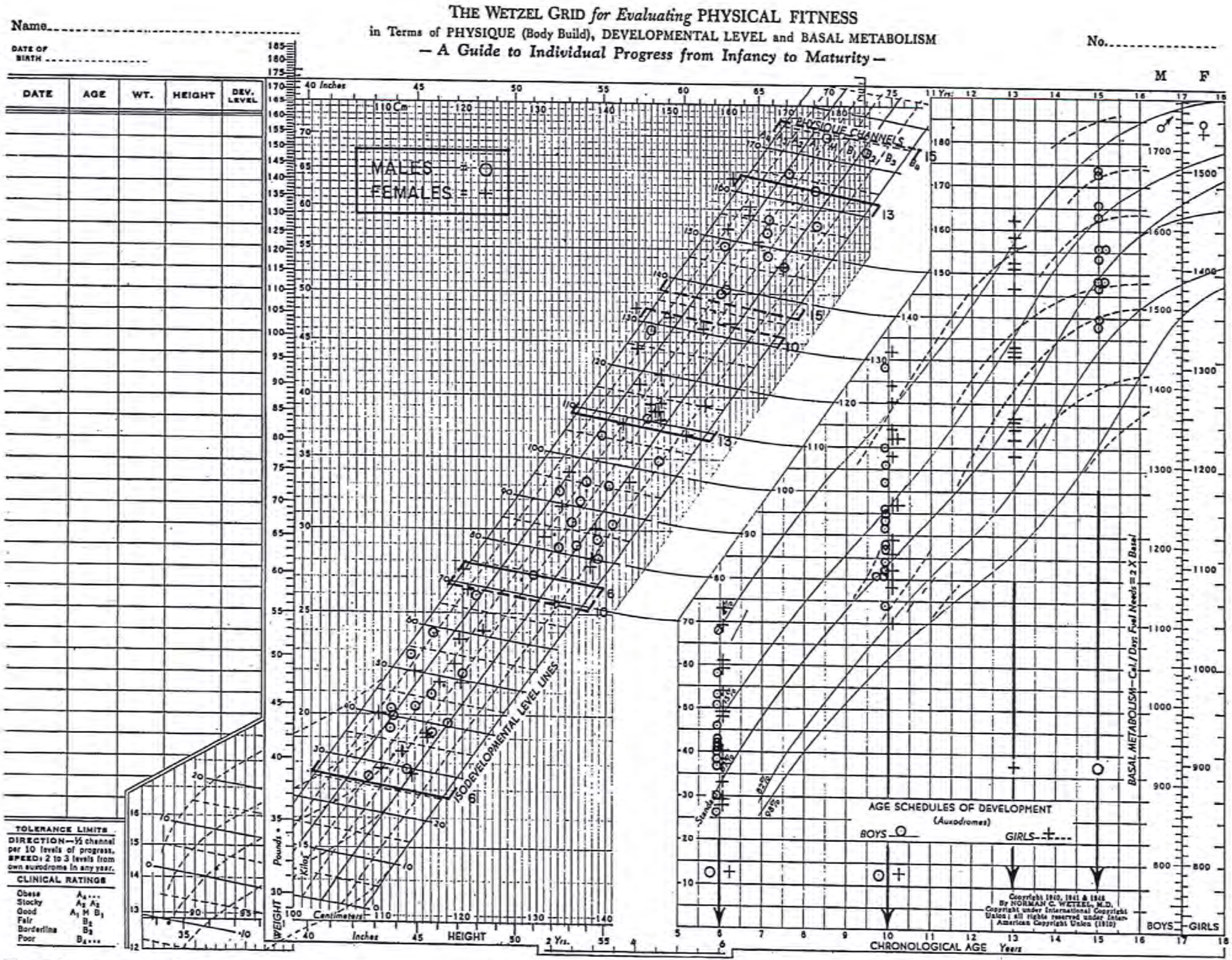


Fig. 4-12. Wetzel grid of Bolton individuals. This grid plots 6-, 10-, and 15-year-old Bolton Standard males and 6-, 10-, and 13-year-old females. The distribution of each group is what might be expected in a healthy normal population. (In some groups less than sixteen measurements are represented, when individual examination records are lacking.)

To further demonstrate graphically this normal range of variation as the previously mentioned factors relate to the Bolton group, Fig. 4-12 shows a plot on a Wetzel grid[9] that gives (chronologic ages indicated) the spectrum of development for the males and females as they individually progress along their own maturational paths.

COMPUTERIZATION OF THE BOLTON STANDARDS

The arduous and time-consuming process of making cephalometric measurements on the large number of tracings involved in the Standards dictated that, if a significant and representative group of measurements were to be presented in this text, some method of computerized information retrieval was necessary for the project. Fortunately for us the willing assistance of Dr. Geoffrey Walker and the Biometrics Laboratory at the University of Michigan was the solution to this problem. Dr. Walker, during his association with Dr. Wilton M. Krogman at the Philadelphia Growth Study Center, developed a 177-point program for digitizing the skeletal outline of the lateral cephalometric tracing and placing it in the computer so that linear as well as angular measurements could be made from any of the selected points of the program.

Dr. Walker, in association with Dr. Kowalski, has reported this method of computerization in the literature.[8] (See Appendix Fig. 1 for a diagrammatic representation of the specific points out of the 177 of the program that were used in digitizing the 568 Bolton lateral tracings.) This method, then, made possible the retrieval of the information contained in the Appendix.

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CHAPTER 5

Clinical applications of the Bolton Standards in case analysis

The uses of the Bolton Standards by the clinician, researcher, or teacher are limited only by the imagination of the individual as long as the inherent qualifications, described in the previous chapters, are respected. These applications may be as simple as the use of the Bolton Standard Correlation (BSC) described in Chapter 1, which will be reviewed in the succeeding paragraphs or as complex as a base line for describing involved morphologic patterns, paths of eruption of dental units, or the correlation of an infinite number of specified linear or angular measurements.

Those who have had only a beginning exposure to the interpretation of cephalometric radiographs or their tracings should realize that, from a comparative standpoint, the relating of serial records of an individual is significantly different from comparing the records of two different individuals or of one individual to a standard such as the Bolton chronologic optimums. One need only review the orthodontic literature through the 1940s and 1950s to appreciate some of the involved interpretations that have been presented as clinical analyses of cephalometric data through the use of angular and linear measurements. Most of the more widely accepted and simplified analyses, such as those of Downs,[1] Steiner,[3] Riedel,[2] Taylor and Hitchcock,[4] and others, embody various elements of the dentofacial complex that have been interpreted by individuals or groups to be the most meaningful in their hands. These analyses actually have made cephalometrics a practical clinical tool, and their use is not to be discouraged. However, when radiographic records or their tracings are to be superposed for comparison and analysis, careful consideration should be given to the approaches used because of the inherent variabilities that are related to each skeletal entity that contributes to the total dentofacial complex.

To give an example of variables that will influence the interpretation of comparative tracings, we cite the cases seen in Fig. 5-1. These are tracings of Caucasian males, both of whom are chronologically 9 years of age. As the two are visually compared side by side, their general morphologic patterns are similar, and the Class I dental arch relationships are acceptable in their anteroposterior positions. Probably the most noteworthy element in a rapid visual comparison lies in the cranial base between sella turcica and the Bolton plane, where we find Case B-2210 with a significantly shorter linear measurement of the depth of the body of the sphenoid bone as compared to a much larger dimension of Case B-2260 in this area.

Fig. 5-2 shows three methods of superposing these two tracings and the different visual impressions that are received by virtue of these variations. Looking at the relationship depicted in *A*, one can see that the anterior cranial base dimension between the sella and

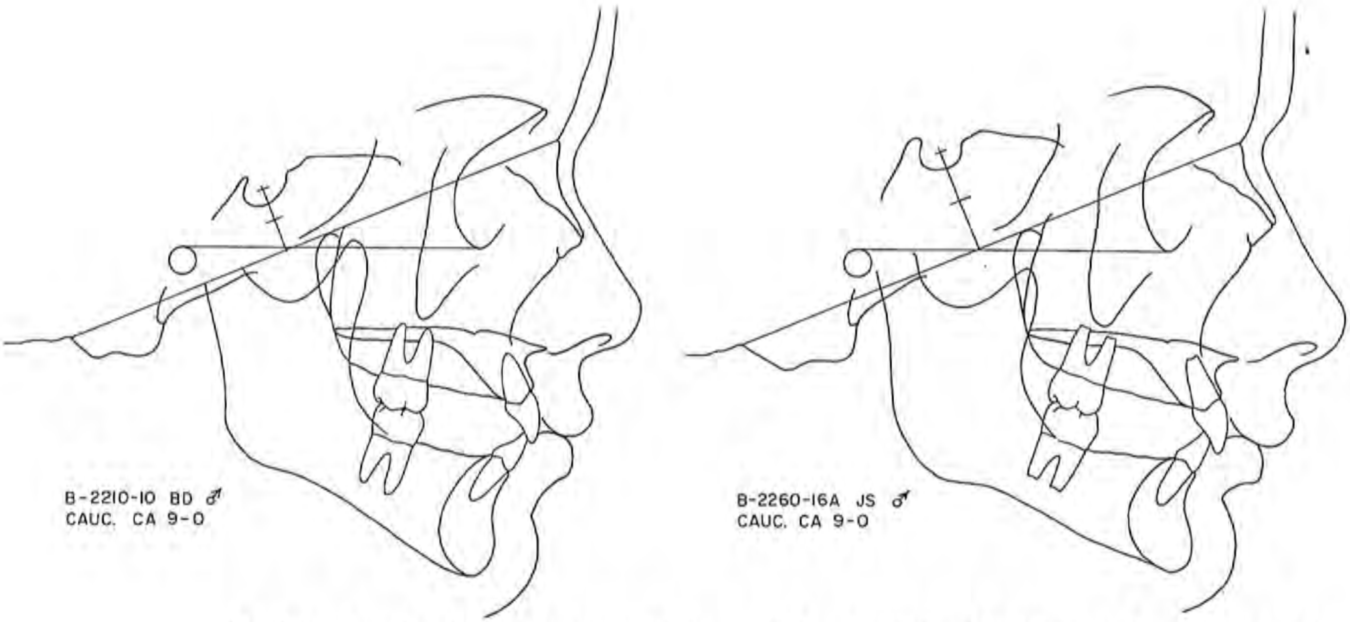

Fig. 5-1. Lateral cephalometric radiographic tracings of Cases B-2210 and B-2260—both Caucasian males of chronologic age 9 years with Class I dental relationships.

nasion is almost exactly the same, so that these two cases superpose readily on the sella-nasion plane at either the sella or nasion. Because of the variability in the depth of the body of the sphenoid bone, however, this superposing may be seen to cause considerable disparity in the relationship of the middle and lower facial outlines and to greatly hinder the ability to relate one to the other visually or measurably.

In the superposed tracings seen in *B*, the correlation has been established in the so-called Bolton relation by placing the two R points directly on one another and paralleling the Bolton planes. This method of superposing eliminates to a significant degree the variability imposed by the disparity in the depths of the sphenoid bones and offers a visual comparison of the middle and lower facial areas that is much more easily interpreted.

If, however, one observes diagram *C*, in which the two maxillary outlines, which are extremely similar in morphology and size, are superposed, an even closer coordination of the rest of the outlines of the skeletal-dental complex is seen and even more detailed observations about the variables between the two patterns can be made. Our point, then, is that no specific method of orientation will adequately reveal all the information potentially available in correlating and interpreting different cephalometric tracings and that a variety of comparisons and superpositions are desirable for obtaining a comprehensive picture of the size, morphologic, and spatial associations of the entire dentofacial complex.

Therefore a more specific interpretation of each of the three basic skeletal areas involved will allow a more critical interpretation from the standpoint not only of quantitative measurement but also of the broadening of understanding and communication for both trained and untrained observers.

The *BSC*, as seen in Fig. 5-3, has as its definitive landmarks *(A)* the Bolton-nasion plane, representing the *cranial base*, or *CB,BSC*, *(B)* the maxillary plane from the posterior nasal spine to the anterior nasal spine in correlation with Downs point *A*, representing the midface, and *(C)* the mandibular dimension (effective length of the mandible) from Bolton articulare to gnathion.

1. To begin with the cranial base, this dimension should be understood to be in some instances difficult to interpret because of the complications in locating the Bo on certain cephalometric radiographs. This point is frequently obscured by the mastoid process in the

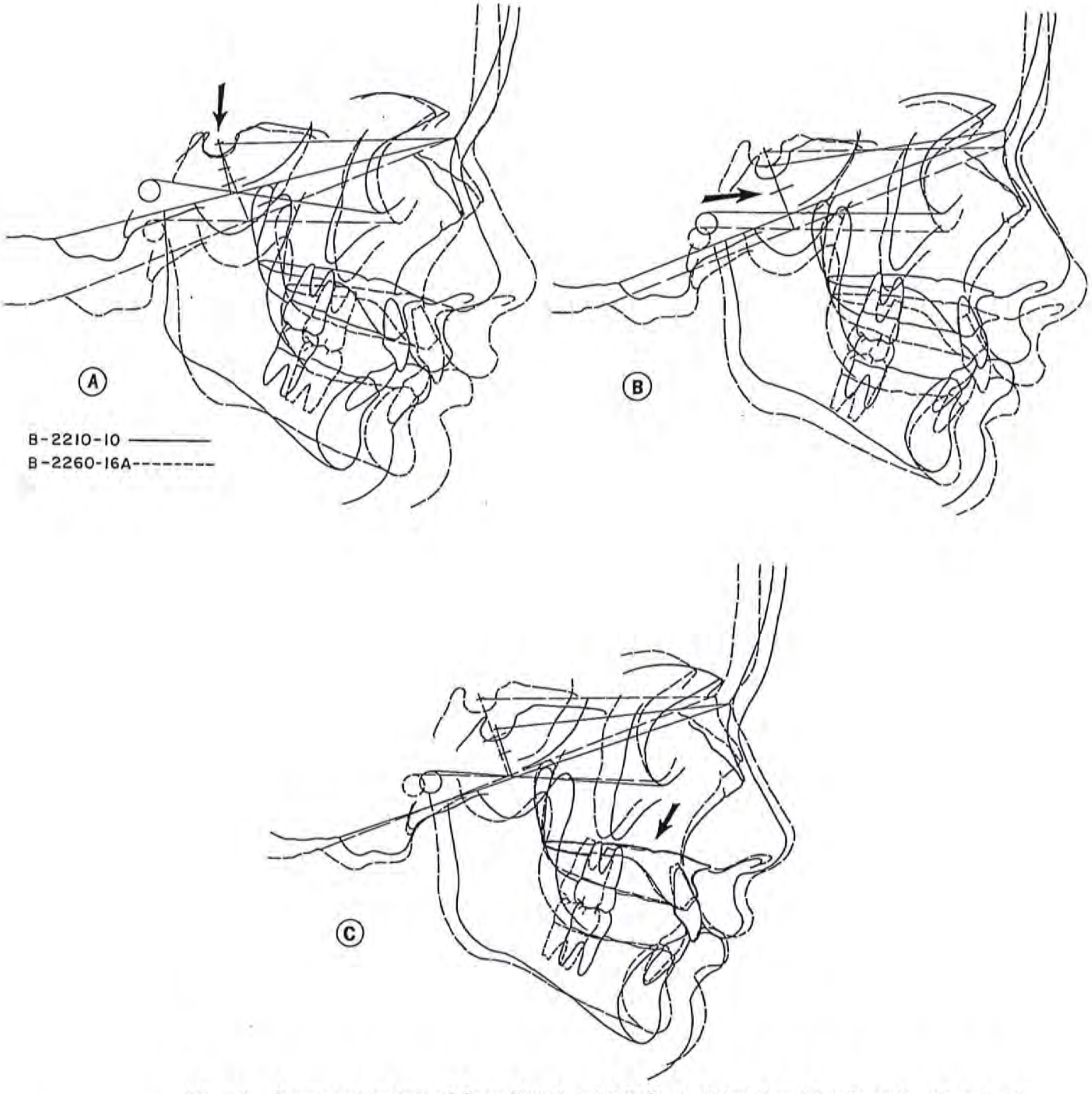

Fig. 5-2. Superposed tracings of Cases B-2210 and B-2260. **A,** Oriented on the sella-nasion plane at sella. **B,** Oriented in Bolton relation with the R points registered and Bolton planes parallel. **C,** Oriented on the outline of the maxilla.

"teen" years; but, with the use of an interpretation, as depicted in Fig. 5-4, one can use the long axis of the first cervical vertebra with a perpendicular tangent to the posterior extremity of the superior articular process to arrive at a reasonably valid location of the Bo in cases in which it is not easily discernible. The Bo is selected rather than the basion because of the desire to gain an impression of the total length of the cranial base as well as the fact that many cephalometric head holders obscure the anterior margin of the foramen magnum and thus make the basion itself a difficult landmark to locate. This does not mean, however, that the basion-nasion plane should not be used and interpreted by those who find it more desirable. The Bolton Standards clearly indicate both Bo and basion.

2. The maxillary Bolton Standard Correlation, or *MX,BSC,* as seen in Fig. 5-3, is defined by superposing the maxillary planes and comparing the linear dimension between the posterior nasal spine (PNS) and both Downs point *A* and the anterior nasal spine (ANS). Morphologic variability is often seen in the area of the ANS, so that interpolation is sometimes necessary.

We also hasten to add that the PNS, in its relationship to the tuberosities and the base of the pterygomaxillary fissure, may be difficult to see in the cephalometric radiograph. A degree of latitude is sometimes necessary in interpretation of this area, since in lateral projection

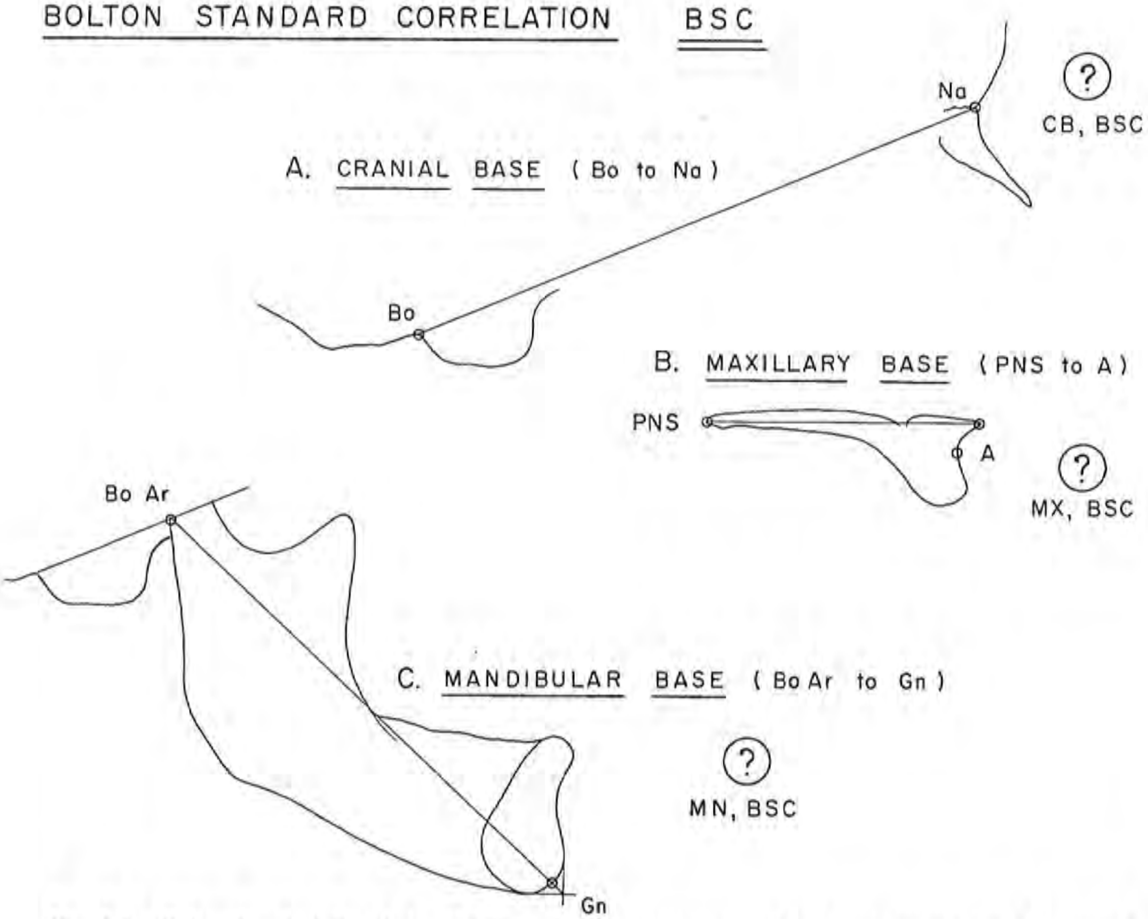

Fig. 5-3. Bolton Standard Correlation (BSC). Diagrammatic representation of an interpretation of **A,** cranial base, **B,** maxillary base, and **C,** mandibular base, each of which is measured with the landmarks indicated.

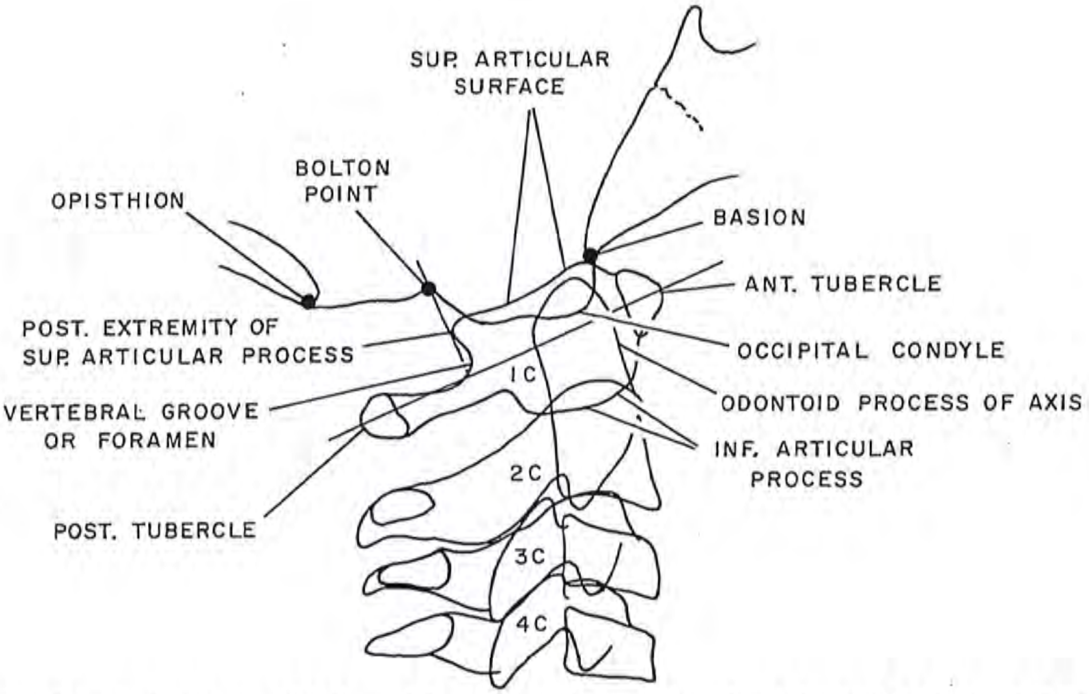

Fig. 5-4. Outline drawing of the base of the skull and first cervical vertebra, indicating the parameters of the foramen magnum, basion, and a general method for locating the Bolton point when its precise visualization in the radiograph is not possible.

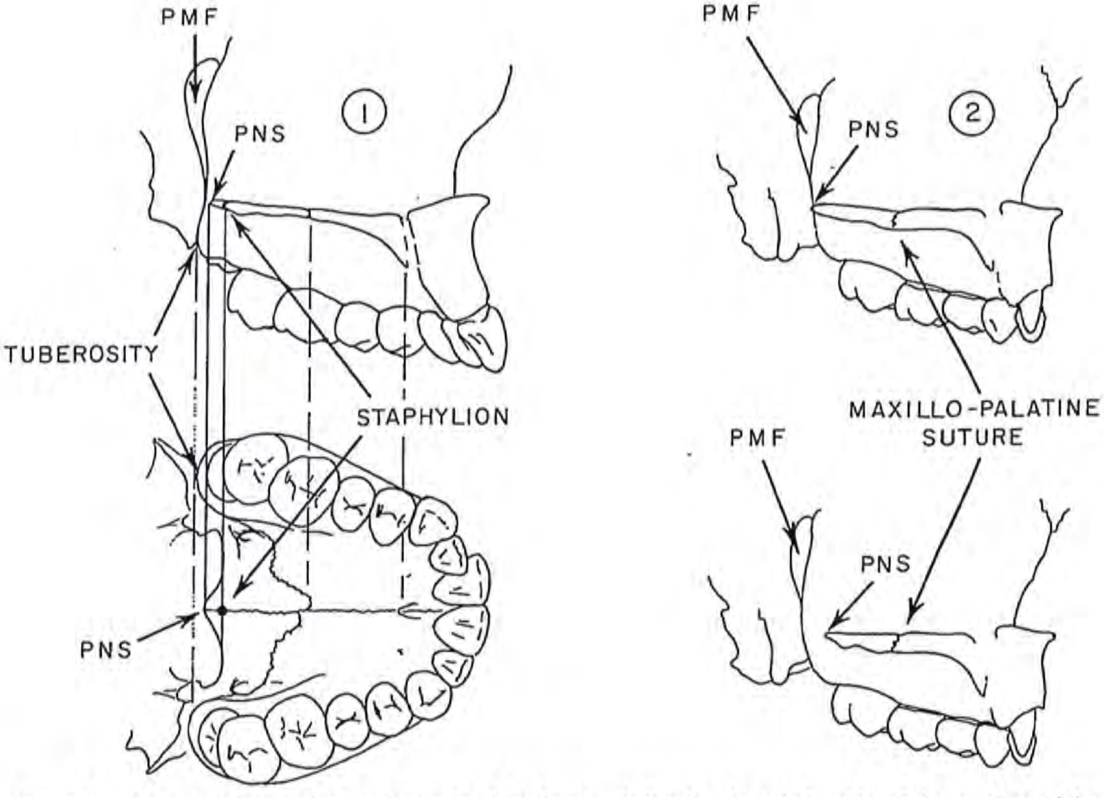

Fig. 5-5. Diagram of the palate and associated landmarks, indicating the relationship of the outlines of the tuberosities, PNS, and staphylion.

frequently what appears to be the PNS is actually the staphylion or the superposed cross-sectional shadows of the deepest aspect of the posterior palatal curvature on either side of the midsagittal plane (Fig. 5-5). Also the maxillary tuberosity may be superposed with the PNS in some cases, whereas in others the PNS may be a number of millimeters anterior (Fig. 5-5).

3. The mandibular Bolton Standard Correlation (MN,BSC) is arbitrarily defined as the linear dimension between Bolton articulare and gnathion. The interpretation of these particular points must also be clearly understood, in that the Bolton articulare is the intersection of the Bolton plane with the posterior outline of the neck or head of the mandibular condyle. It may, in some individual cases, coincide exactly with Björk's articulare, which is the intersection of the posterior outline of the neck or head of the condyle with the outline of the inferior surface of the occipital bone. As the cephalometric clinician is aware, the definition of gnathion is variable, depending on the describer, so that for clarification, gnathion, as used here, should be understood to be defined as the most anterior inferior point on the cross-sectional outline of the symphysis of the mandible. It is located by the bisection of a right angle formed by tangents to the inferior outline of the symphysis and its anterior surface. Note also for clarity that this varies from Downs's definition, which uses the mandibular and facial planes as the lines subtending an angle that, when bisected, would indicate the location of the gnathion.

As will be seen in the representative cases to follow, individual bone morphology as well as soft tissue outline can be described in any way that the observer deems practical for the interpretations and information to be conveyed.

With time and experience, the user of the Bolton Standards will see that the spatial relationship and size of the craniofacial structures (barring environmental influence, such as habits) will dictate the anteroposterior relationship of the maxillary to the mandibular arch. However, exceptions to this general concept exist, and two of these may be seen in Fig. 5-6, *A*, which represents a typical Class II skeletal pattern with a fairly symmetrical mandibular dental arch, which may be seen immediately below the diagram. The distal surface of the mandibular first molars are related to a base line of the dental arch. With this base line drawn distal to the first permanent molars, Fig. 5-6, *B*, presents the same tracing of the Class II facial pattern, with, however, a Class I molar relationship. The extenuating circumstance here is that the break in the contacts in the arch with the extreme anterior crowding has allowed forward migration of the buccal segments, placing the first permanent molar of the mandible in an "unnatural position" for the type of skeletal base supporting the dentition. In Fig. 5-6, *C*, one can observe another qualifying phenomenon that is not only seen in natural orientation but is also frequently seen as the result of Class II orthodontic treatment and its "compromise" correction. This is, as indicated, a dental relationship in which not only has the mandibular arch, symmetrically aligned, been positioned forward on the mandibular base but also the occlusal plane has been tipped superiorly in the molar area and inferiorly in the incisor area to bring about a Class I dental relationship on a persisting Class II skeletal pattern.

These two fundamental variables, disparities in arch length and tipped occlusal planes, will account for the majority of dental arch relationships that do not follow the pattern of the skeletal bases that support them.

With these qualifications and considerations in mind, we present the following case examples to demonstrate how the comparative analysis of a cephalometric radiographic tracing may be assessed with a transparent template (the Bolton Standards) to make practical observations and interpretations. A cursory outline for a method of using the Bolton

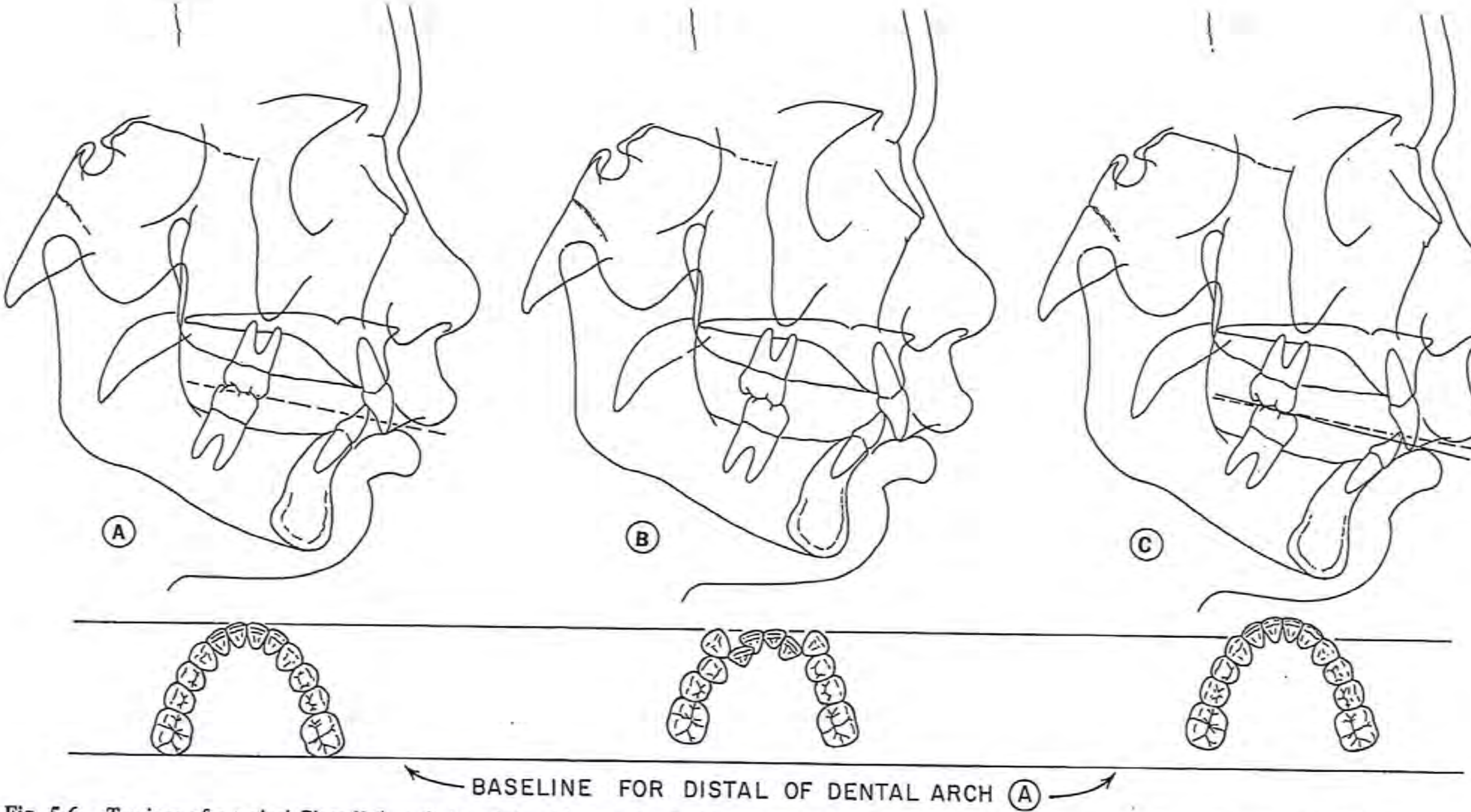

Fig. 5-6. Tracings of a typical Class II dentofacial relationship associated with two variations that may be seen in the mandibular arch and occlusal plane. **A,** Direct tracing of a cephalometric radiograph of a Class II facial pattern and malocclusion. **B,** Same case with an altered mandibular dental relationship, showing a forward migration of the first permanent molars as seen in cases in which a significant break in the arch alignment allows for a Class I buccal relationship on a Class II base. **C,** Forward positioning of the entire mandibular arch in conjunction with a tipping of the occlusal plane that may be seen as a natural, isolated phenomenon but is more frequently observed as a "compromise" orthodontic correction of a Class II malocclusion.

Standards for this general analysis is given with a full understanding that much more comprehensive interpretations may be made if desired within the criteria of the informational goals that the observer wishes to formulate.

SUGGESTED METHOD FOR BOLTON STANDARD ANALYSIS

Lateral cephalometric radiograph

1. Superpose the appropriate chronologic Bolton Standard on the tracing (or radiograph) and compare in Bolton relation (R points superimposed and Bolton planes parallel).
2. Next assess the component skeletal parts individually with the Bolton Standard that best approximates the skeletal area under appraisal and assign a *BSC* age to each (cranial base—CB, maxilla—MX, mandible—MN).
3. Make a coordinated appraisal of the total skeletal relationships, both morphologic and spatial, noting in particular the factors influencing the position of the dental arches.
4. Finally, analyze the soft tissue morphology on a "best fit" basis (starting with the forehead and nose) and relate it to the underlying skeletal and dental structures.

Frontal cephalometric radiograph

1. Superpose the appropriate chronologic Bolton Standard by inspection—coordinating the cranial, midfacial, and mandibular outlines as closely as possible in relation to the midsagittal plane and orbital outlines.
2. Assess the component parts from the standpoint of morphology, size, symmetry, and individual variation—both skeletally and dentally.
3. Observe anomalous positions of individual dental units, both erupted and unerupted.

BOLTON STANDARDS—CASE EXAMPLES

Lateral radiographic tracings

1. Class I malocclusions
    a. Small face with crowding in both arches
    b. Bimaxillary protrusion
2. Class II malocclusions
    a. Classical short mandible
    b. Maxillary protrusion
    c. Long cranial base with adequate maxilla and mandible
3. Class III malocclusions
    a. Classic prognathism
    b. Standard mandible with insufficient maxilla and cranial base
    c. Maxillary insufficiency

Frontal (P-A) radiographic tracings

1. Unilateral maxillary insufficiency with buccal cross-bite
2. Bilateral mandibular dysplasia, accompanied by compensatory occlusion

CASE EXAMPLE: Class I, small facial proportions (Fig. 5-7)

Case 9848-1—K. G., female
(C. A., 11 years 2 months) 11 years

By superposing the Bolton Standard of 11 years over the tracing of this case in Bolton relation, one gets the general picture of a face that is extremely small but well proportioned vertically as well as horizontally. The mandibular first permanent molars are in end-to-end occlusion, as might be expected at this age, just prior to exfoliation of the lower second deciduous molars. However, the anterior dentition presents a protrusive relationship of the maxillary incisors and a lingual positioning of the mandibular incisors. Note also that in this case rotations of the anterior teeth are present in both arches.

A direct assessment of the cranial base (CB) indicates a BSC of 10 years with the temporomandibular joint situated in a favorable anteroposterior position on the cranial base.

The maxilla has a BSC of 7 years, and the midface can be seen, in this comparison, to be situated slightly posterior on the CB, thus compensating for the large Bolton-nasion dimension. The maxillary incisors are protrusive in their position on the alveolar process.

The mandible may also be assigned a BSC of 7 years and is found to be in satisfactory anteroposterior position in relation to the maxilla. The mandibular incisors, as well as the alveolar process, are reflected lingually to a marked degree. The position of the lower lip indicates a possible mentalis habit.

The overall comparison of the 7-year Bolton Standard soft tissue profile with that of this case shows a great degree of similarity. Minor variabilities occur in the upper and lower lip positions because of the relationship of the dentition and in the nasal area with the nose of Case 9848 slightly smaller than that of the Standard.

An overall interpretation of Case 9848 with the Bolton Standards would indicate that the extremely small face in relation to the chronologic age is well proportioned and the disparity of CB length is compensated for by the posterior spatial position of the maxilla. The soft tissue of the upper and lower lips is influenced primarily by tooth position and probable muscular habit rather than by skeletal base relationships.

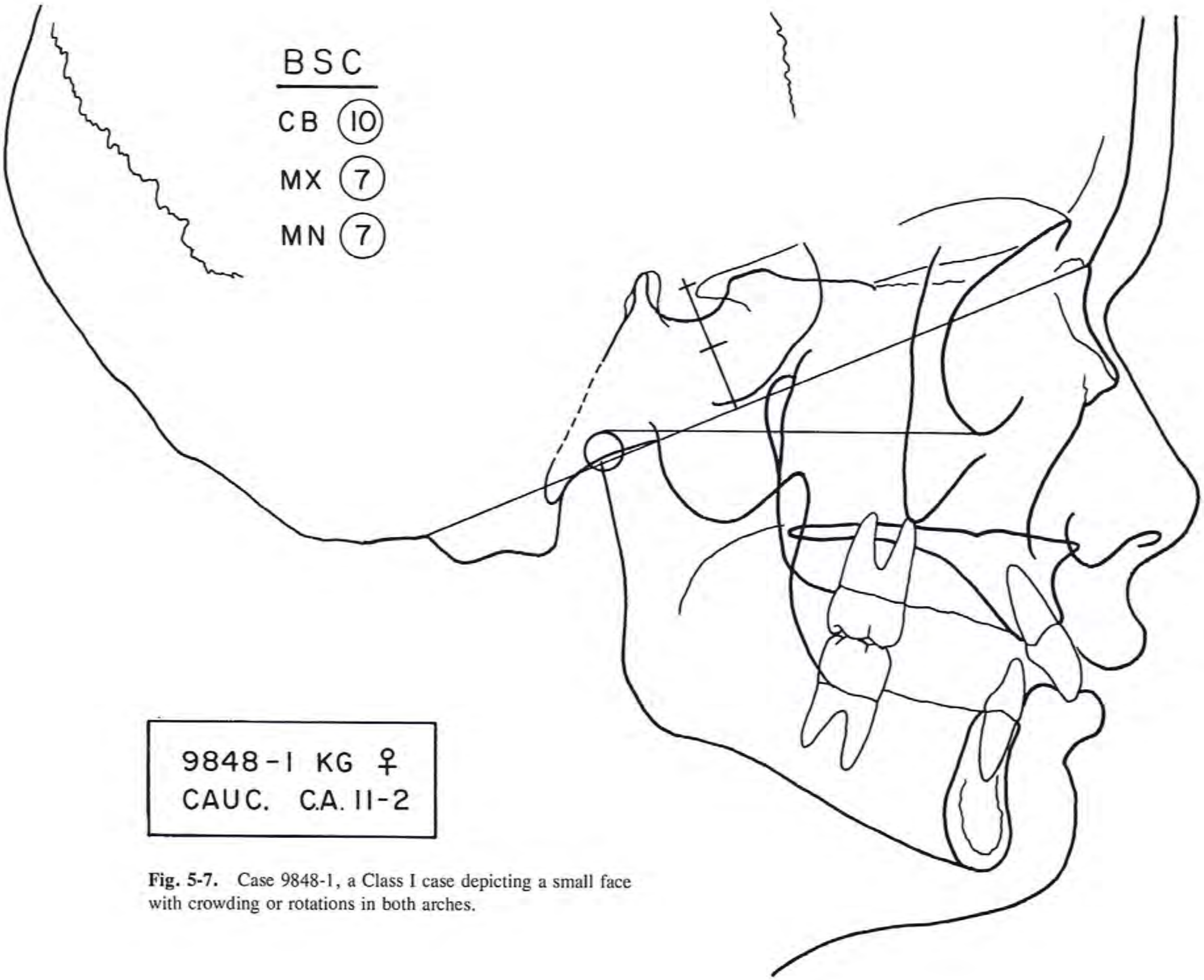

Fig. 5-7. Case 9848-1, a Class I case depicting a small face with crowding or rotations in both arches.

CASE EXAMPLE: Class I, bimaxillary protrusion (Fig. 5-8)

Case 9398-1—S. W., female
(C. A., 14 years 11 months) 15 years

Using the Bolton Standard for 15-year-old subjects for general appraisal through superposing in Bolton relation, one sees the basic differences to be a confirmation of the impression given by the tracing alone—that is, a full and protrusive lower face with protrusive dentition. Superposing on the 15-year CB from Na to Bo, the CB is found to be slightly shorter, and also the sella turcica and the body of the sphenoid bone are seen to be located somewhat posterior in comparison to the Standard. The CB, however, is in generally good proportion and is assigned a BSC of 14 years.

The midface and maxillary components compare well with the Standard from a morphologic standpoint but are obviously larger in dimensional relationships. The MX, BSC is 18 years of age. (Note that not much dimensional change occurs in the cranial base between 15 and 18 years of age.)

The MN, BSC is seen to be 18 years with a marked morphologic difference in the alveolar and symphyseal areas. The symphysis is turned inferiorly, and the alveolar process is significantly more labial in its position, accompanied by a labial position of the anterior teeth.

The soft tissue interpretation on a best fit relationship superposed on forehead, nose, and chin point indicates that the lips are in a demonstrably anterior position.

The overall appraisal of this case, then, can be related to superposing the 15-year Standard on the nasion-pogonion plane and observing the bimaxillary protrusion of the dentition, as well as the upper and lower lip lines.

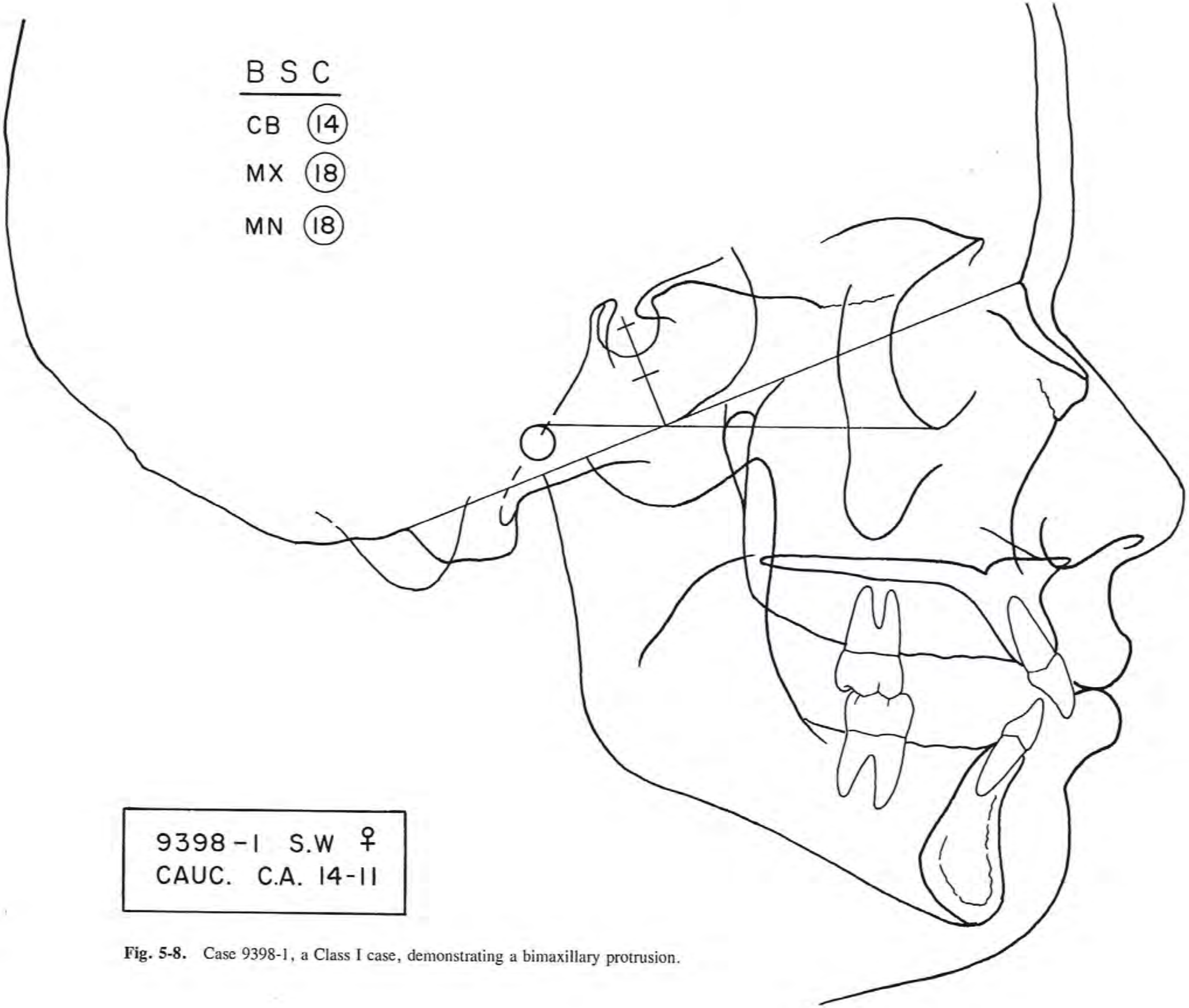

Fig. 5-8. Case 9398-1, a Class I case, demonstrating a bimaxillary protrusion.

CASE EXAMPLE: Class II with a classically short mandible (Fig. 5-9)

Case 9803-1—E. E., female
(C. A., 10 years 11 months) 11 years

A general overview of this case with the 11-year Bolton Standard in Bolton relation indicates that the major dysplasia is located in the mandibular area. A significant posterior relationship of the pogonion with an attendant Class II relation of the dentition and lower lip is present.

The CB, BSC, from Bo to Na, is 12 years with a greater depth of the body of the sphenoid bone.

The maxillary component is positioned slightly posteriorly on the CB, and the MX, BSC is 11 years, which coincides with the patient's chronologic age. The MN, BSC from Bolton articulare to symphysis is 7 years.

The soft tissue superposition, with the nose and forehead coinciding, indicates a typical Class II lip line, an upper lip insufficiency associated with an upward flaccid turn, and a recessive lower lip and chin point, accompanied by an inferior deflection of the lower lip by the maxillary dentition.

The overall interpretation of Case 9803 with the Bolton Standards shows a differential of 4 years between the attained size of the maxilla and the mandible and thus the classic facial relationship that is most often associated with Class II division 1—a short mandibular component.

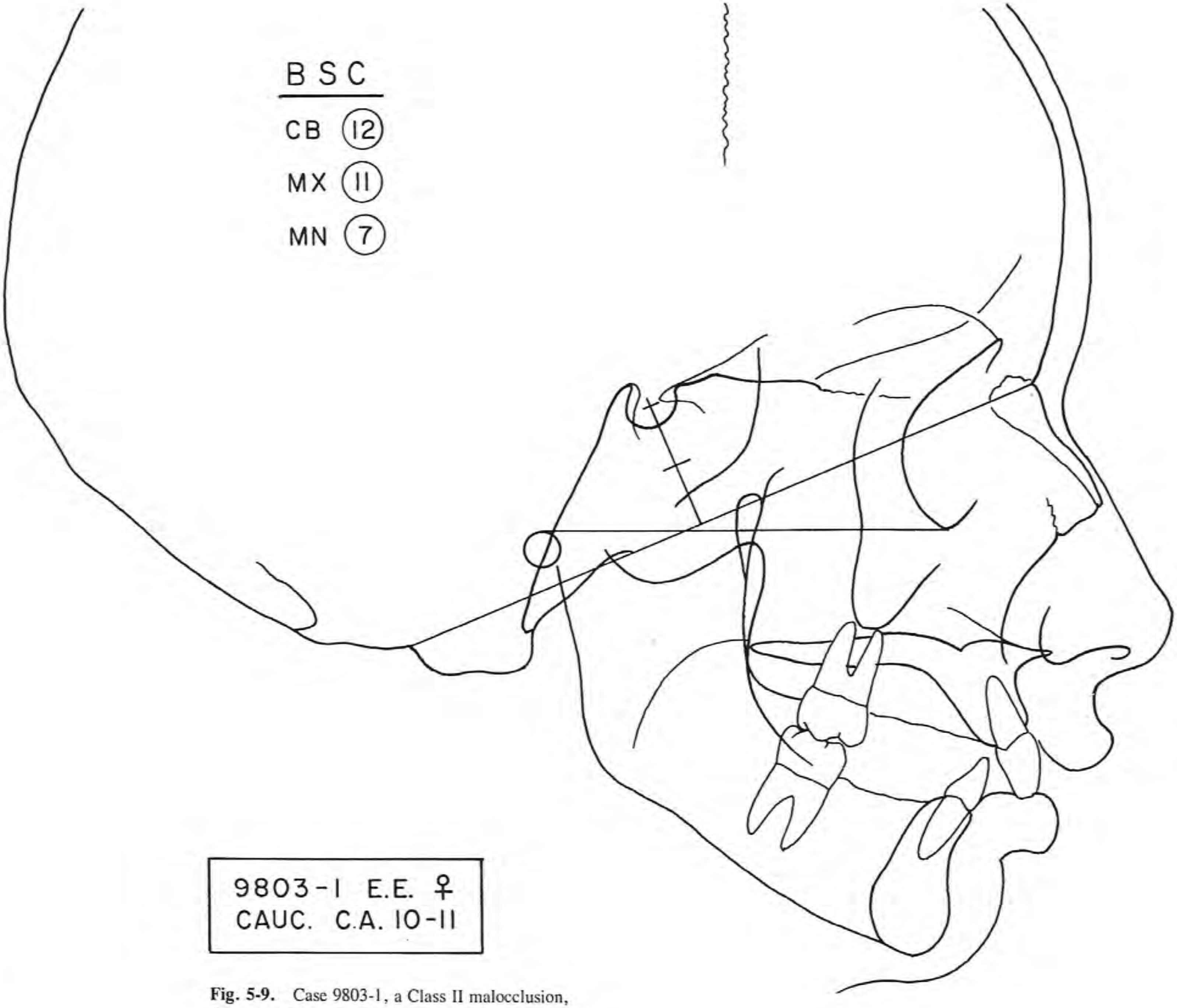

Fig. 5-9. Case 9803-1, a Class II malocclusion, demonstrating a classic short mandible.

CASE EXAMPLE: Class II, maxillary protrusion (Fig. 5-10)

Case 9506-1—T. G., female
(C. A., 9 years 11 months) 10 years

An initial appraisal of Case 9506 with the 10-year Bolton Standard demonstrates a significant forward positioning of the maxillary dentition and alveolar process with a moderate recessiveness in the mandibular pogonial area. In superposing the CB alone, a BSC of 11 years may be assigned.

Next, relating the 13-year Bolton maxilla to this case indicates a larger than 10-year maxillary plane with a significant anterior position of the alveolar process and central incisors. Note that this youngster retained a thumb-sucking habit at this age.

The mandible as viewed from Bolton articulare to chin point is approximately 10 years of age in effective length, but, as viewed in relation to the midface and cranium, it may be seen to have an obtuse ramal body relationship, which rotates the symphysis posteriorly and inferiorly.

Superposing soft tissue elements on a best fit basis for the forehead and nose, the observer sees a flaccid upper lip in a forward position with a decided retrusive and inferior positioning of the soft tissue of the chin and lower lip.

The overall appraisal of Case 9506 is that the cranial base and mandible each compare favorably with the 11- and 10-year Standards, respectively, except for mandibular morphology. However, the midface, or maxillary component, is definitely protrusive in relation to the cranial base and the mandible; in addition to this, the obtuse mandibular angle contributes to the Class II skeletal-dental relationships.

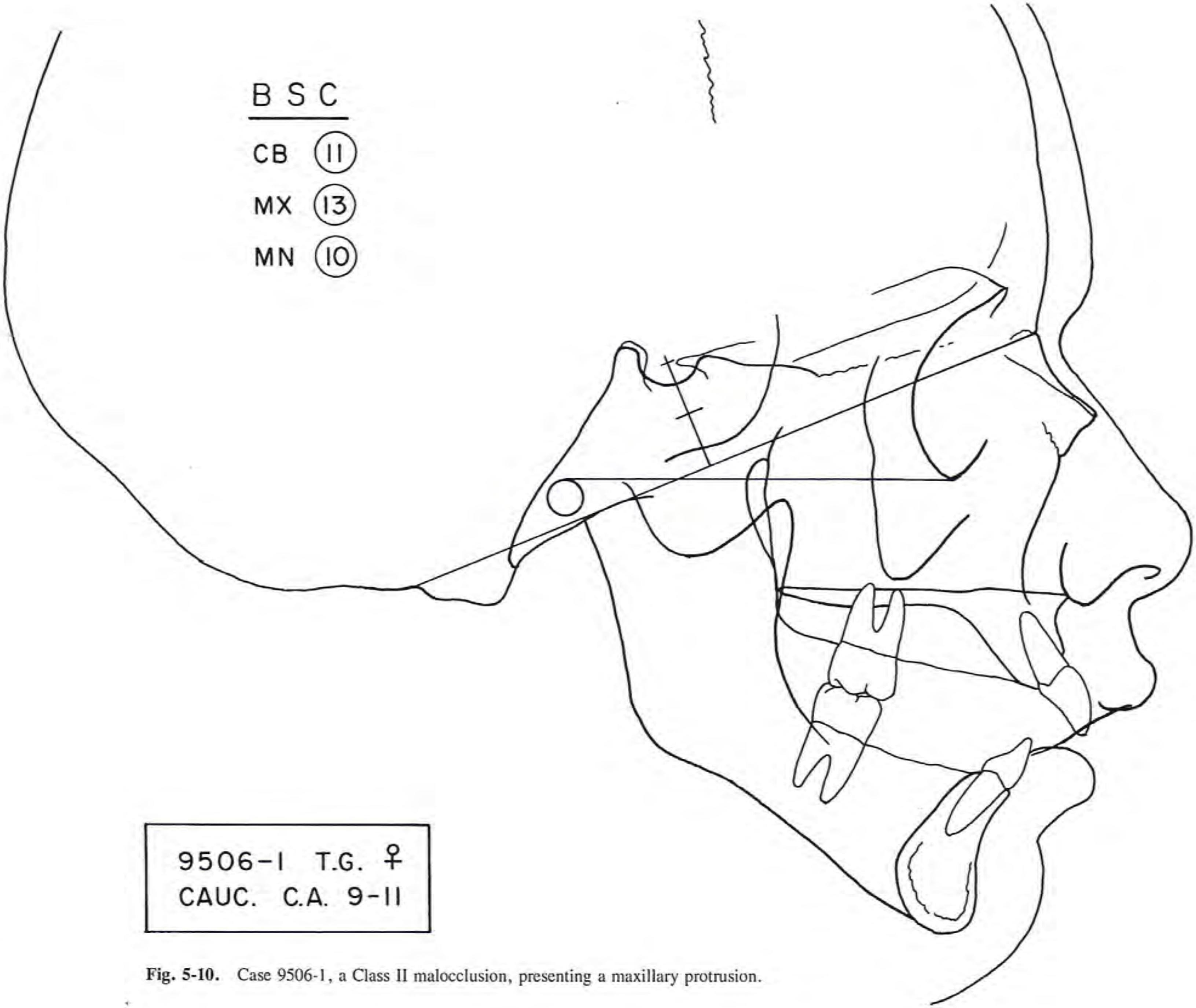

Fig. 5-10. Case 9506-1, a Class II malocclusion, presenting a maxillary protrusion.

CASE EXAMPLE: Class II, long cranial base with adequate maxilla and mandible (Fig. 5-11)

Case 9129-1—R. J., male
(C. A., 8 years 11 months) 9 years

An overall analysis with the 9-year Bolton Standard in Bolton relation indicates a typical Class II division 1 malocclusion with the spatial malrelation of the maxilla and mandible giving the impression that both share the responsibility. The maxilla is in an anterior position, whereas the position of the mandible is posterior, and the CB is significantly longer than the 9-year Standard.

Individual analysis of the components reveals that the CB has a BSC of 15 years, an MX, BSC of 9 years, and an MN, BSC of 8 years with a recessive anterior symphysis in the area of the pogonion. On a best fit analysis of the soft tissue profile with the 9-year Bolton Standard, one notes that the chin is significantly recessive and located posterior to the vertical plane of the midfacial structures. The lower lip has assumed a typical downward and forward roll with a deep sublabial groove.

The overall assessment, then, places the major responsibility for the facial-skeletal malrelationships on the excessive length of the CB, since the maxilla and mandible are in reasonable proportion to their appropriate chronologic Standard. The foregoing set of factors, with the major contributory element being the CB, is one that is frequently seen clinically but that has been unidentifiable with most previously available analyses.

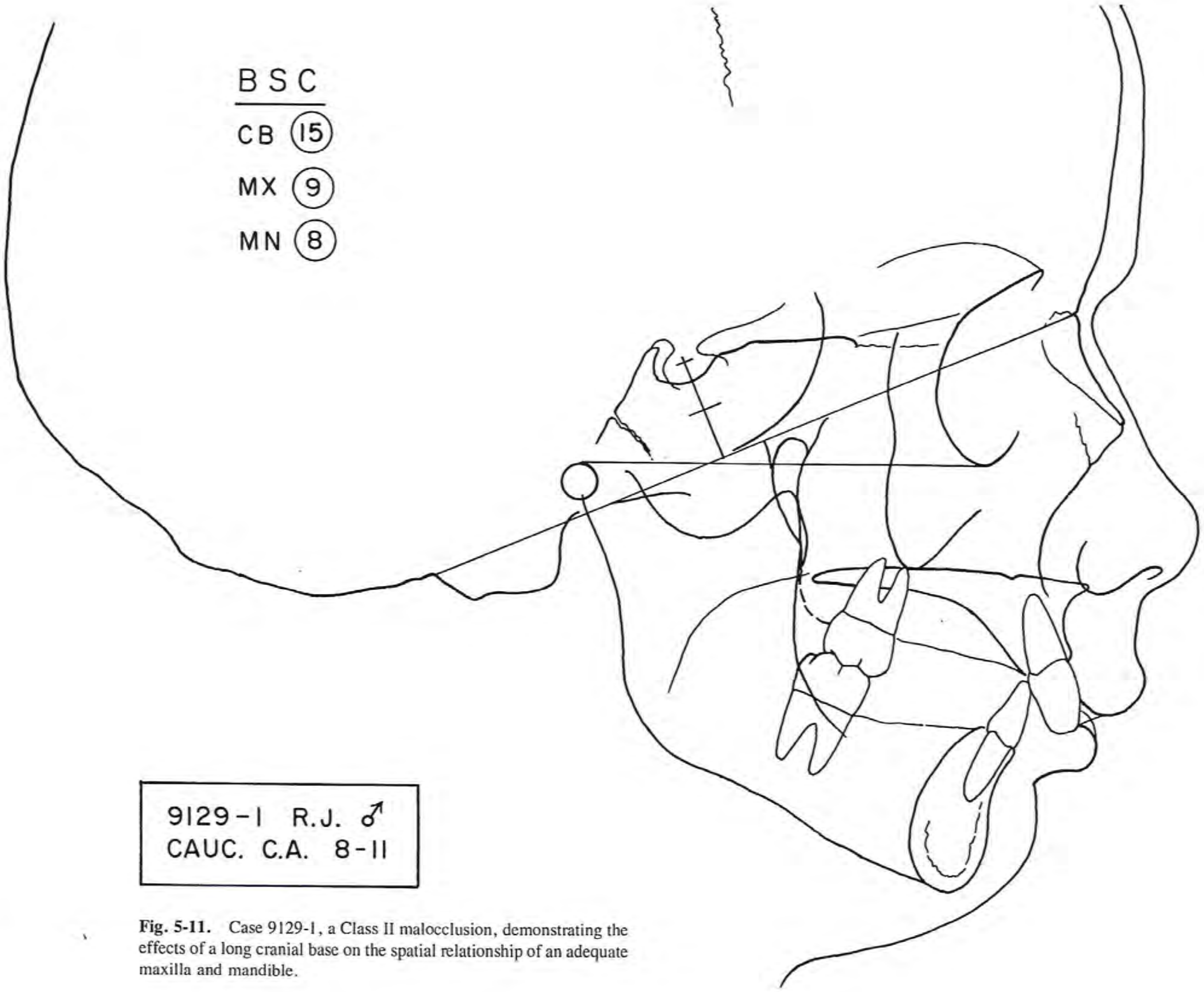

Fig. 5-11. Case 9129-1, a Class II malocclusion, demonstrating the effects of a long cranial base on the spatial relationship of an adequate maxilla and mandible.

CASE EXAMPLE: Class III with classic prognathism (Fig. 5-12)

Case 8874-1—A. C., female
(C. A., 7 years 8 months) 8 years

The 8-year Bolton Standard superposed in Bolton relation demonstrates an anterior position of both the midfacial and lower facial components with the mandibular relationship in its forward position being the most significant element. The long CB has a BSC of 12 years, and the temporomandibular joint is located in a forward position in comparison to the Standard.

The maxilla, although displaying a posterior disparity between the location of the PNS and the tuberosity in the tracing, compares to the 10-year Bolton Standard except for a moderate lack of development in the subnasal area at the ANS. In comparison to the 10-year Bolton Standard, the midface has a marked lack of vertical dimension.

In direct comparison of the mandible, its effective length from Bolton articulare to gnathion can be seen to be comparable to the 12-year Bolton Standard. However, the morphology is significantly different, demonstrating a narrow vertical height of the body as well as of the ramus and an obtuse angulation between the two. The anterior mandibular alveolar process may also be seen to be positioned forward and to support the dentition in an end-to-end relationship with the maxillary incisors.

Viewing the soft tissue profile of Case 8874 in comparison with the Bolton Standard of 12 years, the observer can see a maxillary lip insufficiency and an anterior position of the lower lip with little or no sublabial groove present.

The overall assessment of this case indicates a forward positioning of the mandible on the CB (because of the location of the temporomandibular joint), a lack of vertical height in the midfacial component, and a markedly anterior position of the mandibular alveolar process and anterior teeth. The morphology of the mandible is similar to that seen in the classic pattern of prognathism.

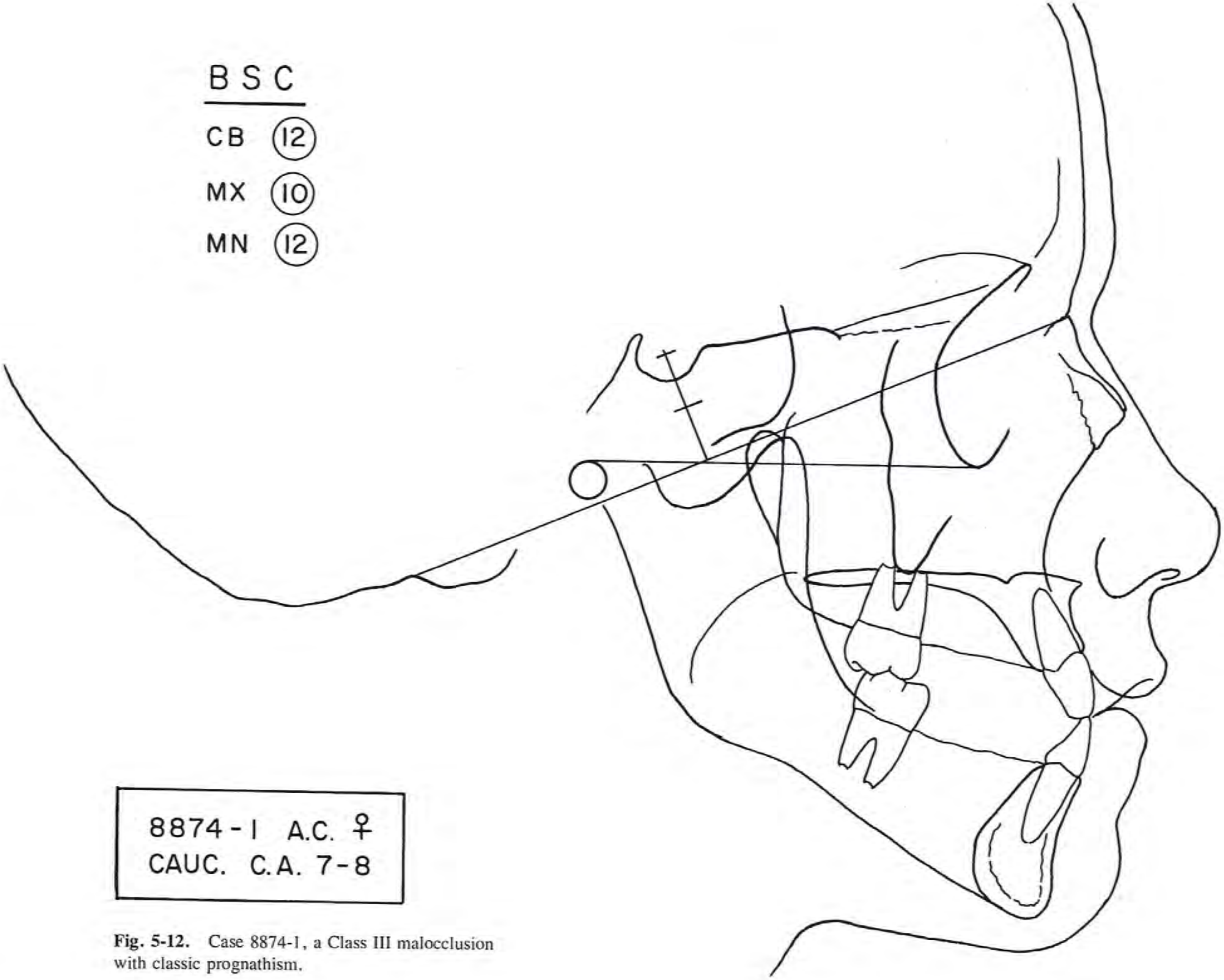

Fig. 5-12. Case 8874-1, a Class III malocclusion with classic prognathism.

CASE EXAMPLE: Class III, standard mandible with insufficient maxilla and cranial base (Fig. 5-13)

Case 7138-1—R. W., female
(C. A., 14 years 7 months) 15 years

A general interpretation of this case with the 15-year Bolton Standard indicates a short anteroposterior dimension of both the cranial base and the midfacial components with a favorably related chin point at the pogonion. The BSC for the short CB is 10 years with the glenoid fossa, or temporomandibular joint, in a forward, or anterior, position on the CB.

The MX, BSC is 9 years; note that the maxillary anterior teeth are labially inclined and positioned anteriorly on the alveolar process.

In contrast to the superior structures, the mandible is close to the proper chronologic age with a BSC of 15 years. The morphology of the mandible is similar to the Standard except in the area of the anterior alveolar process, where the dental units are positioned labially.

The overall skeletal relationships indicate that the CB and maxilla are small for the chronologic age of the patient, whereas the mandible is closely correlated. This disparity of the size of parts, in addition to the anterior position of the temporomandibular joint, dictates the resulting Class III relationships of both the skeletal parts and the dentition.

In viewing the soft tissue, one sees that the nose of Case 7138 is smaller than the 15-year Bolton Standard, as would be expected with a small skeletal base. The total soft tissue relationships reflect the underlying skeletal disparity and give a typical Class III profile.

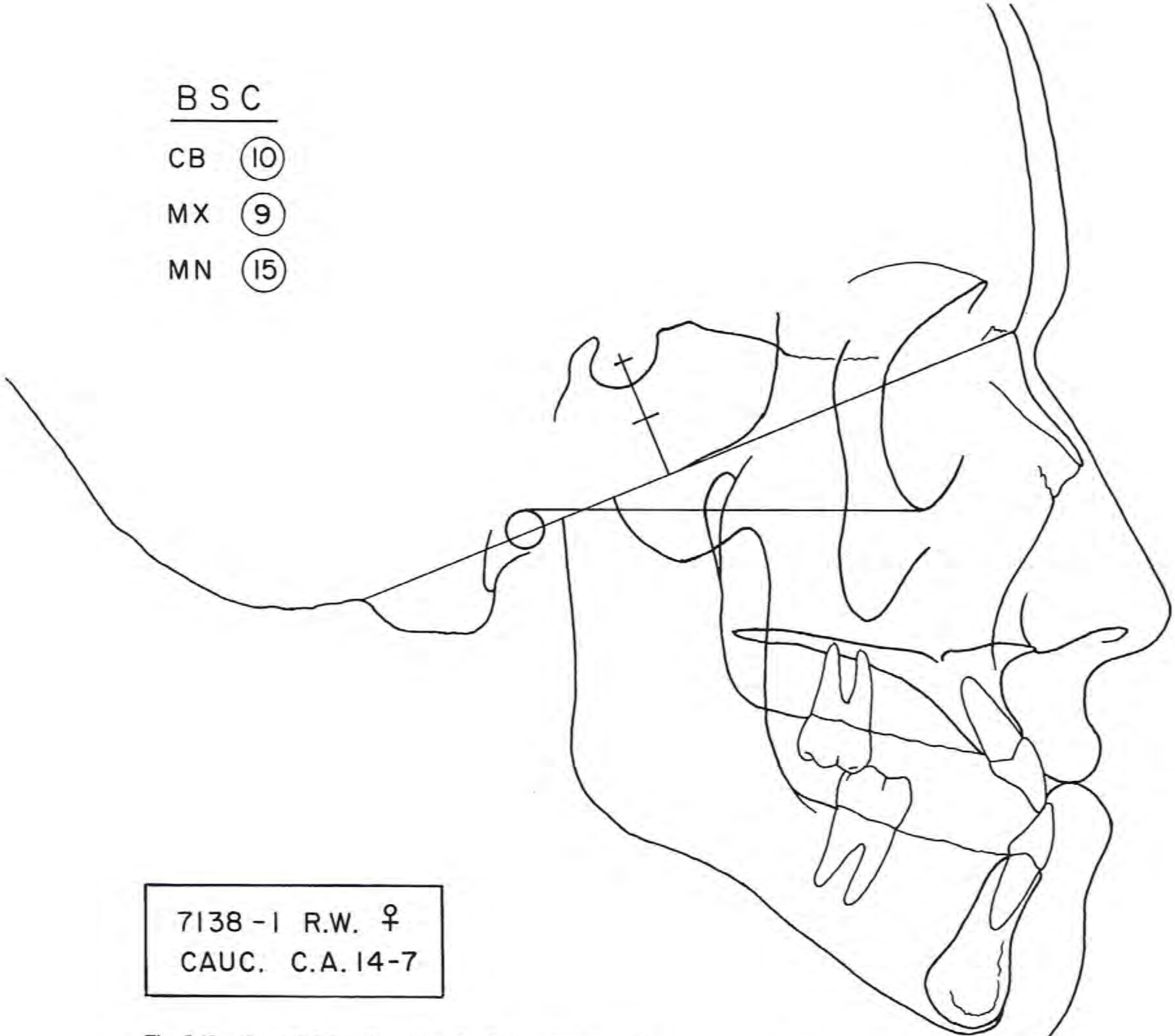

Fig. 5-13. Case 7138-1, a Class III malocclusion, demonstrating a mandible of standard size with an insufficient maxilla and cranial base.

CASE EXAMPLE: Class III with maxillary insufficiency (Fig. 5-14)

Case 7228-1—T. F., male
(C. A., 9 years 1 month) 9 years

General assessment with a 9-year Bolton Standard indicates a Class III skeletal pattern coupled with a significantly short anterior vertical facial dimension. Individual analysis of the craniofacial components shows that the CB is long in relation to the 9-year Standard and can be assigned a BSC of 12 years. This factor in itself would tend to dictate a spatial relationship of lower facial parts assuming a Class II relationship. Note in this case, however, that interestingly the glenoid fossa, or articulating area for the condyles of the mandible, is located significantly forward of that of the Standard and that consequently the spatial position of the temporomandibular joint (TMJ) more than offsets the large overall CB dimension.

A BSC of 5 years can be assigned to the maxilla, indicating not only a lack of anteroposterior developmental growth but also a significantly inadequate vertical dimension in the height of the maxillary alveolar process. This not only contributes to the previously noted lack of entire facial vertical dimension but also allows an ''overclosure'' of the mandible in occlusion. The mandible compares favorably to the 9-year Bolton Standard and would be assigned that BSC.

A soft tissue appraisal done on a best fit basis, superposing on the forehead and nose, indicates once again a lack of maxillary vertical height with a short upper lip, a typical forward positioning of the mandibular soft tissue outline, and a protrusive position of the lips as they reflect the overclosure of the mandible and lack of midfacial vertical dimension.

This Class III example demonstrates two major contributory elements: (1) the inadequacy of the maxilla (both P-A and vertical), which is the most significant, and (2) the forward position of the mandible on the CB because of the location of the TMJ.

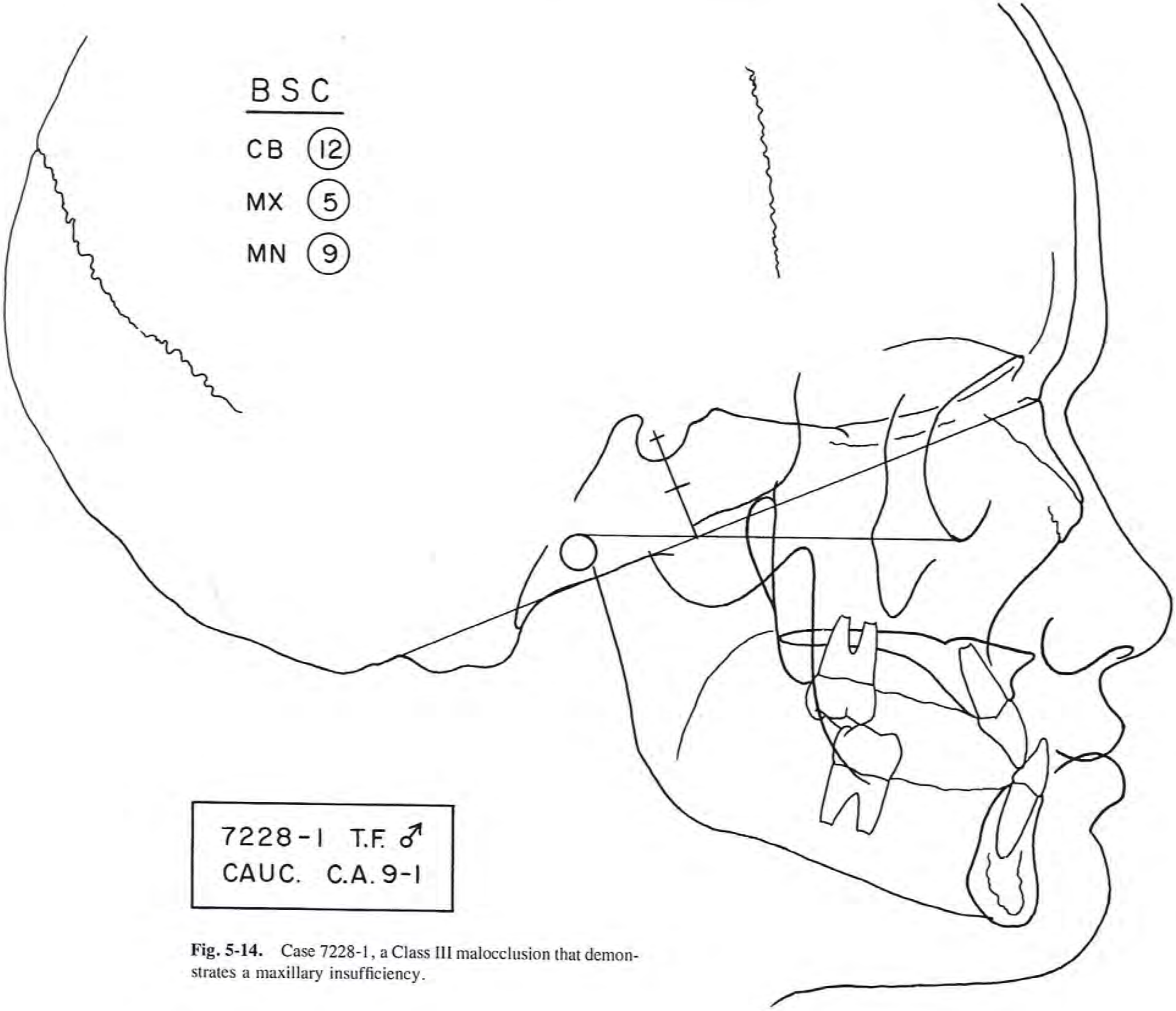

Fig. 5-14. Case 7228-1, a Class III malocclusion that demonstrates a maxillary insufficiency.

CASE EXAMPLE: Maxillary width insufficiency (Fig. 5-15)

Case 9914-1—R. W., male
(C. A., 9 years 11 months) 10 years

Superposing the 10-year Standard over the frontal tracing in a best fit relationship on the cranial and mandibular outlines indicates a symmetrical pattern and a size of these structures approximately equal to the Standard. The mandibular midline between the central incisors, in addition to the rest of the mandibular dentition, is reasonably well oriented. Note, however, that the maxillary component, superior through the orbital area, is positioned to the left of the Standard outline.

On close inspection of the maxillary dentition, the midline may be seen to be also displaced to the left (patient's right) of the midsagittal plane, and the bimolar width is significantly narrow in its spatial relationship on the patient's left side, creating a classic unilateral cross-bite.

The overall interpretation with the 10-year Bolton Standard in relation to Case 9914-1 indicates a definite lateral displacement of the midfacial structures to the patient's right that, in conjunction with a lack of maxillary arch width, contributes to the dental malrelationships.

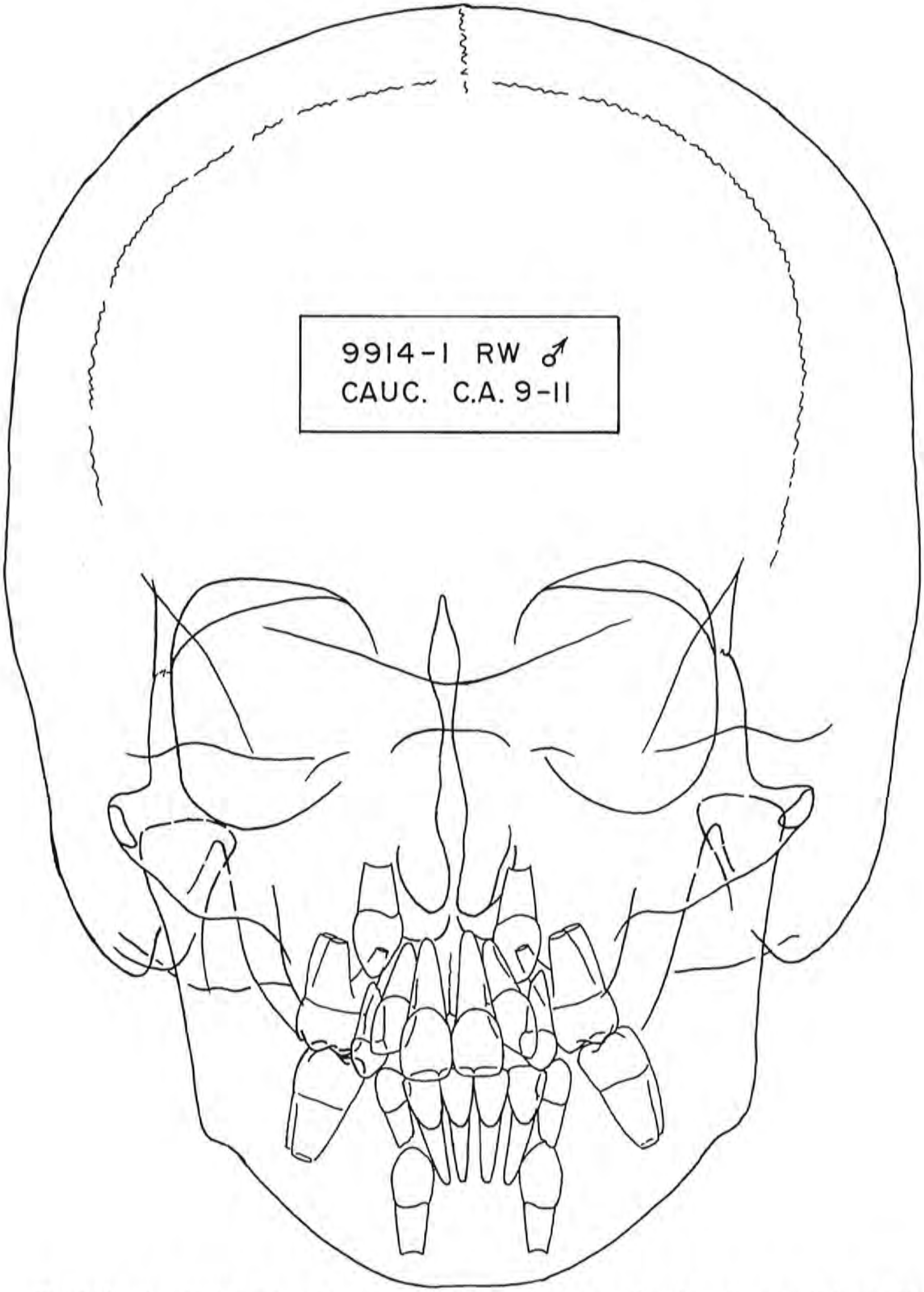

Fig. 5-15. Case 9914-1, a frontal radiographic tracing, indicating a unilateral maxillary insufficiency with associated buccal cross-bite.

CASE EXAMPLE: Mandibular asymmetry (Fig. 5-16)

Case 9422-2—B. W., female
(C. A., 22 years 1 month) 22 years

An overall appraisal of the cephalogram indicates a significant mandibular dysplasia, with distortion of the skeletal and dental midline structures in the mandible and lower maxilla. When the 15-year Standard is superimposed on a best fit relationship with the cranial outlines oriented and the midsagittal plane and orbital structures superposed on a best fit relationship, note that, in spite of a moderate lack of bizygomatic development, the symmetry of Case 9422 is in harmony with the 15-year Standard down to the alveolar process of the maxillary structures. Both dental arches are displaced to the patient's left with obvious asymmetry and distortion of the mandibular outline.

A structure-by-structure comparison indicates an excessive amount of developmental growth on the right side of the body of the mandible and ramus with an associated lack of vertical developmental growth on the left side, accompanied by a lateral warping of the gonial angle. The dental arches have maintained a functional occlusal relationship through this developmental-growth dysplasia by compensation in the cant of the occlusal plane.

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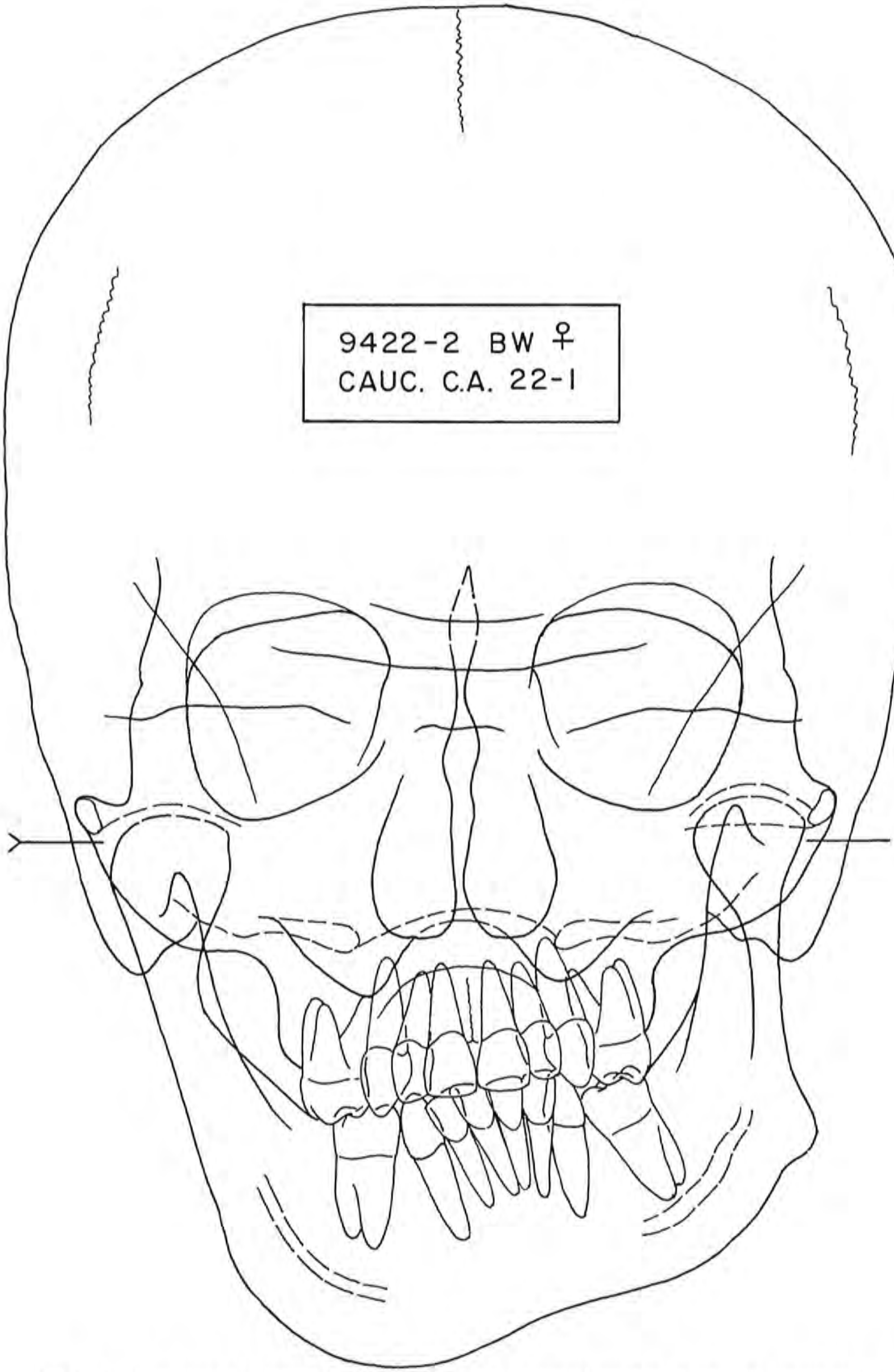

Fig. 5-16. Case 9422-2, a frontal tracing, demonstrating a bilateral mandibular dysplasia, accompanied by a compensatory alteration in the occlusal plane.

CHAPTER 6

Skeletal maturation: hand-wrist radiographic assessment

RÖNTGEN'S HISTORIC DISCOVERY (S. Idell Pyle, Ph.D.)

In February, 1895, Wilhelm Conrad Röntgen was completing his first year as Rector at the University of Würzburg, where he had become the distinguished young Professor of Physics during the preceding six years. In addition to this new administrative role that Röntgen was enjoying as the highest academic honor given to a professor in the university, he was preparing reports from his current research about the effects of pressure on the dielectric constants of hydrogen, ether, water, various alcohols, and powdered crystals. He had just received the latest models of two clear glass conduction instruments, a Lenard vacuum tube and a heavier-walled Hittorf-Crookes tube (Fig. 6-1, *B* and *C*) and his interest was captivated by "the beautiful new results with high-frequency electric discharges in free air" that the inventors, Philipp Lenard, Johann Wilhelm Hittorf, and Sir William Crookes, had obtained with their instruments.[15, 17]

Now the invitation came to Röntgen to become the Director in the new Institute of Physics at the University of Freiberg. This was a tempting professional honor. By October, 1895, Röntgen had decided to stay at the University of Würzburg, to set aside his reports on compressivity, and to devote himself entirely to researches with cathode rays in free air. Accordingly on Friday, November 8, 1895, his familiar laboratory in the Würzburg Institute of Physics abruptly became the setting for his historic discovery within the next three weeks of "a new luminescent agent with some of the properties of sun rays and cathode rays; all materials I tested and also my hand are transparent to it although to widely differing degrees."[16] On December 28, 1895, Röntgen himself named the new agent in a written communication to his colleagues by saying in a footnote "For the sake of brevity I should like to use the term 'rays' and to distinguish them from others I shall use the name 'the X-rays'."

Figs. 6-2 and 6-3 are copies of Röntgen's first radiographs of living tissues made with the x rays. The radiograph of Mrs. Röntgen's fingers (Fig. 6-2) was made in November, 1895; and Röntgen photographed the hand of the distinguished anatomist Rudolf Albert von Kölliker on January 23, 1896, to demonstrate the technique when he described the apparatus to his colleagues in the Würzburg Physical Medical Society for the first time.

Figs. 6-1 to 6-3 were published in 1931 by Glasser,[15] who became the renowned x-ray dosimetrist in the Cleveland Clinic Foundation of Cleveland, Ohio, between 1925 and 1964. Otto Glasser was a young doctoral candidate in radiation physics at the University of Munich during the postwar years 1918 to 1922 while Röntgen was Director of the Institute of Physics there prior to his death on February 10, 1923. Glasser's book, *Wilhelm Conrad Röntgen und die Geschichte der Röntgenstrahlen*,[15] and his subsequent translation, *Dr. W. C. Röntgen*,[17] is a biographic masterpiece, filled with carefully verified personal and technical facts and dates.

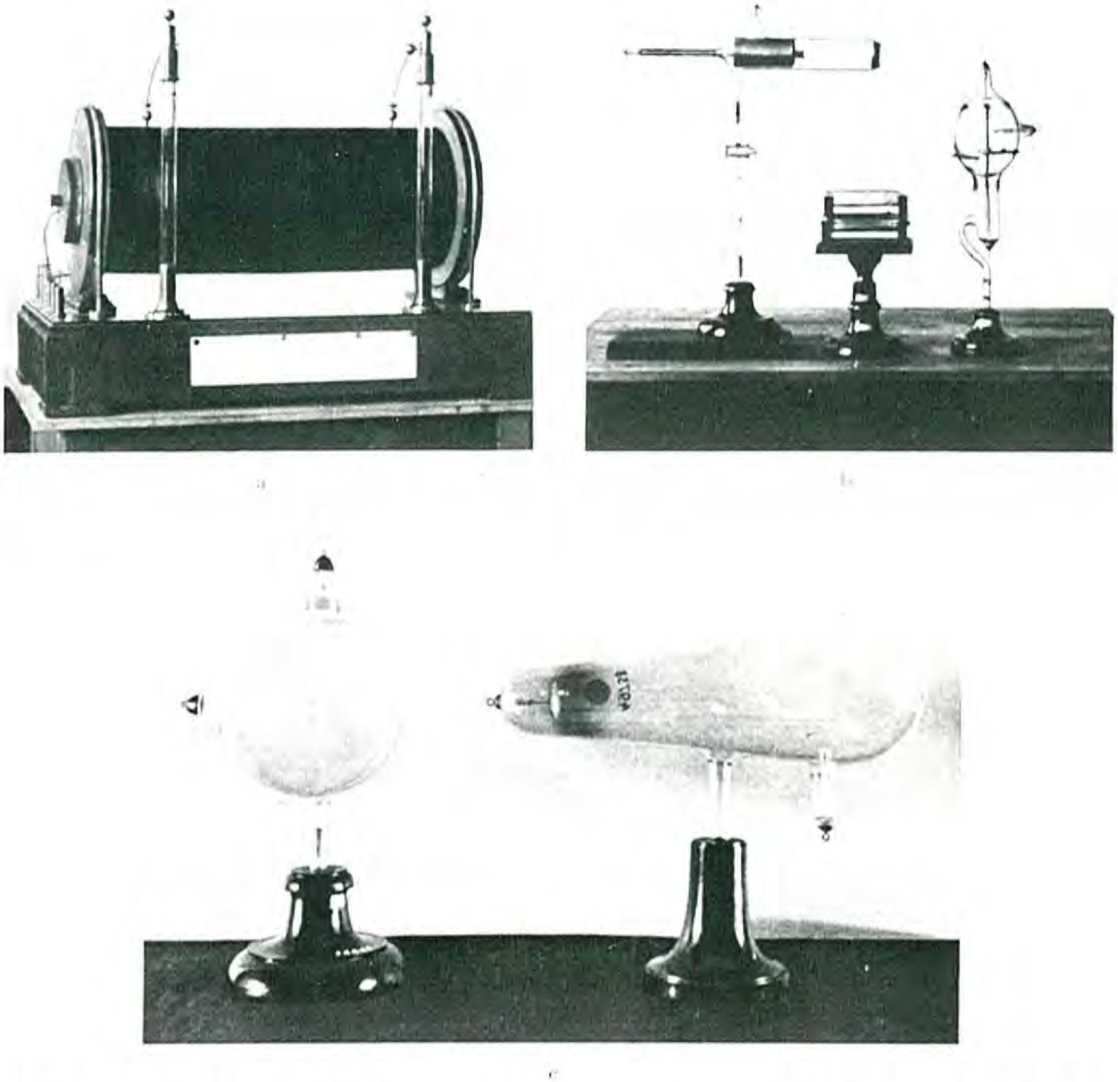

Abb. 1. RÖNTGENs Originalapparate im Deutschen Museum in München. a RUHMKORFFsche Induktionsspule, b LENARDsche Röhren, c HITTORF-CROOKESsche Röhren. (Mit Genehmigung des Deutschen Museums in München.)

Fig. 6-1. Experimental apparatus used by Röntgen in his original investigations. **a,** Ruhmkorff induction coil. **b,** Lenard vacuum tubes. **c,** Hittorf-Crookes tubes. (From Glasser, O.: Wilhelm Conrad Röntgen und die Geschichte der Röntgenstrahlen, Berlin, 1931, Springer Verlag.)

Young Glasser himself saw how the great strides taken by scientists and industrialists between 1896 and 1918 in producing better x-ray generators, conduction tubes, and radiographic paper filled Röntgen with a certain pride in the first results that he and his peers obtained with the apparatus shown in Fig. 6-1.

Glasser had studied 1,044 of the reports on applications of the Röntgen technique that were published in 1896 alone, and he knew the primary reason that it was Röntgen who abruptly identified the invisible rays in the high-tension current sent through the Hittorf-Crookes and Lenard vacuum tubes: because he had covered these clear glass tubes with tightly fitted jackets of black paper and had conducted his experiments with cathode rays in "an air-tight, unlighted zinc box large enough to accommodate myself and the instrument."[17] Lenard himself advised Röntgen to cover his new Lenard conduction tube (Fig. 6-1, *B*) with the black paper jacket to ensure that all the rays would travel outward through the aluminum window of the tube and also that no visible light rays could enter the tube when the instrument was used in a lighted laboratory. The "unlighted zinc box" was Röntgen's darkroom.

By the end of October, 1895, Röntgen had confirmed three of Lenard's classic observations about the nature of the cathode rays: the rays emerging through the aluminum window of a Lenard tube made the free air at the window electrically conductive for a few centimeters, produced recognizable shadows on photographic paper, and induced fluorescence on a small cardboard screen painted with barium platinocyanide crystals.

To dosimetrist Glasser in retrospect, the personal significance of physicist Röntgen's zinc-walled darkroom that he had used almost from the beginning of his research with cathode rays was tragically overlooked by more than a few physicians and anatomists who began to use the x rays so effectively as soon as Röntgen released his first report on December 28, 1895, in which he stated briefly their power to penetrate vital tissues. Röntgen described his experimental darkroom in his second report on March 9, 1896.[17] He had suspected for some time

Abb. 39. Die erste Röntgenphotographie (Frau RÖNTGENS Hand).

Fig. 6-2. First radiographic print made by Röntgen of his wife's hand. (From Glasser, O.: Wilhelm Conrad Röntgen und die Geschichte der Röntgenstrahlen, Berlin, 1931, Springer Verlag.)

that cathode rays might not be the source of the electrostatic effects produced in the free air at the aluminum window of the Lenard tube. Accordingly he planned this small darkroom and had it built during October, 1895, to contain a compact instrument unit and a larger observation unit with its zinc walls lined with lead plate to protect the unit against all electrostatic forces except the rays in the high-tension discharge from the instrument. A cutout in the wall between the two units, framed with lead, contained a 4 cm. square conduction window made airtight with a thin sheet of aluminum foil through which the x rays in the high-tension discharge could enter the observation unit. Röntgen also prepared a large zinc diaphragm thickened with lead plate to stand in the observation unit between himself and the x rays freed at the conduction window. In so doing he had protected himself unknowingly against the power of the x rays to penetrate his body—a power he was soon to discover.

On Friday, November 8, 1895, Röntgen decided to start his further observations of fluorescence induced on barium platinocyanide crystals, using a high-tension discharge and a clear glass vacuum tube without a window. The pear-shaped Hittorf-Crookes tube (Fig.

Abb. 17. Bild der Hand des Anatomen VON KOELLIKER, welches RÖNTGEN in der berühmten Sitzung der Würzburger Physikalisch-Medizinischen Gesellschaft vom 23. Januar 1896 anfertigte.

Fig. 6-3. Radiograph of von Kölliker's hand made at the first public demonstration of Röntgen's technique. (From Glasser, O.: Wilhelm Conrad Röntgen und die Geschichte der Röntgenstrahlen, Berlin, 1931, Springer Verlag.)

6-1, *C*) had no window. He covered this tube with a black paper jacket, hooked the jacketed tube onto the electrodes of his largest Ruhmkorff induction coil, and started the current through the tube to test the opacity of the black paper. No light was visible through the jacket.

Röntgen was preparing to interrupt the current to set up his barium platinocyanide screen in the observation unit when he noticed a weak light shimmering on a little bench that he knew was located nearby. "It was as though a ray of light or faint spark from the induction coil had been reflected by a mirror."[17] Highly excited, since the darkroom had no mirror, he lit a match and saw green fluorescence, now resembling a small green cloud, shimmering in unison with the fluctuating current from the induction coil. The fluorescence was above the little screen that was lying on the bench. He knew at once that the high-tension discharge from the Ruhmkorff coil had traveled in a straight line to the barium platinocyanide screen and to a much greater distance through free air than anyone had reported for cathode rays. This was Röntgen's first glimpse of "an unknown luminescent agent with some properties of sun rays and cathode rays."[16,17]

Now Röntgen decided that he ought to observe how the emanation from the Hittorf-Crookes tube penetrated other substances. He began studying the brightness of the fluorescence induced on barium platinocyanide crystals when he placed solid objects singly in the pathway of the current from the tube to the screen. He experimented tirelessly for about three weeks with thin plates of lead, zinc, glass, wood, silver, platinum, and gold, and a stack of thin slices of tinfoil, "and so forth."[17] All these objects were alike in thickness. He concluded that no property influenced their transparency to the unknown agent in the current so much as their individual density.

The lead plate had blocked the fluorescence most completely. Röntgen selected a small lead disk to observe in more detail how the shadow of the lead appeared against the fluorescence and on photographic paper. While he was bringing the little disk into place with the barium platinocyanide screen directly behind it, he noticed the unmistakable outlines of his thumb and index finger with the denser shadow of their bones within the flesh, curved around the shadow of the small lead disk. This was the crest of the physicist Röntgen's abrupt and great accidental discovery of x rays.

Thirty-five years later in 1931, physicist Glasser finished his vivid narrative of this event by remarking:

> One can only imagine how this first ghostly shadow picture of the human skeleton within living tissues affected the observer. Doubt must have been followed by wonder and perhaps by reluctance to continue experiments that promised to bring him disrepute in the eyes of his colleagues. At this point he determined to continue his work in secrecy until such time as he himself was certain of the validity of his observations. Thus during the closing weeks of 1895 Röntgen worked in seclusion in order to prove to himself that his chance observation was a fact, and then to build up sufficient faith in his own findings to hand them over to other scientists for confirmation or refutation.*

Without any introduction, Röntgen summarized his discovery of the x rays in a report, consisting of seventeen carefully worded paragraphs, that was released immediately to the members of the Würzburg Physical Medical Society. He included the radiograph of Mrs. Röntgen's hand in the copies of the report that he sent to a few friends in Vienna for their counsel about the wisdom of including the announcement of his observation of the relative transparency of bone and living tissues to the rays, since he could not describe as yet the basic nature of these rays. The responses of these peers were prompt and completely reassuring that they endorsed his "preliminary communication" of the facts that he had ready.[15]

News of the discovery was cabled "all over the world on January 6, 1896."[11] Röntgen

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*From Glasser, O.: Dr. W. C. Röntgen, ed. 2, Springfield, Ill., 1958, Charles C Thomas, Publisher, pp. 38-39.

released this report and the use of the x rays without any restrictions, continued as a physicist with his research, and supplemented his first seventeen conclusions with three others on March 9, 1896, and on March 10, 1897, with thirteen updated evaluations of his original twenty conclusions.

HAND-WRIST RADIOGRAPHIC INTERPRETATION

In gathering diagnostic signs and symptoms to use in dentofacial treatment planning, the clinician routinely tabulates the patient's chronologic and dental ages as fundamental elements. Less routinely considered, but increasingly recognized as important, are indicators of the patient's skeletal maturity level and body maturational status. Researchers in human growth and development have long accepted an assessment of skeletal age by hand-wrist radiographic interpretation as one of the most reliable indicators of the time on the patient's own "biologic clock."[24] Since a wide range of individual variability in growth timing is present among youngsters (up to six years from the mean, according to Pyle[28]), this natural diversity may well negate proper application of anticipated orofacial growth increments if the patient's own "clock" is disregarded.

Within four months after Röntgen discovered the penetrating nature of the x ray in 1895, investigators such as Rowland[31] in England (Fig. 6-4) introduced the idea of using the comparative size and shape of the radiographic shadows of growing bones within a child's body as indicators of the rate and symmetry of their maturation during preceding months. He illustrated his concept by describing the shape and size of the ossifying portions of the hand-wrist bones that were visible in his clinical radiograph of the hand of a 9-year-old girl. Pryor,[27] Rotch,[30] and Crampton,[12] in the early 1900s, began serially following by radiography the skeletal development of the growing hand and wrist and tabulating sequential indicators of maturational progress. Through the ensuing years, many qualified researchers have contributed significantly to the practical interpretation of these maturational phenomena. Flory,[13] Acheson,[1] Todd,[33] Greulich and Pyle,[19] and Tanner and associates,[32] to name just a few, have brought into critical focus the essential elements that allow a clinical value to be placed on individual skeletal status.

Although determining the precise skeletal age of the patient is an exacting science, a mean assessment from which useful information can be derived for correlation with other diagnostic procedures can be easily performed by the health clinician.

Initially, the following generalities should be understood as they apply to human skeletal maturational development because it is on these fundamentals that an association with orofacial concepts of skeletal development can be built:

1. Skeletal maturation, as it is serially interpreted from the hand-wrist radiograph, is an orderly sequence of events, taking place over an extended period of time, that is, in the main unrelated to racial background or sexual dimorphism.[33]
2. Females precede males in their skeletal maturation as related to chronologic age by approximately 2 years at the prepubertal and early adolescent levels.[19]
3. The circumpubertal growth spurt, typified by a rapid increase in statural height, which occurs in both males and females at the time of puberty, varies markedly as to chronologic time of onset, velocity, and duration from one person to another.
4. In broad terms on a population basis, females begin their circumpubertal growth spurt between 10 and 12 years of age, whereas boys lag behind approximately 2 years and experience the onset of their growth spurts between 12 and 14 years.[19]
5. Individuals, however, may vary by as much as 3 to 6 years from the population average or median—thus the need for specific patient evaluation.

6. To facilitate interpretation of these naturally occurring variations in skeletal age, youngsters may be categorized into one of three groups: (a) accelerated, or *advanced*, maturers, whose skeletal age is 1 or more years ahead of their chronologic age; (b) average, or *moderate*, skeletal maturers; and (c) retarded, or *delayed*, skeletal maturers, whose skeletal age is 1 or more years behind their chronologic age.[20]

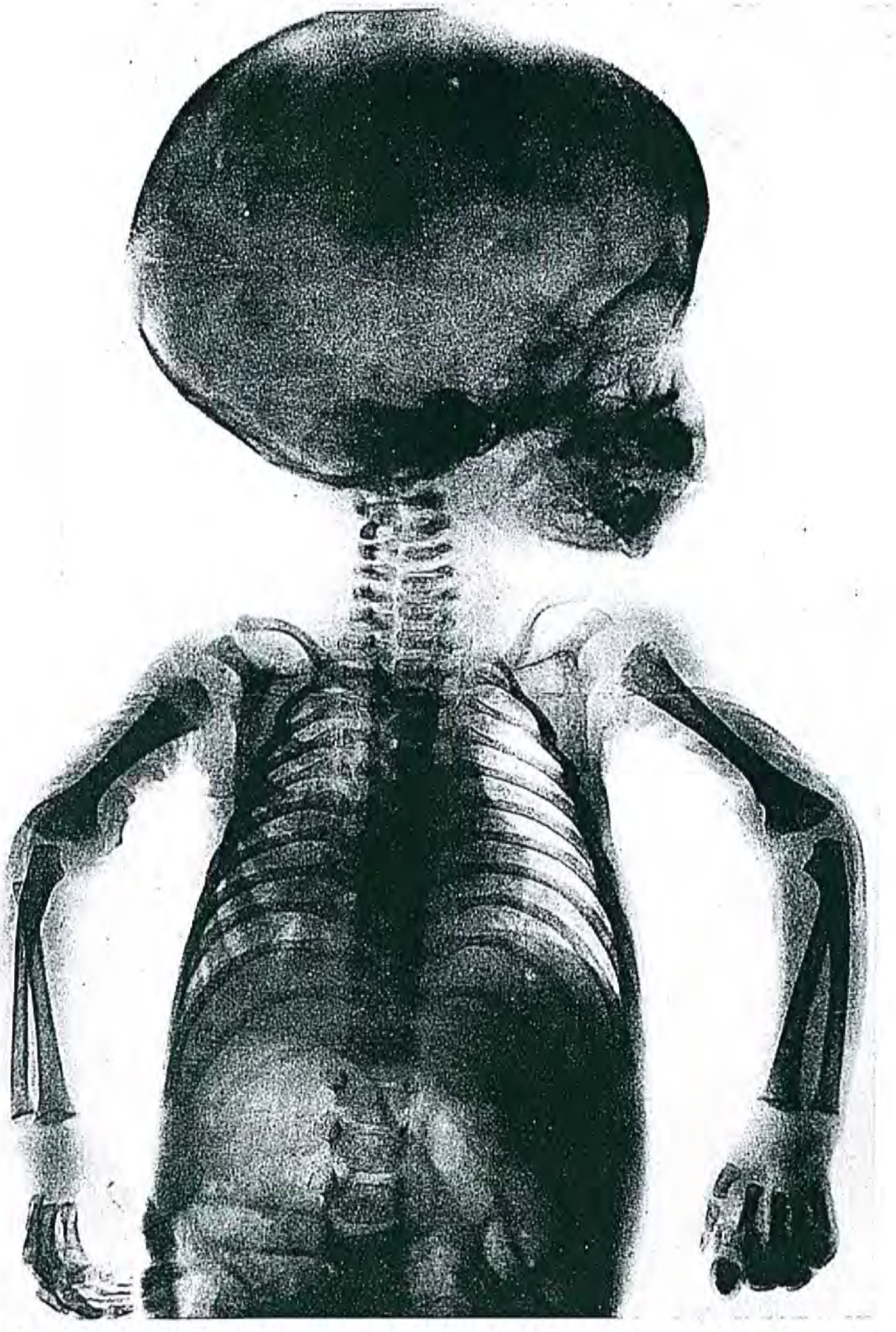

Fig. 6-4. Copy of original radiographic plates made by Rowland, illustrating the skeleton of a growing child, age 3 months. (From Rowland, S.: Archives of clinical skiagraphy, London, 1896, The Rebman Publishing Co., Ltd.)

Investigators of dentofacial developmental growth have logically been the ones to correlate bodily skeletal maturation with the associated phenomena observed in facial growth changes. Although these investigations have been limited in number and much of the data that has been studied and reported has been on relatively small population samples, their findings agree significantly. They have correlated the circumpubertal growth spurt as observed in increased velocity of statural height increments with increased velocity in the increments of facial development growth.* Fig. 6-5 indicates four basic dimensions that may be used in measuring overall facial growth which have been generally shown to have high correlations with the circumpubertal growth spurt as it is expressed in standing height.

Simple serial documentation of increases in statural height will reveal a direct measure of the individual adolescent growth spurt[4]; so the recording of this data serves as an aid to the clinician.[26] Obviously though, by the time that a significant increase in height is recorded, most of the magnitude of the growth spurt will have expressed itself. This somewhat tardy indicator led to a search for diagnostic signs that precede the growth spurt and thus to the utilization of the hand-wrist film with its wealth of maturational information.[21]

To use the hand-wrist film in a practical manner, a working knowledge of the nomenclature of the bones must first be established. Fig. 6-6 is a tracing of a radiograph of these bones with

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*References 3, 5-7, 9, 14, 18, 22, 23, 25.

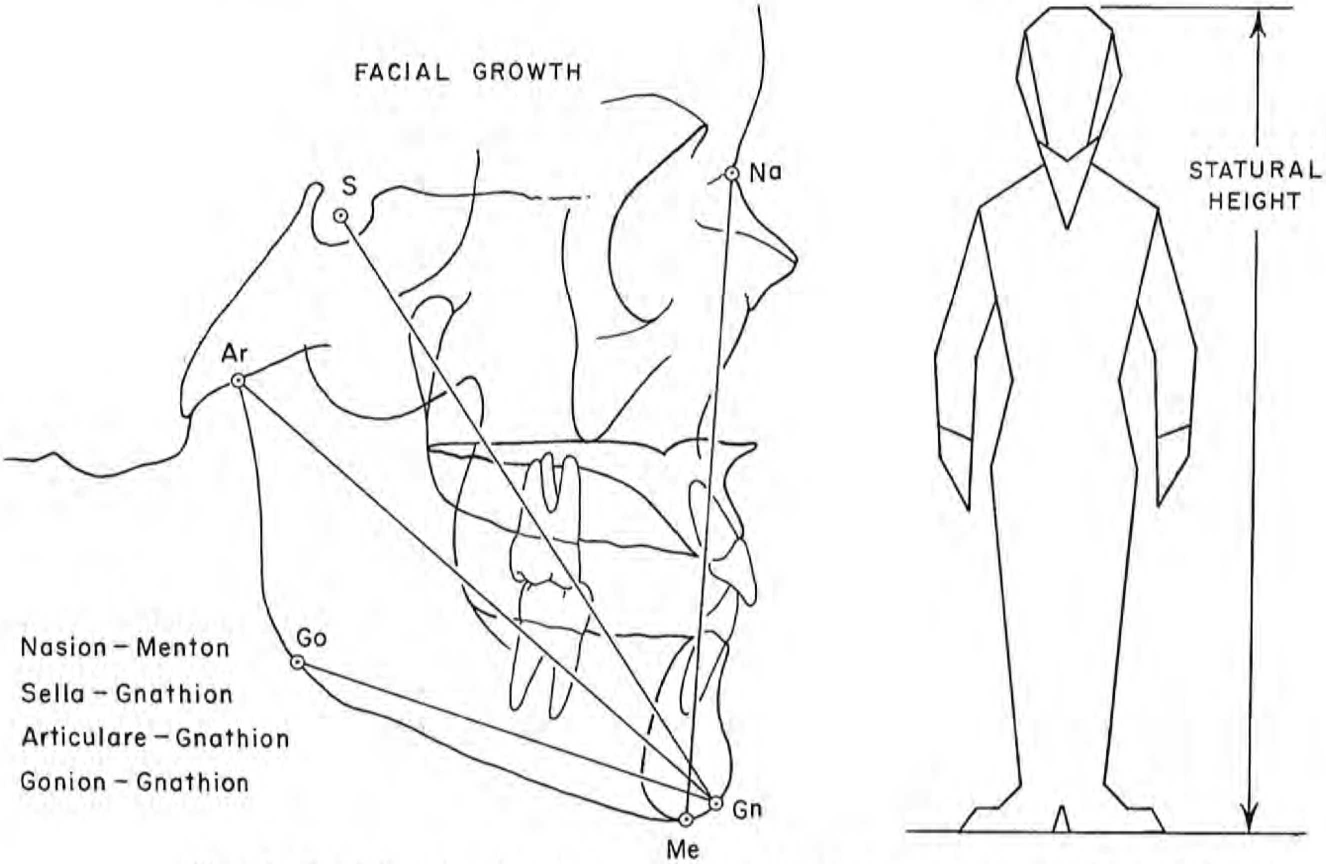

Fig. 6-5. Facial dimensions that have been shown to exhibit a high correlation to statural height during the circumpubertal growth spurt.

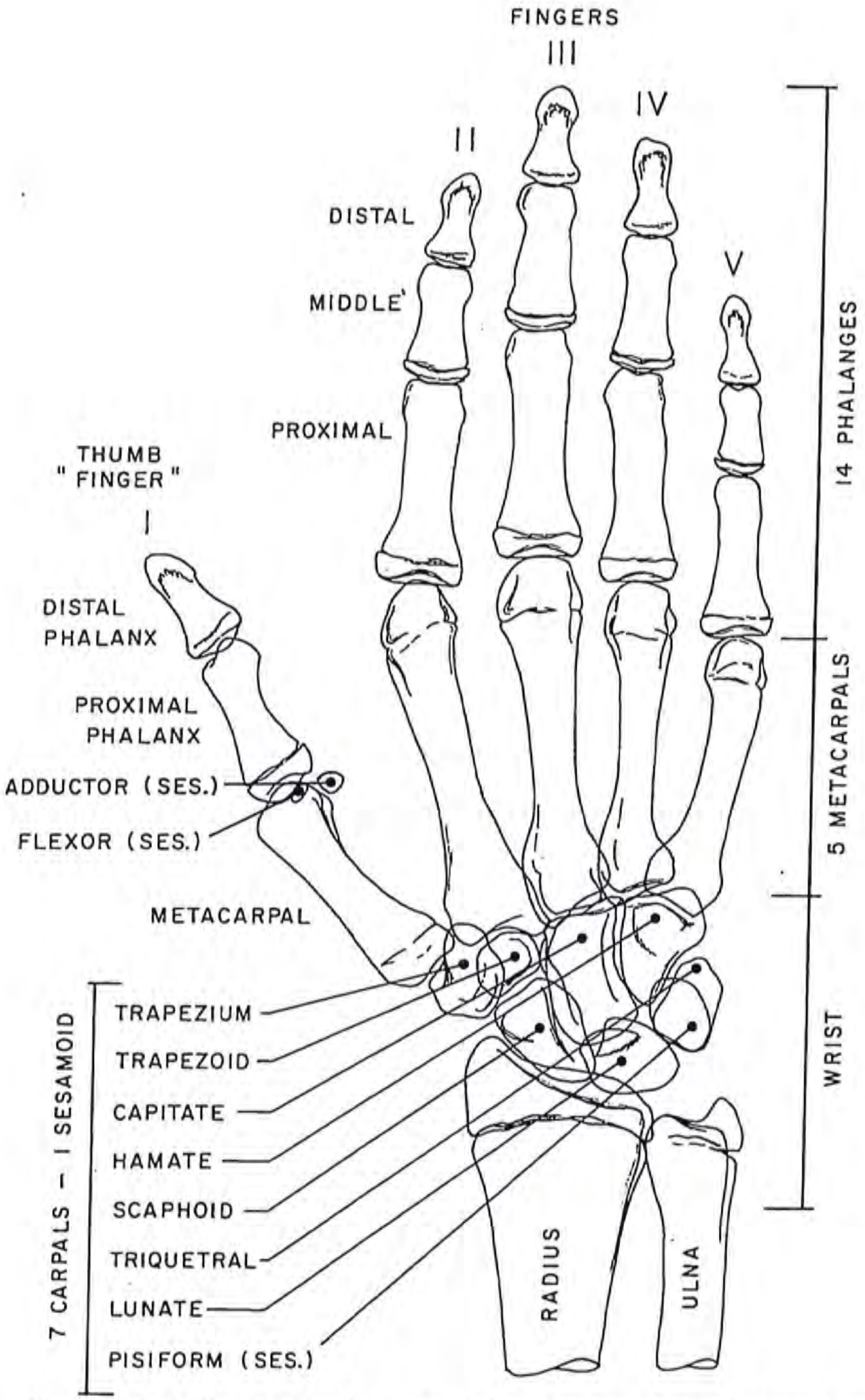

Fig. 6-6. Diagrammatic outline of the hand and wrist, indicating nomenclature and structural grouping.

their common terminology indicated, and it warrants careful study by the newly initiated before they proceed.

Many investigators have searched for specific hand-wrist bone maturity indicators that are directly correlated with the onset of puberty. Buehl and Pyle[10] have demonstrated that development of the pisiform is the best indicator of the onset of the circumpubertal growth spurt, but unfortunately, in the dorsopalmar position (the projection used for the standard radiograph), the pisiform is obscured by the triquetral bone (Fig. 6-7).

Flory,[13] in his investigations, has indicated that the beginning of calcification of the metacarpal sesamoid, or, as commonly termed, *adductor sesamoid* (hand), is another good guide

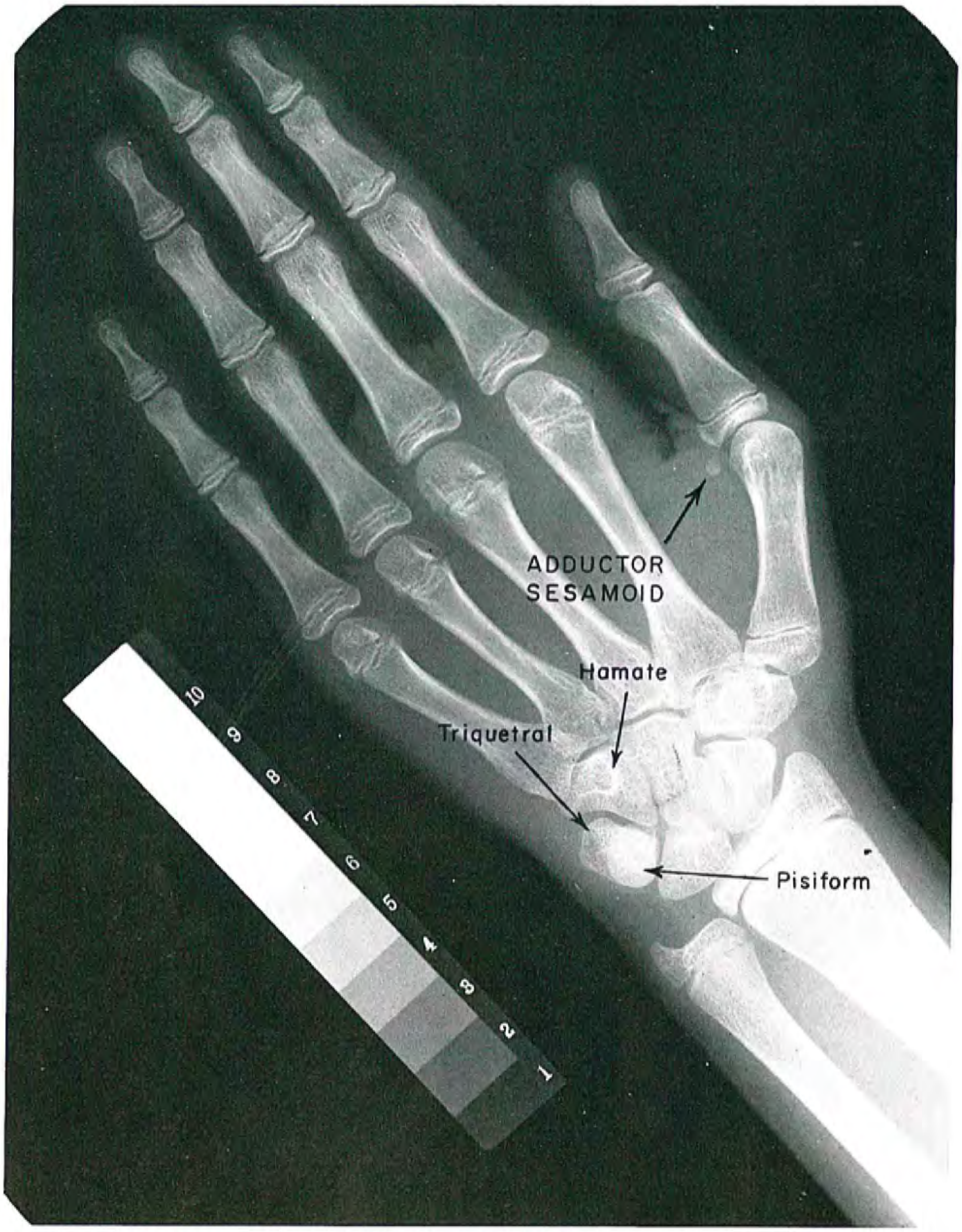

Fig. 6-7. Hand-wrist radiograph with the adductor sesamoid indicated as well as the relationship of the pisiform, triquetral, and hamate. The Webber[34] step wedge densitometer is shown adjacent to the hand.

for determining the period immediately prior to the onset of puberty. The adductor sesamoid is easily visualized (Fig. 6-7), and its onset of calcification is initially picked up by the observance of a small dot of mineralization, which gradually increases in circumference over a period of two to three years.

Brown[9] and others have shown that, immediately after the initial verification that the adductor sesamoid has started its calcification, statural height and the facial components begin a rapid and definite spurt in their developmental growth velocity. Grave,[18] in recent work with Australian aborigines and Caucasians, has confirmed and also related the association of this maturational phenomenon with orofacial growth velocity.

A limiting factor in using this clinical signal is, of course, that without serial records the clinician may have difficulty determining with reasonable accuracy when the adductor sesamoid started its mineralization if it is present at the time of the first recording. Obviously, though, if onset of ossification or a significant percentage of calcification of the adductor sesamoid has taken place, the individual is within or beyond the pubertal phase of accelerated growth. The converse is also true; without any initial signs of calcification, the circumpubertal growth spurt may be reliably assumed to have not as yet begun.

Bergersen[6] has prepared a prediction table for forecasting the male pubertal growth spurt in the face by the association of chronologic and skeletal ages. This guide may be used without specific reference to the adductor sesamoid.

HAND-WRIST RADIOGRAPHIC ASSESSMENT METHODS

Through an evolutionary process, standardized interpretation of hand-wrist radiographs has become a practical clinical tool. Although Todd[33] was not the first to develop an inspection method of comparing wrist films to selected "standards," his distillation of previous attempts[13] and the establishment of cardinal maturity indicators brought about the first comprehensive assessment method described in his book. His co-workers, Greulich and Pyle,[19] further refined this method of inspection-comparison in their book, published in 1950 and revised in 1959. The latter volume is most frequently used for hand-wrist assessment.

At an early stage in the utilization of hand-wrist films, Baldwin and colleagues[2] introduced a method of quantifying the area of physical development of the wrist bones by direct measurement on the radiograph.

Another method of wrist assessment, which embodies a series of drawings accompanied by written descriptions, is that devised by Tanner and co-workers.[32] These indicate the sequential stages of development of the individual hand-wrist bones as they progress from initial calcification to maturity. This method is useful if the interpretation is done by a well-trained assessor. However, the Greulich-Pyle method is less involved and more easily adapted to interpretation by the inexperienced practicing clinician.

Through the auspices of the U. S. Public Health Service and the Brush Foundation of Case Western Reserve University, Pyle and associates[29] have consolidated still further the major attributes of the Greulich-Pyle atlas into one series of sequential radiographs. These are applied to both males and females with the chronologic variability between the two clearly indicated. In our opinion it is the most concise and easily usable method of hand-wrist interpretation that is currently available.*

Todd initially thought that the left-hand wrist radiograph was more representative of skeletal maturation, since the majority of the population is right handed and thus possibly

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*This publication is obtainable through Year Book Medical Publishers, Inc., 35 E. Wacker Dr., Chicago, Ill. 60601.

would exhibit in the right hand influences of greater manual dexterity with increased physical development. A number of investigators have shown, however, that the left and right hands do not appreciably differ and that either may be used for a determination of skeletal maturation. Thus a radiograph of a right hand may be interpreted as for a left and vice versa when viewed from the opposite side. This reversibility is of help when comparisons are made to standards based on either right-hand[29] or left-hand[19] views.

MECHANICS OF OBTAINING A HAND-WRIST RADIOGRAPH

The conventional practice has been to obtain the hand-wrist radiograph by using an x-ray tube supported vertically over a horizontal table surface.[13] The distance of the x-ray head from the film used by different investigators has ranged from 30 to 36 inches (Fig. 6-8).

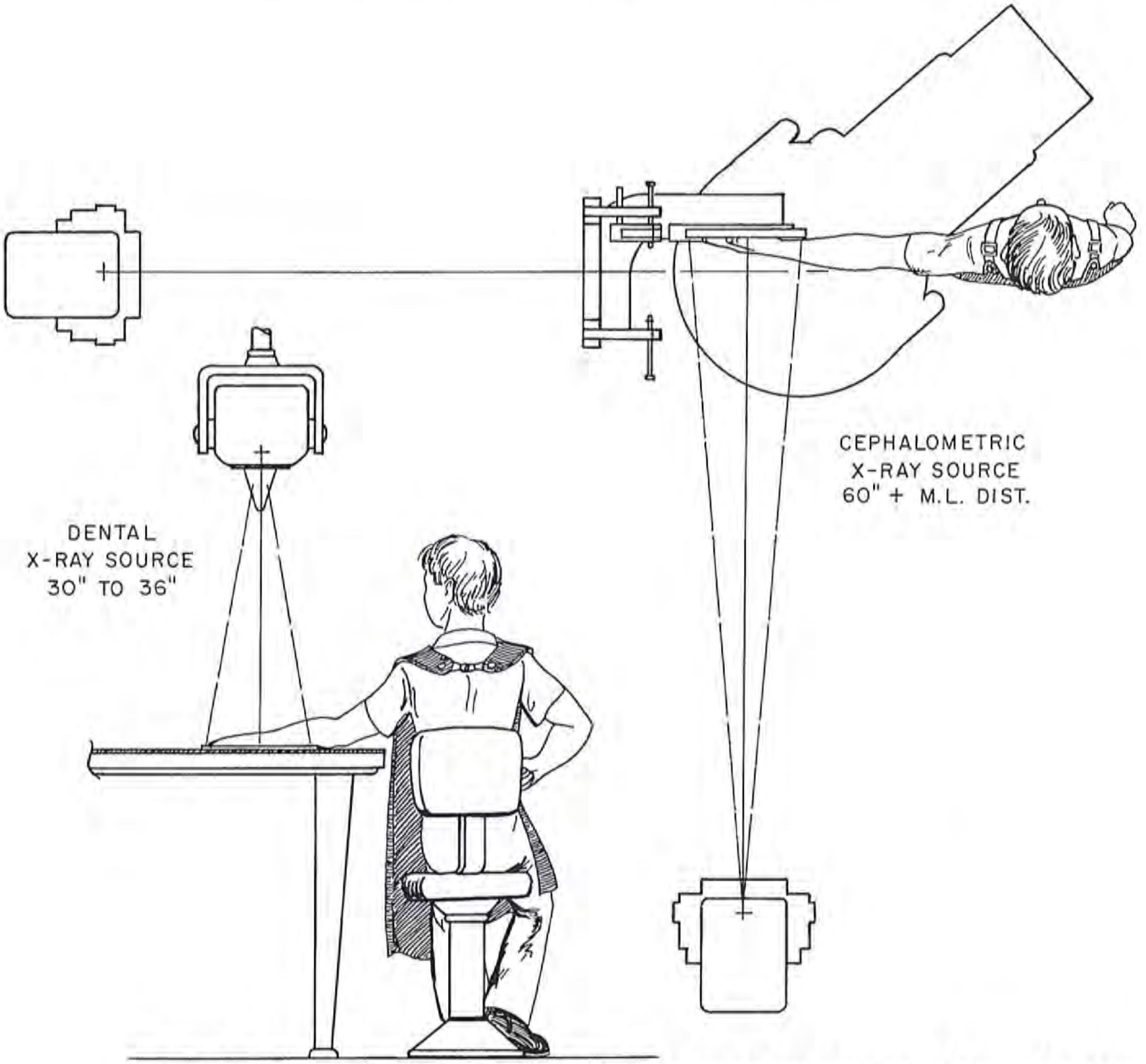

Fig. 6-8. Diagram indicating the use of the dental x-ray machine in vertical relationship for taking a wrist film and of the cephalometer for a horizontal projection in taking the hand-wrist radiograph.

Another method that is equally satisfactory and most easily adapted to the clinical office that has a cephalometric setup employs the use of the lateral film cassette holder with a conventional 5-foot target distance (Fig. 6-8). Because the hand is in direct approximation to the film surface in either setup, enlargement of the image is a negligible factor. Also, since interpretation of the film does not involve direct quantitative measurements, either the 3-foot or 5-foot target-object distance provides satisfactory results.

Optimum radiographs are obtained by using a nonscreen film in a cardboard cassette designed for this purpose or a sheet of nonscreen film as it is presently supplied in a self-contained lighttight envelope. The cassette or film packet should rest flat on the table or be firmly fixed vertically while the hand is placed against the film surface with the fingers and thumb slightly separated. Note that positioning of the hand with fingers outstretched is detrimental to clear visualization of the hamate bone; so a relaxed position with slight finger separation is to be preferred.

The hand-wrist and film are centered directly in the central ray of the x-ray tube. The wrist must be held firmly against the surface of the cassette (not angulated), or the distortion in the projection of the wrist bones will add confusion to the interpretation of the picture. Even though the extended arm removes the irradiated area a safe distance from the body, care should be taken as in all radiographic procedures to shield the patient adequately from any extraneous radiation.

In all cases proper identification should be placed on the film at the time of exposure. In addition, a practical procedure is to place a densitometer,[34] or aluminum step wedge, on the film surface during exposure, so that, at a later date, if an assessment of mineralization or bone density is desired, this information will have been included in the radiograph (Fig. 6-7).

Exposure times must be varied, as in all radiographic procedures, depending on the individual radiation output of the unit used, as well as for subject contrast. Following are general guidelines that one may use as a starting base, utilizing a 60-inch (plus) distance and taking into consideration the patient's weight range.

Wrist x-ray exposure

Weight (pounds)	*Kvp*	*MAS*
50-100	60	15.0
110-150	60	28.0
50-100	70	7.5
110-150	70	14.0
50-100	80	4.5
110-150	80	8.2
50-100	90	2.9
110-150	90	5.4

MAS = MA × seconds

Distance: 64 inches

No-Screen film

Develop 8 minutes, 68° F.

(Blue-Brand film with par-speed screens requires approximately 10% of exposures shown.)

A second practical method of obtaining a diagnostically acceptable film is the use of the cephalometric film holder with its conventional cassette and standard screen (Blue-Brand)[26] film. The cassette is placed in the cephalometer in its customary position for a lateral radiograph, and the previously described routines are followed. The two major variables in technique are the exposure time, which is approximately 10% that of the No-Screen film, and the processing time.

MAKING A SKELETAL AGE ASSESSMENT BY HAND-WRIST RADIOGRAPHIC DETERMINATION

After a satisfactory radiograph of the hand-wrist has been obtained and with the aid of a radiographic atlas,[19,29] one of two ways of determining the skeletal age may be selected.

1. *A cursory or general assessment of the entire film may be made by comparing it with one or more of the standard plates of the atlas in an overall association by inspection.*. Usually a good starting point is the standard plate of the same chronologic age as that of the subject, and then one proceeds from this plate forward or back in the atlas, depending on the appearance of the entire hand-wrist, until the most similar plate is selected. This method should be considered a cursory assessment.

2. *The recommended method, which we will refer to as a mean assessment, is a more precise appraisal of skeletal age.* Since variation among bones frequently occurs within the same hand, this requires a bone-by-bone inspection with the assigning of a developmental age level to each bone, followed by an arithmetic averaging of all the bones to assign a mean skeletal age to the entire radiograph. Fig. 6-9 is a suggested form that may be used, providing a column for tabulating each bone age and additional columns for serial wrist x-ray recordings, allowing a direct comparison of one to the next as a series is developed.

To begin the assessment, the date of the radiograph is noted along with the chronologic age of the subject, as well as the sex; then the individual comparisons are made. In the evaluation of each bone, two possible conditions preclude a specific age assignment. The first is lack of calcification, causing the bone to be unobservable in the radiograph and consequently impossible to record. The second is the adult status of a particular bone rendering impossible any degree of accuracy in determining when that stage was reached.

In the first instance, on the assessment sheet, the area for the age assignment is left blank; in the second situation, the letter *A* is placed in the space, indicating *adult;* these bones, then, are not averaged in the total.

The clinician should proceed with the assessment in a uniform manner, beginning at the distal ends of the radius and ulna and comparing each to the plates of the atlas. The size, shape, and contours of the bones are noted as well as the presence or absence of their epiphyses and the relation of these to the shafts.

Next the carpal bones are individually compared to the standard plates, and attention is paid to their outlines with regard to rounding, flattening, or notching as well as densities, surface features, and the shaping and proximity of each to adjacent bones. Then the metacarpals are inspected, and a determination is made as to the relationship of the epiphysis to the shaft, in addition to the degree of ossification and the maturing contours and markings.

Each of the proximal, middle, and distal phalanges is now inspected and compared to the standard plates with regard to epiphyseal, metaphyseal, and diaphyseal relationships plus the lines and areas denoting densities, surface features, and degree of development. The final group considered is the sesamoids with particular regard to their presence or absence and then their general size and shape. Last, any anomalous features that might be observed (such as missing bones, osseous scarring, and fusions) should be noted on the assessment sheet for future reference.

Once the list of individual bone-age assessments is complete, the resolving step in the process is to total arithmetically the skeletal age for all bones and divide this by the number of bones with age assignments. The result is a "mean skeletal age" for that hand-wrist radiograph.

SKELETAL MATURITY AND BODY MATURATION LEVEL

Name ______________________ Birthdate ____________ Case No. ________

Sex ______

	Exam #1	Exam #2	Exam #3	Exam #4
Date of x-ray				
Chronologic age				
Height in cms.				
Weight in lbs.				
	Skeletal Age in Months			
Distal end of radius				
Distal end of ulna				
Capitate				
Hamate				
Triquetral				
Lunate				
Scaphoid				
Trapezium				
Trapezoid				
Metacarpal I				
Metacarpal II				
Metacarpal III				
Metacarpal IV				
Metacarpal V				
Proximal phalanx I				
Proximal phalanx II				
Proximal phalanx III				
Proximal phalanx IV				
Proximal phalanx V				
Middle phalanx II				
Middle phalanx III				
Middle phalanx IV				
Middle phalanx V				
Distal phalanx I				
Distal phalanx II				
Distal phalanx III				
Distal phalanx IV				
Distal phalanx V				
Pisiform				
Adductor sesamoid				
Flexor sesamoid				
Skeletal ages (sum)				
*Skeletal age (mean)				
Anomalies				

Fig. 6-9. Suggested form for recording individual bone ages and tabulating a "mean" hand-wrist assessment of skeletal age. This form is adapted from one that has been used by many investigators.

The preceding description is obviously superficial and meant only to develop a working knowledge of the procedures involved in determining skeletal age. With this superficial exposure, it is hoped that the clinician will have developed enough understanding and appreciation for the method described to pursue a study in more depth.

A comprehensive and thorough discussion of both skeletal age determination and the history and rationale of maturational standards can be obtained in the atlases previously described.[19, 29, 33]

APPLICATION OF SKELETAL AGE ASSESSMENT IN OROFACIAL TREATMENT PLANNING

Although the use of a standardized hand-wrist radiograph in determining skeletal age and maturational level is a well-accepted diagnostic procedure, the application of the information derived in this manner must be weighed carefully by the clinician, who is dealing with many variables when correlating the orofacial diagnostic factors in an individual case. Following are some of these, as previously stated:

1. Chronologic age
2. Dental age
3. Skeletal age
4. Intrinsic and extrinsic causal factors as they influence facial balance and malocclusion
5. BSC of craniofacial components
6. Morphology of individual bones
7. Orofacial spatial relationships

Beyond the purview of this limited text is the attempt to enumerate completely the infinite number of variations that these factors may impart to a clinical situation; let us simply say that the trained clinician, with a patient under firsthand observation, may apply the knowledge of skeletal age in many ways such as the following examples:

1. Knowing that a patient is on an average, or *moderate,* skeletal maturational schedule allows the clinician the general latitude of applying matching norms of chronologic development in making clinical judgments. Understand that a major limitation in this area lies in the variability of growth vectors,[26] or directions of expression of facial growth, since individual morphology varies. The Bolton Standards assist in this determination of size, shape, and interrelation of parts.
2. Diagnosis of an *advanced* maturational pattern may indicate limitations to the orthodontic clinician in treatment timing or method (i.e., extraction versus nonextraction) whereas in considerations of orofacial surgery, in which the earliest intervention may be psychologically desirable, a knowledge of advanced maturation will be a welcome assistance in the treatment planning.
3. Conversely, knowledge of *delayed* maturational schedules will be of significant diagnostic help when further growth is either desired or would be detrimental to results if surgery is performed too soon.
4. A knowledge of an impending circumpubertal growth spurt, which has been discussed previously, can also be of great benefit in determining the timing of treatment as well as the procedures to be employed.
5. The determination of cessation of growth of the long bones, by observation of epiphyseal closure in the radius and ulna, can aid in programing orosurgical procedures by conveying the specific information that further facial growth of any significance is not to be expected and thus will not endanger completed procedures.

Fig. 6-10. Wrist x-ray film of male patient who presented a pronounced Class III facial pattern. His chronologic age *(C. A.)* of 15 years 10 months and skeletal age *(S. A.)* of 16 years 1 month indicated a moderate maturational pattern.

Fig. 6-10 is a wrist radiograph of an adolescent male patient who had a pronounced Class III dentofacial pattern. If the pattern is deemed best corrected by surgical procedures, the knowledge that the patient's chronologic age of 15 years 10 months is close to his skeletal age of 16 years 1 month is of importance. The clinician will understand that, with an average maturational velocity, the facial structures can be expected to continue to grow for another two to three years. As has been stated previously in this volume, male facial growth continues into the eighteenth and nineteenth years of age. Pyle and associates state that, in selecting the male representative radiographs from a "normal" male series, "only twenty-five of the fifty-six boys had completed epiphyseal-diaphyseal fusion in the wrist at the time of their last examinations, which were made at age eighteen years."[29]

Fig. 6-11 shows radiographs of two young male patients, the first of which, *A*, has a chronologic age of 8 years 18 days, although his skeletal age is 6 years 7 months. This patient would fall into our "late maturer" category and should be so handled diagnostically. Fig. 6-11, *B*, shows the wrist radiograph of a male patient with a chronologic age of 7 years 8 months 11 days who demonstrates a mean skeletal age of 9 years 9 months. In following this patient, the clinician is immediately directed to the understanding that, whatever treatment program is instituted, action should be considered at an earlier date than when the same procedure is carried out on a patient with a moderate maturational schedule. Although these two individuals are of similar chronologic age, they differ approximately 3 years in skeletal age.

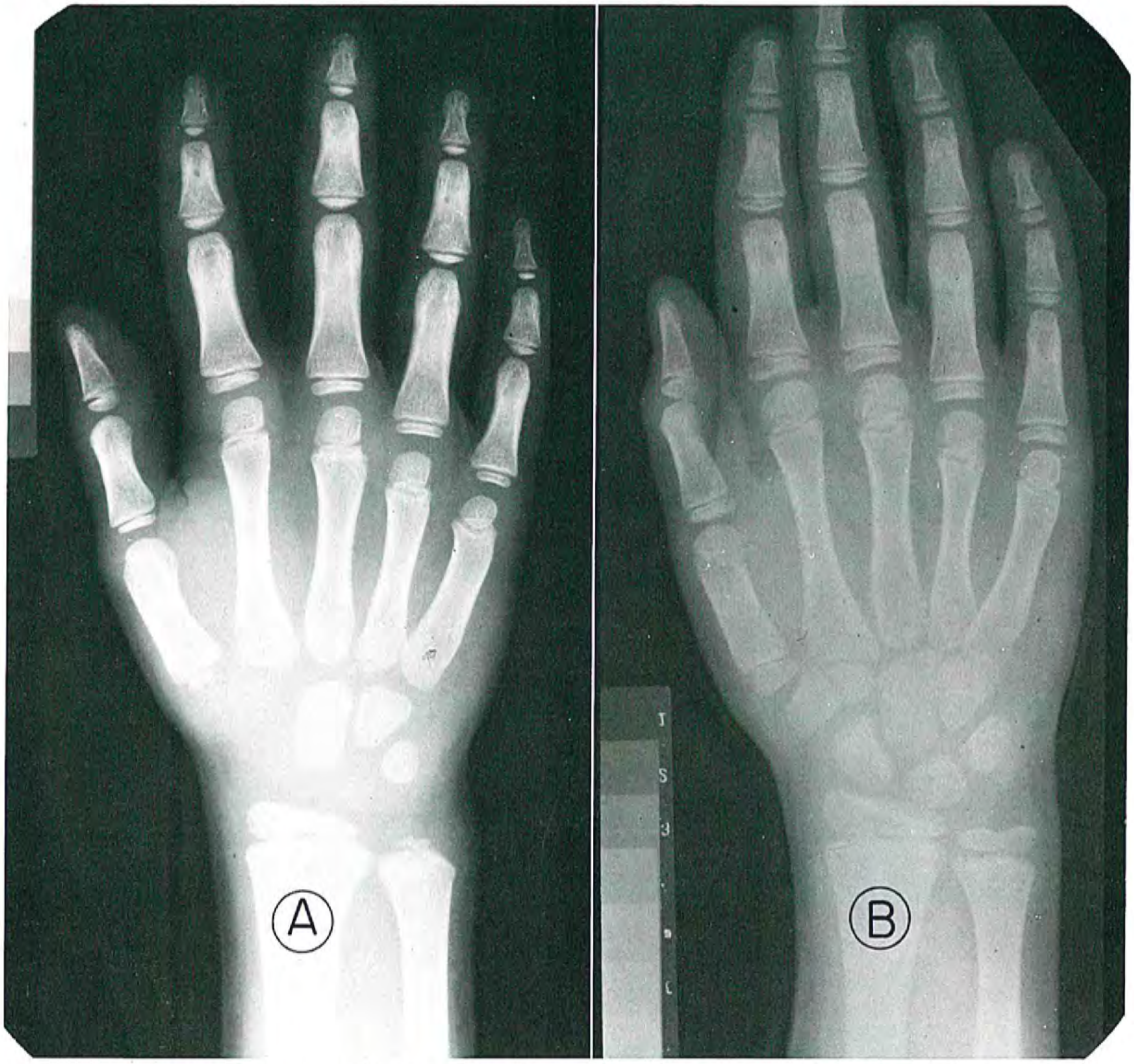

Fig. 6-11. Wrist radiographs of one individual with a delayed maturational pattern **(A)** and another of similar chronologic, but advanced skeletal, age **(B)**.

The last example, Fig. 6-12, is the wrist radiograph of a young female patient of chronologic age 10 years 6 months. Her skeletal age, as assessed by *A Radiographic Standard of Reference for the Growing Hand and Wrist,*[29] is 9 years 9 months, giving a differential of approximately 9 months, or not enough variance to place her in a delayed skeletal age status. In viewing her dentofacial relationships (Fig. 6-13), one finds that she has a Class I malocclusion, since crowding is present in the dental arches, not illustrated in the tracing, and she has lost deciduous cuspids prematurely. In comparing her CB and facial components to the Bolton Standards, a correlation of 11 years is found for the CB, which is not appreciably different from her chronologic age, but her maxilla has a BSC of 5 years and her mandible of 6 years. Using the limited amount of clinical information presented, one could hypothesize that a program of serial extraction might be the best long-term resolution of the variables involved.

A knowledge of skeletal age, therefore, whether it indicates a moderate maturational pattern or a divergent relationship from dental and chronologic determinants, is valuable diagnostic information. Its favorable application, as well as the limitations of interpretation, should be well understood by the clinician before clinical procedures of an irreversible nature are instituted.

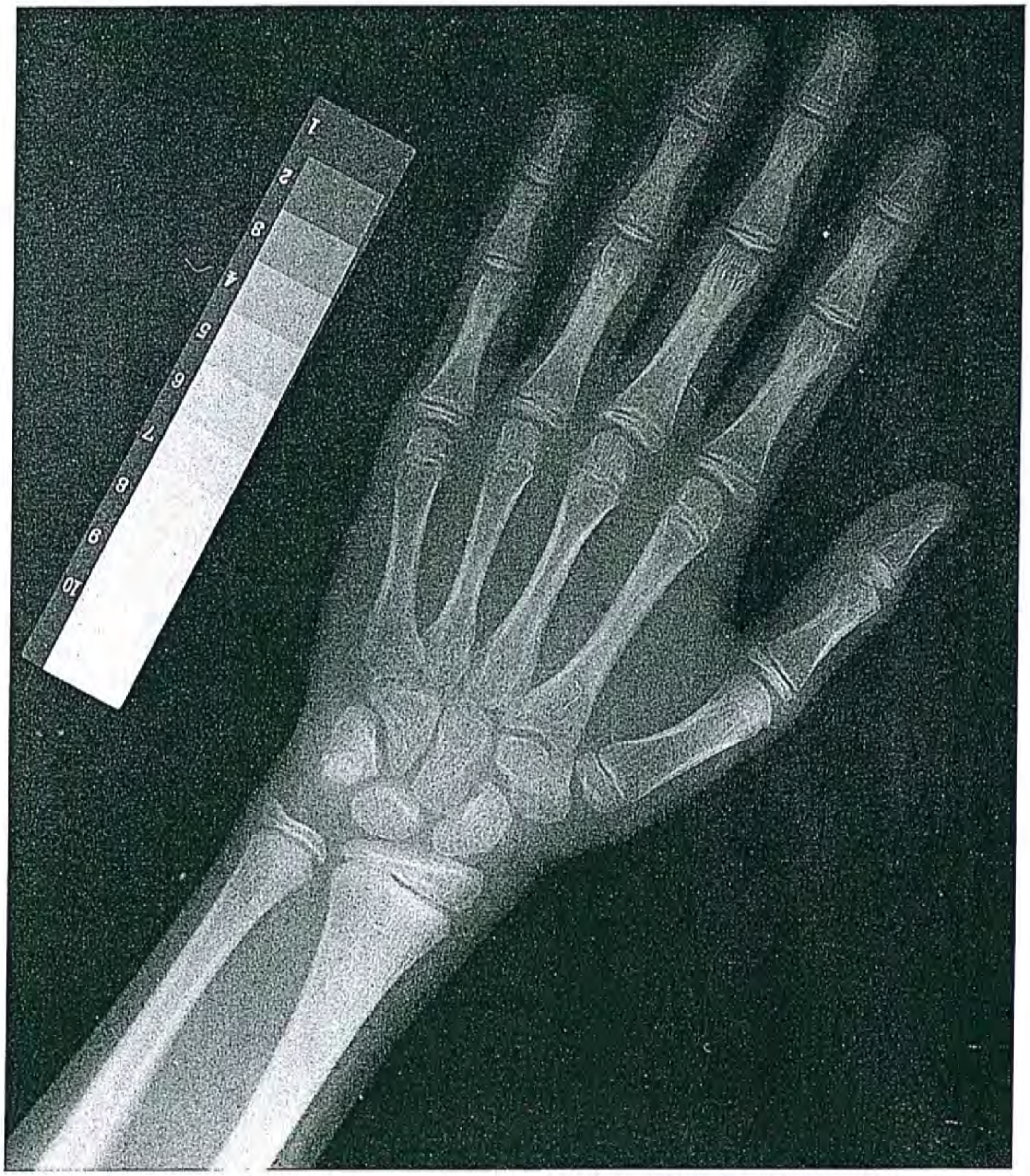

Fig. 6-12. Wrist x-ray film of a girl with a chronologic age of 10 years 6 months and a skeletal age of 9 years 9 months.

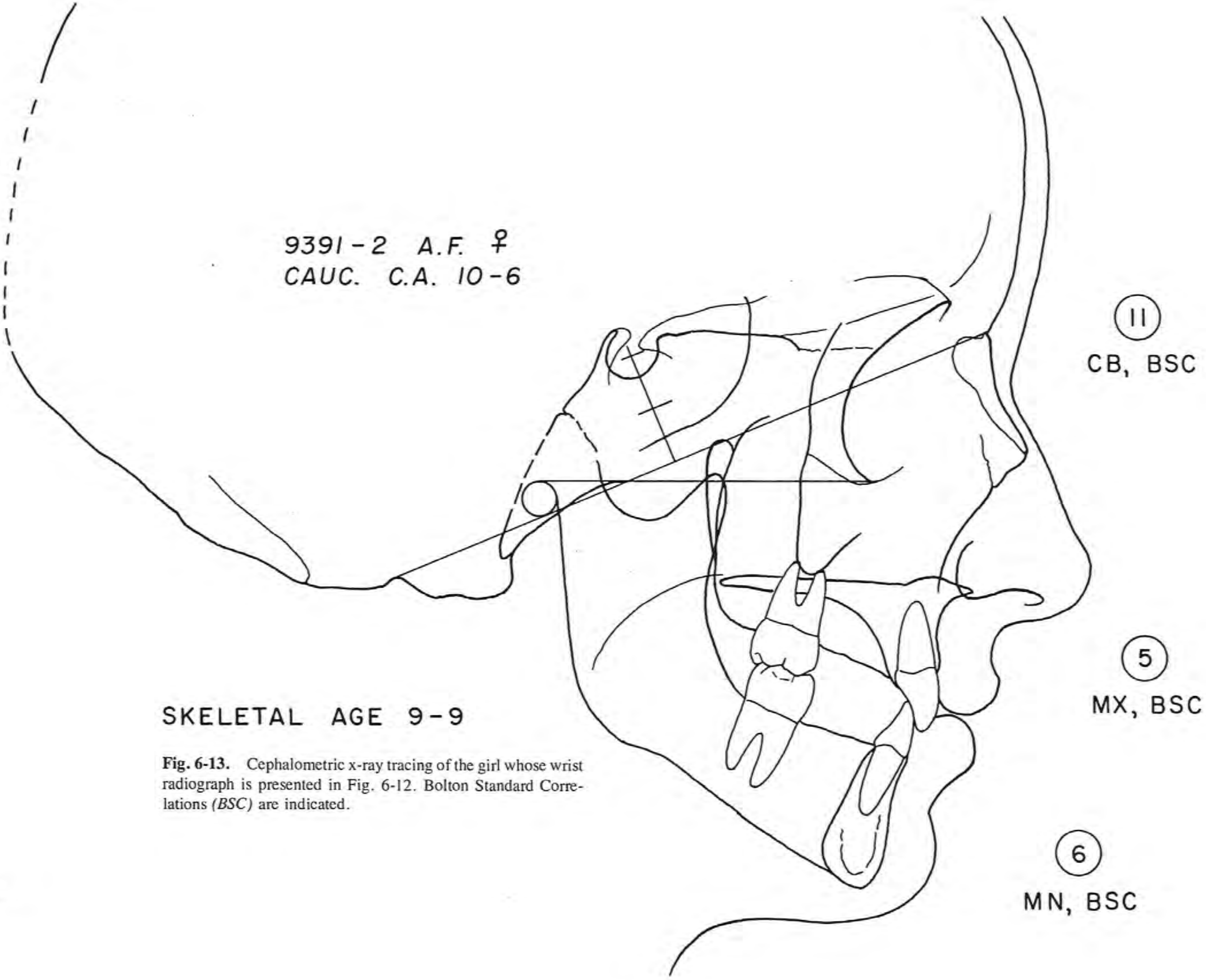

Fig. 6-13. Cephalometric x-ray tracing of the girl whose wrist radiograph is presented in Fig. 6-12. Bolton Standard Correlations *(BSC)* are indicated.

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Epilogue

To facilitate the use of the Standards in teaching programs, lectures, and periodicals, we hereby grant permission for their use in photographs in which direct clinical comparisons are being made or research base lines are being established, since it is hoped that this will assist in their wider application. This, of course, will not supersede the copyright as it affects duplication of the text or the Standards themselves.

Most will note that we have not included an additional reading list or a comprehensive bibliographic reference section. We have done this for two personal reasons: the first relates to our inability to categorize and catalogue the tremendous volume of information that is directly or indirectly germane to this text and, second, out of deference to the many clinicians and researchers who have made exceptionally fine contributions to the literature in this area, we are reluctant to enumerate them, since some might be omitted by oversight, whereas all have our admiration and gratitude!

For those who have sought precision without interpolation and rules without exceptions in this book, we are sorry that you must necessarily be disappointed. Although cephalometric radiography and its associated techniques have a broad scientific base, we must all continue to realize the latitudes inherent in these procedures and allow room for legitimate variation in application and interpretation.

Finally, in summary we would like to offer one of our favorite quotations:

> What we think we know today shatters the errors and blunders
> of yesterday and is tomorrow discarded as worthless.
>
> So we grow from larger mistakes to smaller mistakes—
> as long as we don't lose courage.
>
> This is true of all therapy; no method is final.
>
> *Frederick Jensen*

GLOSSARY OF CEPHALOMETRIC AND ANTHROPOMETRIC DEFINITIONS

antegonion Highest point of the notch or concavity of the lower border of the ramus where it joins the body of the mandible.

anterior nasal spine (ANS) Sharp median process formed by the forward prolongation of the two maxillae at the lower margin of the anterior aperture of the nose.

A-P (anteroposterior) growth axis, or frontal growth axis, of the head and face Transverse zone delineated by a plane running through the coronal suture superiorly, passing down through the pterygomaxillary fissure near the posterior termination of the hard palate and then through the junction of the horizontal and vertical components of the mandible. It marks the division of the anterior from the posterior component of craniofacial developmental growth when lateral tracings are oriented in Bolton relation.

articulare Intersection of the lateral radiographic image of the posterior border of the ramus with the base of the occipital bone *(Björk)*. On the lateral cephalometric tracing, the point of intersection of the posterior border of the condyle of the mandible with the Bolton plane *(Bolton)*.

basion Point where the median sagittal plane of the skull intersects the lowest point on the anterior margin of the foramen magnum.

Bolton cranial base Triangular base formed by the Bolton-nasion plane and lines joining the center of the sella turcica with the Bolton point and nasion.

Bolton plane Line joining the Bolton point and nasion on the lateral radiograph.

Bolton point Point in space, about the center of the foramen magnum, that is located on the lateral cephalometric radiograph by the highest point in the profile image of the postcondylar notches of the occipital bone. Since the postcondylar notches are close to the median sagittal plane, their shadows generally register on the lateral film as a single image. Also the posterior termination of the Bolton plane.

cephalogram Generally accepted term describing a standardized radiographic picture of the head.

cephalometer In craniometry an instrument for measuring the head. (See *radiographic cephalometer*.)

coronal suture Transverse union of the frontal with the parietal bones.

craniostat Device for holding the skull in a fixed position for craniometric study.

development In its simplest term, progress toward maturity.

developmental growth *Growth* and *development*, frequently used in discussions of dentofacial changes from birth to adulthood, are terms that often are used as synonyms. In the normal youngster, these processes work in concert with one another and are actually inseparable. It is helpful, however, in understanding the contributions that each makes to the progress of individual change to divide them arbitrarily into their actual areas of manifestation. Therefore we consider development to be the area of differentiation and maturation, which leads to increase in skill, more comprehensive function, and sexual dimorphism in progress toward adulthood. Growth, as it is arbitrarily separated from development, relates to the changes in physical size, which may be measured in increments of weight or linear change. Through this artificial separation of these two elements one is able to note individual changes that may exhibit an increase in size but be lacking in maturational evolution, whereas, on the other hand, one may observe conditions in which the natural maturational processes toward adulthood take place without a significant, or measurable, increase in size. Developmental growth is the comprehensive association of increase in size coupled with progress toward maturity.

eruption Dental eruption is more than the appearance of a tooth through the gingiva. Clinically it begins when the crypt is visible in the radiograph. It includes the migration of the crypt with its developing crown through the bone to the point where the tooth enters the mouth and arrives at its place in occlusion. It may occur through tooth movement, increase in tooth length, or both.

facial angle Angle formed by the junction of a line connecting the nasion and pogonion (facial plane) with the horizontal plane of the head (i.e., the Frankfort plane). This may be measured on the dead skull with a craniostat or on the living one with the lateral cephalometric radiograph.

facial height

total Distance between nasion and gnathion when projected on a frontal plane.

lower face Distance between anterior nasal spine and gnathion when projected on a frontal plane.

upper face Distance between anterior nasal spine and nasion when projected on a frontal plane.

facial plane Line connecting nasion and pogonion on the lateral cephalometric radiograph.

Frankfort plane Horizontal plane determined by the two poria and the left orbitale. It approximates closely the position in which the head is carried during life and is established on the lateral cephalometric radiograph by a line joining orbitale with porion, as indicated by the top of the ear rod of the cephalometer.

frontal plane Any plane parallel with the long axis of the body and perpendicular to the median plane. A frontal plane of the head is perpendicular to the median sagittal plane and to the Frankfort horizontal plane.

functional matrix Descriptive phrase used to identify all the soft tissues and empty spaces that functionally relate to and surround a specific skeletal element. In the case of the face, the maxillae, and the mandible, the teeth are also considered a part of the functional matrix.

The soft tissues, made up of neurovascular bundles, muscles and tendons, and glands, are augmented by the teeth and also the empty spaces of the nasal and oral cavities. All influence the associated bones to the degree of their functional demands and patency. The functional matrix plays a significant role in the developmental growth pattern of the skeletal elements with which it is associated. *(Moss.)*

gnathion Lowest, most anterior midline point on the symphysis of the mandible.

gonion External angle of the mandible, located on the lateral radiograph by bisecting the angle formed by tangents to the posterior border of the ramus and the inferior border of the mandible (a line from the menton to the posteroinferior border of the mandible).

growth Increase in size.

heredity Process of transmission of physical and psychic characteristics from parents to their offspring. It is basically related to genetics and to the observed phenomenon of the resemblance of animals and plants to their progenitors. The manifestation of heredity is never quite an exact duplication but is always modified to some degree resulting in differences between individuals and in the formation of new species. Dr. T. Wingate Todd has given us the following summation of facial hereditary patterns as they are influenced by environmental factors: "Everyone knows, of course, that faces differ, and most of us are content to assume that the differences are largely due to the *hereditary tendencies* implicit in the genes. But as the face, like the rest of the body, is a plastic thing and since its progress may be expedited, interrupted, retarded, warped, or inhibited by misadventures of health and by vagaries in the interplay of those organically originated influences by which the pattern is promoted, it is evident that *environment*, external and more particularly internal, must contribute in no small manner to the final results."*

horizontal plane Any transverse plane at right angles to the long axis of the body.

inion Most posterior point on the external occipital protuberance.

internal angle of the mandible Located on the lateral radiograph by bisecting the angle formed by tangents to the anterior border of the ramus and the superior border (alveolar crests) of the mandible. (A line joining the internal angle and antegonion marks the junction of the ramus with the body of the mandible.)

key ridge Prominent ridge, formed by the malar process, that divides the canine fossa from the infratemporal fossa on the lateral surface of the maxillary bone.

lateral growth axis Division between the right and left lateral components of growth. (See *median sagittal plane*.)

mandibular planes (1) Tangent to the lower border. (2) Line joining gonion and gnathion. (3) Line joining gonion and menton. (4) Line from menton tangent to the posteroinferior border.

maxillary plane (palatal plane) Line connecting the tip of the anterior nasal spine with the tip of the posterior nasal spine, as recorded in the lateral radiograph.

median sagittal plane Anteroposterior median plane of the body. (See *lateral growth axis*.)

menton Most inferior point on the symphysis of the mandible in the median plane. Seen in the lateral radiograph as the most inferior point on the symphyseal outline when the head is oriented in Frankfort relation.

nasion Craniometric point where the midsagittal plane intersects the most anterior point of the nasofrontal suture; the anterior termination of the Bolton plane.

normal child Child who is healthy in mind and body, harmoniously developed, physically, emotionally, and mentally, and compatible in developmental progress with his or her chronologic age.

normal face By normal face we do not mean a face of certain dimensions or particular form (features),

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*From Todd, T. W.: Integral growth of the face. I. The nasal area, Int. J. Orthodontia **22:**321-322, 1936.

but a well-grown face, harmoniously developed, skeletally and dentally, and consistent in developmental progress with its years *(Bolton)*.

occlusal plane Line passing through one half the cusp height of the first permanent molars and one half the overbite of the incisors.

orbitale In craniometry the lowest point on the inferior margin of the orbit. The left orbital point is used in conjunction with the poria to orient the skull on the Frankfort horizontal plane.

orbital plane Frontal (transverse) plane of the head passing through the left orbital point.

palatal (maxillary) plane Line connecting the tip of the anterior nasal spine with the tip of the posterior nasal spine as recorded in the lateral radiograph.

pogonion Most anterior point on the symphysis of the mandible in the median plane when the head is viewed in Frankfort relation.

point A See *subspinale*.

point B See *supramentale*.

point R (Bolton registration point) Center of the Bolton cranial base; a point midway on a perpendicular erected from the Bolton plane to the center of the sella turcica (S).

porion Point on the upper margin of the porus acusticus externus; the two poria and the left orbitale define the Frankfort horizontal plane.

posterior nasal spine (PNS) Process formed by the united projecting medial ends of the posterior borders of the two palatine bones.

pterygomaxillary fissure (PTM) Inverted, elongated, teardrop-shaped area formed by the divergence of the maxilla from the pterygoid process of the sphenoid. The posterior nasal spine and staphylion are generally located beneath the lower pointed end of this area.

radiographic cephalometer Cephalometer combined with radiographic equipment for the production of standardized complementary lateral and frontal radiographs for measuring developmental growth of the dentition, face, and head.

sella turcica (Turkish saddle), S Hypophyseal, or pituitary, fossa of the sphenoid bone, lodging the pituitary body. The landmark S is the center of the sella, as seen in the lateral radiograph and located by inspection.

S′ (S prime) Point of origin on the Bolton plane of a perpendicular erected through S.

staphylion (sta.) Point in the median line (interpalatal suture) of the posterior part of the hard palate where it is crossed by a line drawn tangent to the curves of the posterior margins of the palate. (In lateral radiographs the posterior curved margins of the hard palate frequently may be seen more clearly than the posterior nasal spine.)

subspinale Point in the median sagittal plane where the lower front edge of the anterior nasal spine meets the front wall of the maxillary alveolar process (Downs point A).

supramentale Deepest midline point on the mandible between infradentale and pogonion (Downs point B).

Y axis Line joining sella turcica center (S) and gnathion, which subtends a measurable angle with the Frankfort horizontal plane.

zygion (zig-ee-on) Craniometric point at either end of the greatest bizygomatic diameter, or width, on the outer surface of the zygomatic arch.

APPENDIX

Cephalometric measurements of the Bolton Standards

To avoid the need for individual measurement of selected and frequently used cephalometric linear and angular measurements, a group of basic and representative determinations follows. (See Figs. 1 and 2.)

Angular measurements

1.	(1-108)-(58-138)	(Po-Or)-(Na-Pogo)
2.	95-58-138	S-Na-Pogo
3.	14-58-138	Bo-Na-Pogo
4.	(108-1)-(144-139)	(Or-Po)-(Go-Gn)
5.	(108-1)-(95-139)	(Or-Po)-(S-Gn)
6.	(108-1)-(170-162/174-166)	(Or-Po)-(Occl pl)
7.	(164-162)-(166-168)	$\underline{1}$-$\overline{1}$
8.	(58-14)-(1-108)	(Na-Bo)-(Po-Or)
9.	(170-162/174-166)-(144-139)	(Occl pl)-(Go-Gn)
10.	(58-95)-(170-162/174-166)	(Na-S)-(Occl pl)
11.	(58-95)-(144-139)	(Na-S)-(Go-Gn)
12.	58-95-12	Na-S-Ar
13.	12-144-139	Ar-Go-Gn
14.	(127-132)-(164-162)	(PNS-ANS)-$\underline{1}$
15.	(95-58)-(164-162)	(S-Na)-$\underline{1}$
16.	(132-127)-(144-139)	(ANS-PNS)-(Go-Gn)
17.	(95-58)-(166-168)	(S-Na)-$\overline{1}$
18.	(144-139)-(168-166)	(Go-Gn)-$\overline{1}$
19.	(170-162/174-166)-(166-168)	(Occl pl)-$\overline{1}$
20.	95-58-133	S-Na-A
21.	95-58-137	S-Na-B
22.	133-58-137	A-Na-B
23.	58-133-138	Na-A-Pogo
24.	(58-138)-(137-133)	(Na-Pogo)-(B-A)
25.	(58-133)-(164-162)	(Na-A)-$\underline{1}$
26.	(58-137)-(166-168)	(Na-B)-$\overline{1}$

Linear measurements

Anteroposterior measurements (mm.)

Parallel to horizontal plane

1A	127-132	PNS-ANS

Anteroposterior measurements (mm.)

Perpendicular distance from (plane) to point

1B	(133-138)-162	(A-Pogo)-$\underline{1}$ tip
2B	(58-133)-162	(Na-A)-$\underline{1}$ tip
3B	(58-137)-166	(Na-B)-$\overline{1}$ tip
4B	(58-137)-138	(Na-B)-Pogo
5B	(58-138)-162	(Na-Pogo)-$\underline{1}$ tip

Vertical measurements (mm.)		
Perpendicular to horizontal plane		
1C	58-132	Na-ANS
2C	132-140	ANS-Me
3C	58-140	Na-Me
Direct measurements (mm.)		
Point to point		
1D	95-58	S-Na
2D	95-13	S-Ba
3D	95-139	S-Gn
4D	144-138	Go-Pogo
5D	12-144	Ar-Go
6D	12-58	Ar-Na
7D	14-95	Bo-S
8D	14-58	Bo-Na

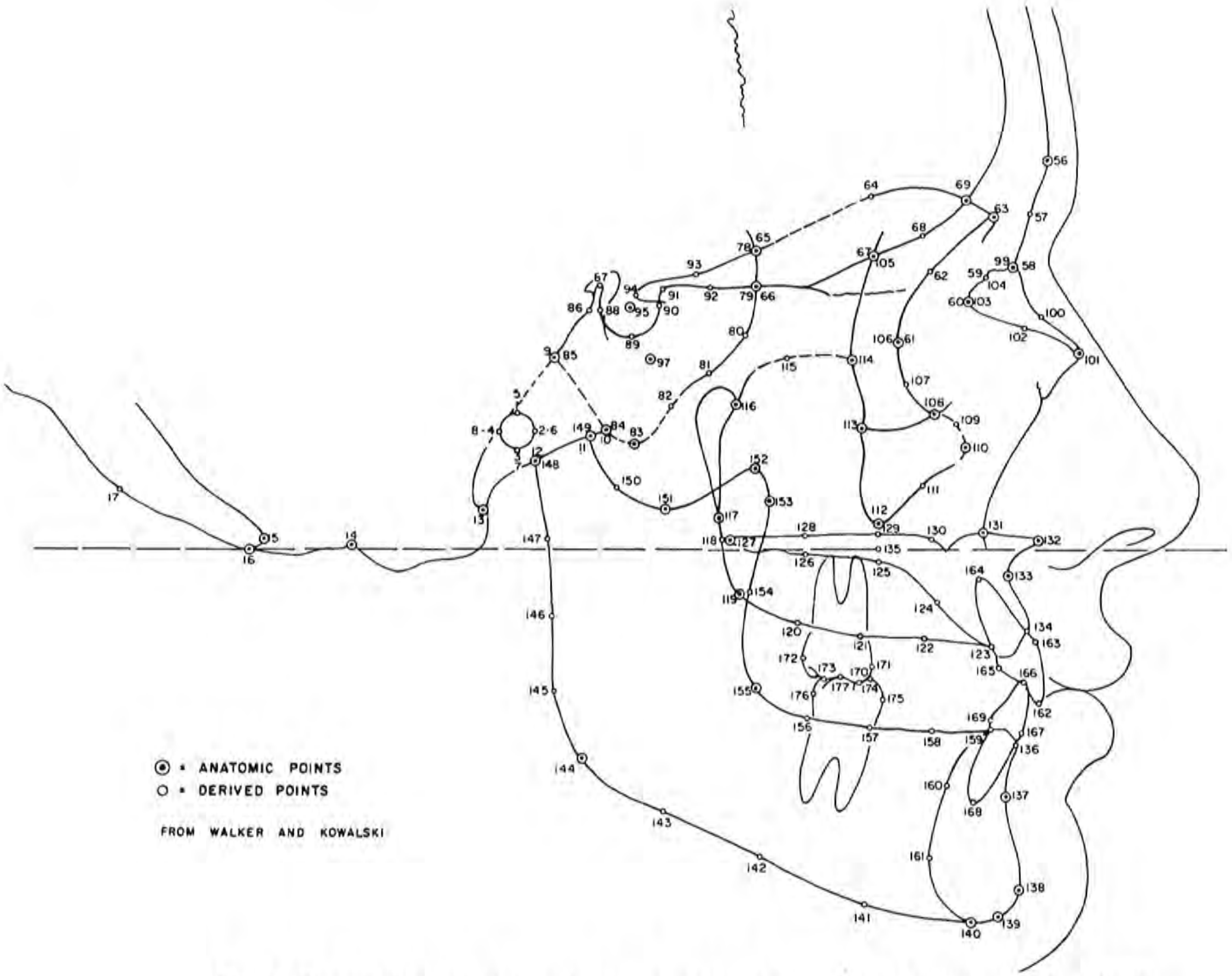

Fig. 1. Diagram of lateral cephalometric tracing, indicating the anatomic and derived points from Walker and Kowalski's computer program. The points indicated are those which can be located on the anatomic structures that are routinely traced in the Bolton Faces cephalometric records.

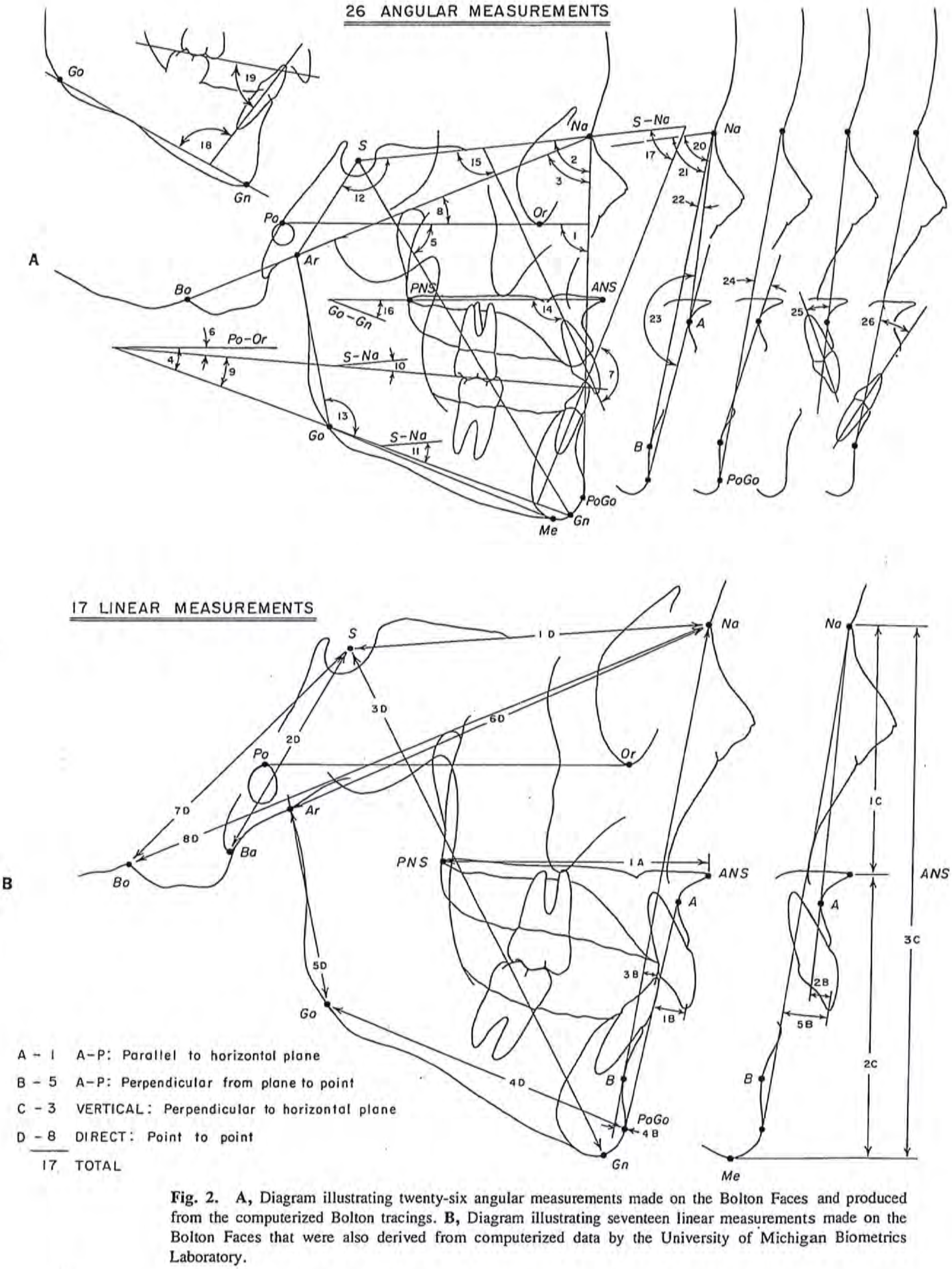

Fig. 2. **A,** Diagram illustrating twenty-six angular measurements made on the Bolton Faces and produced from the computerized Bolton tracings. **B,** Diagram illustrating seventeen linear measurements made on the Bolton Faces that were also derived from computerized data by the University of Michigan Biometrics Laboratory.

The first group contains the angular measurements and the second group the linear measurements. They were selected by perusing most of the analyses and comparative relationships that are frequently to be seen in the cephalometric and orthodontic literature. Fig. 2 diagrammatically describes these measurements and their points of derivation. Keep in mind that in making comparisons some landmarks that are defined in one way by the Bolton terminology have been defined somewhat differently in the computerized program. An example in point is *gnathion*, which, in the definition accepted by the Bolton group, is "the most anterior-inferior point on the symphysis of the chin," whereas its definition in the Walker program is related to the mandibular plane and a perpendicular erected from it tangent to the symphysis (similar to the definition used by Downs*). Our measurements are made as indicated in the list of angular and linear determinations. Each is carried through from 1 to 18 years of age, and they are grouped as males, females, and male and female pooled, which indicates the Standard itself. The columns are in sequence in each group and give, first, the mean of the group for the particular measurement; second, the standard deviation; third, the standard error of the mean; fourth, the minimum measurement of the range; and, fifth, the maximum of the range for the particular measurement described. Once again, if a slight variation is observed in the numerical sequence of any of these columns, it frequently can be attributed to the insertion of a cross-sectional record that was used to complete a longitudinal series.

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*Downs, W. B.: Variations in facial relationships: their significance in treatment and prognosis, Am. J. Orthod. **34:**812-840, 1948.

Angular measurement No. 1. (Po-Or)-(Na-Pogo)/(1-108)-(58-138)

	Male					*Female*					*Male and female pooled*				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	80.9	2.05	.72	77.3	83.2	82.4	3.98	.99	75.7	91.7	81.9	3.48	.71	75.7	91.7
2	82.4	2.77	.69	76.2	86.6	84.1	4.01	1.00	78.0	92.9	83.2	3.50	.62	76.2	92.9
3	83.7	2.87	.72	79.8	89.3	84.7	2.63	.66	80.6	88.3	84.2	2.76	.49	79.8	89.3
4	82.9	4.25	1.06	72.8	87.8	85.5	2.19	.55	81.6	88.5	84.2	3.57	.63	72.8	88.5
5	83.9	2.29	.57	79.9	87.1	85.6	2.01	.50	81.9	88.2	84.7	2.28	.40	79.9	88.2
6	83.6	2.74	.68	79.7	87.1	84.3	3.19	.80	77.0	90.7	84.0	2.95	.52	77.0	90.7
7	84.8	2.84	.71	80.3	90.8	84.7	2.41	.60	80.2	89.1	84.7	2.59	.46	80.2	90.8
8	85.1	2.71	.68	80.5	90.5	83.9	2.44	.61	80.3	89.0	84.5	2.62	.46	80.3	90.5
9	85.4	2.57	.64	79.2	89.3	85.8	2.02	.50	81.5	89.1	85.6	2.28	.40	79.2	89.3
10	85.6	2.12	.53	81.1	88.2	85.1	2.48	.62	80.3	90.5	85.3	2.28	.40	80.3	90.5
11	86.5	1.81	.45	81.5	88.7	85.1	2.44	.61	80.3	89.1	85.8	2.23	.39	80.3	89.1
12	85.9	2.13	.53	82.0	88.9	86.5	2.81	.70	81.0	89.9	86.2	2.47	.44	81.0	89.9
13	86.5	2.49	.62	81.7	89.9	87.4	2.64	.66	83.8	92.2	87.0	2.57	.45	81.7	92.2
14	86.6	1.83	.46	83.8	89.2	87.6	2.08	.52	83.2	91.0	87.1	2.00	.35	83.2	91.0
15	87.3	2.54	.64	83.1	90.7	87.5	2.56	.64	82.3	92.3	87.4	2.51	.44	82.3	92.3
16	87.8	2.59	.65	82.0	91.1	88.3	2.10	.52	83.4	90.7	88.0	2.33	.41	82.1	91.1
17	87.6	3.22	.80	82.4	92.1	88.3	3.40	.85	83.3	94.2	87.9	3.28	.58	82.4	94.2
18	87.6	2.47	.62	83.5	91.4	87.9	2.79	.70	81.8	92.9	87.7	2.60	.46	81.8	92.9

Angular measurement No. 2. S-Na-Pogo/95-58-138

	Male					*Female*					*Male and female pooled*				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	74.0	2.90	1.03	70.2	78.1	76.1	3.79	.95	69.9	82.7	75.4	3.59	.73	69.9	82.7
2	76.3	2.54	.63	72.1	81.3	78.6	2.78	.69	73.8	84.3	77.5	2.86	.50	72.1	84.3
3	76.4	3.75	.94	67.8	83.3	78.8	3.10	.77	73.9	85.1	77.6	3.60	.64	67.8	85.1
4	75.9	3.64	.91	67.5	85.2	78.3	2.38	.59	73.7	82.5	77.1	3.27	.58	67.5	85.2
5	76.6	2.67	.67	69.5	80.3	78.9	1.93	.48	75.7	81.8	77.8	2.58	.46	69.5	81.8
6	77.6	3.08	.77	69.6	81.0	79.0	2.28	.57	75.2	82.5	78.3	2.75	.49	69.6	82.5
7	77.2	3.02	.76	69.9	81.1	79.6	1.99	.50	75.3	82.2	78.4	2.81	.50	69.9	82.2
8	78.5	3.08	.77	71.8	83.0	79.9	1.80	.45	76.0	82.2	79.2	2.58	.46	71.8	83.0
9	78.9	3.03	.76	72.8	83.4	80.3	1.83	.46	76.5	83.1	79.6	2.56	.45	72.8	83.4
10	79.1	3.07	.77	73.4	84.7	81.1	1.79	.45	77.6	83.9	80.1	2.67	.47	73.4	84.7
11	79.3	2.91	.73	74.6	84.1	81.4	1.84	.46	77.8	83.9	80.4	2.63	.47	74.6	84.1
12	79.4	3.11	.78	74.0	84.9	81.0	1.83	.46	78.1	84.0	80.2	2.65	.47	74.0	84.9
13	80.2	2.58	.64	75.9	85.0	82.4	2.40	.60	78.7	85.8	81.3	2.69	.48	75.9	85.8
14	80.7	2.88	.72	76.3	85.8	83.1	2.23	.56	79.4	86.1	81.9	2.82	.50	76.3	86.1
15	81.6	2.91	.73	76.7	87.7	82.4	1.95	.49	78.9	84.9	82.0	2.47	.44	76.7	87.7
16	81.3	2.87	.72	76.7	86.6	83.1	1.99	.50	80.1	86.5	82.2	2.60	.46	76.7	86.6
17	82.3	2.95	.74	77.0	87.3	83.4	2.10	.52	79.4	86.1	82.8	2.58	.46	77.0	87.3
18	82.8	3.24	.81	76.7	88.0	82.9	2.23	.56	79.0	86.1	82.8	2.74	.48	76.7	88.0

Angular measurement No. 3. Bo-Na-Pogo/14-58-138

	Male					*Female*					*Male and female pooled*				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	58.0	1.65	.58	54.5	59.7	60.0	2.76	.69	55.9	65.3	59.4	2.59	.53	54.5	65.3
2	60.0	1.43	.36	57.2	62.4	61.5	2.09	.52	58.7	66.1	60.8	1.92	.34	57.2	66.1
3	60.1	2.01	.50	55.7	64.0	61.6	2.45	.61	57.7	66.8	60.9	2.34	.41	55.7	66.8
4	60.4	2.08	.52	55.5	65.0	62.5	1.74	.44	59.9	65.4	61.5	2.18	.39	55.5	65.4
5	60.9	1.67	.42	57.5	64.0	62.7	1.53	.38	60.2	64.6	61.8	1.82	.32	57.5	64.6
6	61.5	1.89	.47	57.8	64.7	62.1	1.92	.48	58.1	65.9	61.8	1.90	.34	57.8	65.9
7	61.4	1.87	.47	57.3	63.9	62.3	1.88	.47	58.8	65.8	61.8	1.89	.33	57.3	65.8
8	62.0	1.61	.40	59.1	64.7	62.4	1.63	.41	60.1	65.7	62.2	1.61	.28	59.1	65.7
9	62.2	1.74	.44	59.7	64.9	62.6	1.29	.32	60.7	65.5	62.4	1.51	.27	59.7	65.5
10	62.4	1.58	.39	60.0	64.9	63.3	1.73	.43	60.0	66.5	62.8	1.69	.30	60.0	66.5
11	62.5	1.70	.42	59.9	65.4	63.3	1.93	.48	60.6	66.8	62.9	1.83	.32	59.9	66.8
12	62.7	2.00	.50	59.7	66.1	63.8	1.77	.44	59.8	66.7	63.3	1.94	.34	59.7	66.7
13	63.3	2.10	.52	60.5	66.7	64.9	2.14	.54	61.6	67.7	64.1	2.22	.39	60.5	67.7
14	63.5	1.96	.49	61.0	67.2	65.3	1.99	.50	62.4	68.4	64.4	2.15	.38	61.0	68.4
15	64.4	2.04	.51	61.7	68.7	65.1	1.68	.42	60.7	67.6	64.8	1.88	.33	60.7	68.7
16	64.4	2.18	.54	61.5	67.8	65.5	1.45	.36	63.0	67.9	64.9	1.90	.34	61.5	67.9
17	65.1	2.01	.50	62.2	68.7	65.8	1.51	.38	63.1	67.9	65.5	1.78	.31	62.2	68.7
18	65.1	2.01	.50	61.8	67.8	65.2	2.01	.50	60.3	68.7	65.2	1.98	.35	60.3	68.7

Angular measurement No. 4. (Or-Po)-(Go-Gn)/(108-1)-(144-139)

	Male					*Female*					*Male and female pooled*				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	30.3	4.33	1.53	24.8	36.6	27.2	3.72	.93	20.2	33.8	28.3	4.13	.84	20.2	36.6
2	26.3	4.49	1.22	21.3	35.9	24.2	4.27	1.07	17.1	31.8	25.3	4.44	.78	17.1	35.9
3	25.7	3.94	.99	19.4	32.5	25.9	3.40	.85	21.7	32.4	25.8	3.62	.64	19.4	32.5
4	26.4	4.52	1.13	21.1	37.1	24.0	4.01	1.00	17.0	31.7	25.2	4.37	.77	17.0	37.1
5	25.7	2.67	.67	22.7	32.6	24.5	3.79	.95	18.5	29.9	25.1	3.29	.58	18.5	32.6
6	26.3	2.97	.74	22.5	31.4	27.0	3.19	.80	19.5	32.1	26.7	3.04	.54	19.5	32.1
7	24.9	3.12	.78	20.2	31.3	26.1	3.44	.86	19.6	30.2	25.5	3.29	.58	19.6	31.3
8	25.1	2.83	.71	21.3	29.8	27.3	3.29	.82	20.0	31.6	26.2	3.22	.57	20.0	31.6
9	25.4	3.59	.90	20.8	34.0	25.6	3.04	.76	21.7	32.9	25.5	3.28	.58	20.8	34.0
10	24.9	3.30	.82	20.2	31.3	26.4	4.47	1.12	16.9	33.6	25.7	3.93	.70	16.9	33.6
11	24.7	2.59	.65	20.5	29.6	26.5	4.39	1.10	18.3	34.5	25.6	3.65	.65	18.3	34.5
12	25.1	3.58	.89	19.3	29.6	25.3	3.00	.75	21.6	32.0	25.2	3.25	.57	19.3	32.0
13	24.8	4.13	1.03	18.0	32.0	24.3	4.13	1.03	19.4	31.0	24.6	4.07	.72	18.0	32.0
14	24.9	3.71	.93	17.6	31.0	23.4	4.03	1.01	17.3	30.8	24.2	3.88	.69	17.3	31.0
15	24.4	4.47	1.12	17.5	31.3	24.4	3.31	.83	19.7	30.7	24.4	3.87	.68	17.5	31.3
16	23.4	4.64	1.16	16.7	30.9	23.7	3.45	.86	19.1	30.7	23.5	4.02	.71	16.7	30.9
17	23.6	4.47	1.12	15.3	32.1	23.6	4.57	1.14	17.4	32.0	23.6	4.45	.79	15.3	32.1
18	23.8	4.51	1.13	16.2	32.3	23.9	3.16	.79	18.4	29.4	23.9	3.83	.68	16.2	32.3

Angular measurement No. 5. (Or-Po)-(S-Gn)/(108-1)-(95-139)

	Male					*Female*					*Male and female pooled*				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	60.6	3.43	1.21	56.3	65.1	59.0	3.08	.77	53.7	63.9	59.5	3.22	.66	53.7	65.1
2	58.2	3.42	.86	52.9	64.9	57.4	4.31	1.08	49.2	63.7	57.8	3.85	.68	49.2	64.9
3	57.8	2.55	.64	53.0	62.3	57.9	2.15	.54	55.0	62.8	57.8	2.32	.41	53.0	62.8
4	58.9	3.55	.89	54.1	66.8	56.8	2.37	.59	52.8	61.0	57.9	3.16	.56	52.8	66.8
5	58.8	2.59	.65	54.4	63.9	57.5	3.08	.77	52.6	63.3	58.2	2.88	.51	52.6	63.9
6	59.7	2.81	.70	55.3	64.5	59.9	3.31	.83	54.7	68.0	59.8	3.02	.53	54.7	68.0
7	58.8	2.70	.67	55.1	64.1	59.9	3.33	.83	54.7	65.4	59.4	3.03	.54	54.7	65.4
8	59.3	2.22	.55	55.6	63.1	61.1	2.92	.73	55.9	66.2	60.2	2.71	.48	55.6	66.2
9	59.4	3.03	.76	55.0	67.4	59.7	2.18	.54	56.0	64.0	59.6	2.60	.46	55.0	67.4
10	59.3	2.66	.66	55.6	65.1	60.6	3.63	.91	53.7	67.3	60.0	3.21	.57	53.7	67.3
11	58.9	2.30	.58	55.5	65.9	61.1	3.37	.84	55.5	68.4	60.0	3.06	.54	55.5	68.4
12	59.7	2.85	.71	55.1	65.3	60.1	2.97	.74	56.1	66.6	59.9	2.87	.51	55.1	66.6
13	59.7	3.24	.81	55.5	66.1	59.3	2.56	.64	56.4	65.0	59.5	2.88	.51	55.5	66.1
14	60.1	2.43	.61	54.0	64.2	59.5	2.84	.71	54.8	65.0	59.8	2.62	.46	54.0	65.0
15	60.1	3.15	.79	55.6	65.7	59.9	2.56	.64	55.4	65.0	60.0	2.83	.50	55.4	65.7
16	59.7	3.21	.80	54.9	66.2	59.3	2.16	.54	56.2	64.0	59.5	2.70	.48	54.9	66.2
17	60.0	3.79	.95	53.4	67.1	59.5	3.34	.84	54.0	65.2	59.8	3.52	.62	53.4	67.1
18	60.5	3.19	.80	55.1	65.0	60.0	2.94	.74	54.4	65.4	60.2	3.03	.54	54.4	65.4

Angular measurement No. 6. (Or-Po)-(Occl pl)/(108-1)-(170-162/174-166)

	Male					*Female*					*Male and female pooled*				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	15.0	3.90	1.38	8.8	19.0	12.7	4.67	1.17	2.1	22.7	13.5	4.47	.91	2.0	22.7
2	15.2	2.91	.73	10.8	20.5	12.2	4.96	1.24	5.0	22.1	13.7	4.28	.76	5.0	22.1
3	12.5	3.02	.75	5.6	16.6	11.9	2.43	.61	7.6	15.2	12.2	2.71	.48	5.6	16.6
4	13.7	3.57	.89	7.4	20.2	9.7	4.06	1.01	1.7	17.5	11.7	4.27	.75	1.7	20.2
5	13.4	3.03	.76	9.4	19.5	10.4	3.61	.90	5.0	16.1	11.4	3.20	.57	5.0	16.4
6	11.6	3.47	.87	6.0	19.8	16.7	2.97	.74	10.4	23.0	15.7	3.47	.61	8.3	23.0
7	12.4	2.81	.70	7.4	16.9	13.1	4.41	1.10	5.6	20.5	12.8	3.75	.66	5.6	20.5
8	10.2	3.38	.85	1.6	16.0	13.1	3.27	.82	7.3	18.3	11.7	3.59	.63	1.6	18.3
9	11.0	3.33	.83	4.9	18.5	11.2	3.21	.80	5.6	20.0	11.1	3.22	.57	4.9	20.0
10	10.3	2.27	.57	6.4	14.8	11.6	3.92	.98	5.1	16.9	11.0	3.21	.57	5.1	16.9
11	9.4	2.35	.59	4.9	14.7	11.7	4.17	1.04	6.1	20.8	10.5	3.53	.62	4.8	20.8
12	9.5	2.20	.55	4.8	12.3	10.1	3.86	.97	5.0	18.4	9.8	3.11	.55	4.8	18.4
13	8.9	3.46	.87	1.3	14.0	9.3	4.19	1.05	1.8	16.3	9.1	3.79	.67	1.3	16.3
14	8.6	3.25	.81	3.8	13.6	8.1	3.77	.94	1.5	12.5	8.3	3.47	.61	1.5	13.6
15	8.0	3.23	.81	1.7	14.5	8.5	3.46	.86	1.8	15.5	8.2	3.30	.58	1.7	15.5
16	7.1	3.69	.92	1.8	13.0	7.9	2.65	.66	3.4	12.7	7.3	3.19	.56	1.8	13.0
17	7.0	3.90	.97	1.1	12.6	7.5	3.81	.95	−2.0	13.3	7.2	3.80	.67	−2.0	13.3
18	7.4	2.65	.66	1.1	12.6	8.5	3.27	.82	− .1	14.7	8.0	2.98	.53	− .1	14.7

Angular measurement No. 7. $\underline{1}$-$\overline{1}$/(164-162)-(166-168)

	Male					*Female*					*Male and female pooled*				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	141.6	12.49	4.42	128.8	165.5	147.9	10.75	2.69	134.5	170.2	145.8	11.49	2.35	128.8	170.2
2	147.6	5.97	1.49	136.5	159.3	148.2	7.34	1.84	133.7	163.1	147.9	6.59	1.16	133.7	163.1
3	148.8	7.83	1.96	132.0	161.3	149.4	8.57	2.14	135.3	167.0	149.1	8.08	1.43	132.0	167.0
4	152.7	7.13	1.78	136.9	160.1	151.8	7.67	1.92	138.1	165.0	152.2	7.30	1.29	136.9	165.0
5	151.7	9.28	2.32	135.3	169.6	150.6	9.22	2.30	133.9	177.5	151.2	9.12	1.61	133.9	177.5
6	148.7	9.85	2.46	126.9	163.5	150.6	9.68	2.42	135.2	167.1	149.6	9.66	1.71	126.9	167.1
7	143.6	15.04	3.76	120.4	165.5	141.1	14.42	3.60	119.7	165.3	142.4	14.54	2.57	119.7	165.5
8	133.3	7.20	1.80	120.5	144.1	133.6	7.03	1.76	123.0	151.0	133.4	7.00	1.24	120.5	151.0
9	134.1	6.67	1.67	122.8	147.8	135.5	8.27	2.07	123.0	152.0	134.8	7.42	1.31	122.8	152.0
10	134.3	6.93	1.73	121.0	144.0	134.6	9.04	2.26	124.2	153.0	134.4	7.93	1.40	121.0	153.0
11	133.4	6.51	1.63	120.8	144.2	135.1	8.98	2.24	124.0	158.1	134.2	7.76	1.37	120.8	158.1
12	135.4	6.63	1.66	124.0	149.4	135.2	3.48	.87	129.1	142.7	135.3	5.21	.92	124.0	149.4
13	134.2	8.58	2.14	117.1	145.4	135.0	9.25	2.31	121.0	163.2	134.6	8.79	1.55	117.1	163.2
14	135.3	7.60	1.90	119.4	143.2	136.1	8.55	2.14	124.3	160.3	135.7	7.97	1.41	119.4	160.3
15	135.0	7.58	1.89	121.3	148.3	136.0	4.16	1.04	130.0	144.2	135.5	6.03	1.07	121.3	148.3
16	136.3	7.85	1.96	120.2	146.0	138.3	8.60	2.15	124.6	159.4	137.3	8.16	1.44	120.2	159.4
17	138.0	8.41	2.10	119.4	148.3	138.5	7.31	1.83	127.1	154.2	138.2	7.76	1.37	119.4	154.2
18	141.3	8.15	2.04	124.1	151.4	139.8	8.38	2.09	127.2	164.0	140.6	8.16	1.44	124.1	164.0

Angular measurement No. 8. (Na-Bo)-(Po-Or)/(58-14)-(1-108)

	Male					*Female*					*Male and female pooled*				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	22.9	2.00	.71	19.8	25.2	22.4	3.47	.87	17.2	28.7	22.6	3.02	.62	17.2	28.7
2	22.4	2.63	.66	17.5	25.7	22.6	3.69	.92	17.2	32.3	22.5	3.15	.56	17.2	32.3
3	23.7	2.52	.63	20.7	28.4	23.2	2.69	.67	18.5	27.6	23.4	2.58	.46	18.5	28.4
4	22.6	3.25	.81	15.9	26.9	23.0	2.52	.63	19.5	28.5	22.8	2.87	.51	15.9	28.5
5	23.0	1.81	.45	19.0	26.1	22.9	2.19	.55	19.9	27.6	23.0	1.98	.35	19.0	27.6
6	22.2	2.16	.54	18.4	25.8	22.2	3.17	.79	16.1	27.6	22.2	2.67	.47	16.1	27.6
7	23.5	2.10	.53	20.2	28.8	22.5	1.99	.50	19.3	26.2	23.0	2.07	.37	19.3	28.8
8	23.1	2.06	.51	20.0	27.5	21.5	2.49	.62	18.6	26.7	22.3	2.40	.42	18.6	27.5
9	23.2	2.38	.59	16.5	26.3	23.3	1.73	.43	20.2	26.1	23.2	2.05	.36	16.5	26.3
10	23.2	1.99	.50	19.0	26.2	21.9	2.40	.60	16.2	26.0	22.6	2.27	.40	16.2	26.2
11	24.0	1.87	.47	20.4	27.6	21.8	2.19	.55	17.9	25.4	22.9	2.29	.40	17.9	27.6
12	23.2	1.97	.49	20.2	28.2	22.6	2.30	.58	17.9	26.1	22.9	2.13	.38	17.9	28.2
13	23.2	1.98	.49	19.4	27.2	22.6	2.02	.51	18.9	26.2	22.9	1.99	.35	18.9	27.2
14	23.1	2.52	.63	19.6	27.1	22.4	2.03	.51	17.6	26.3	22.8	2.28	.40	17.6	27.1
15	22.9	3.05	.76	17.4	28.1	22.4	1.95	.49	18.2	25.6	22.7	2.54	.45	17.4	28.1
16	23.4	2.27	.57	20.1	28.0	22.8	2.10	.52	17.3	25.2	23.1	2.17	.38	17.3	28.0
17	22.4	2.48	.62	18.1	27.6	22.5	3.09	.77	17.0	28.0	22.4	2.76	.49	17.0	28.0
18	22.5	2.07	.52	18.9	27.3	22.7	2.21	.55	17.5	25.4	22.6	2.11	.37	17.5	27.3

Angular measurement No. 9. (Occl pl)-(Go-Gn)/(162-170/166-174)-(144-139)

	Male					*Female*					*Male and female pooled*				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	15.4	3.56	1.26	9.4	20.4	14.5	3.37	.84	8.0	19.4	14.8	3.38	.69	8.0	20.4
2	11.1	2.75	.69	6.7	15.8	12.1	2.02	.51	7.6	15.5	11.6	2.42	.43	6.7	15.8
3	13.2	2.70	.67	9.8	17.4	14.0	1.81	.45	11.4	17.7	13.6	2.29	.41	9.8	17.7
4	12.7	2.66	.67	8.7	17.3	14.3	2.39	.60	11.3	19.6	13.5	2.62	.46	8.7	19.6
5	13.4	3.03	.76	9.4	19.5	14.0	1.72	.43	11.2	17.5	13.7	2.44	.43	9.4	19.5
6	11.6	3.47	.87	6.0	19.8	10.2	2.74	.69	4.6	15.2	10.9	3.16	.56	4.6	19.8
7	12.4	2.81	.70	7.4	16.9	12.9	4.39	1.10	1.1	19.6	12.7	3.64	.64	1.1	19.6
8	14.9	2.86	.71	9.7	20.2	14.2	2.22	.55	10.2	17.7	14.5	2.54	.45	9.7	20.2
9	14.4	2.75	.69	10.0	20.4	14.4	2.35	.59	11.2	19.5	14.4	2.52	.44	10.0	20.4
10	14.6	3.00	.74	9.9	19.8	14.8	2.57	.64	9.0	19.6	14.7	2.73	.48	9.0	19.8
11	15.3	2.94	.74	10.3	19.7	14.8	2.80	.70	10.3	19.5	15.1	2.84	.50	10.3	19.7
12	15.6	3.01	.75	11.1	21.8	15.2	2.33	.58	11.4	19.4	15.4	2.66	.47	11.1	21.8
13	15.9	3.11	.78	11.0	21.0	15.0	3.22	.80	9.3	19.1	15.5	3.15	.56	9.3	21.0
14	16.3	3.05	.76	10.5	22.2	15.3	2.78	.69	11.2	19.1	15.8	2.91	.51	10.5	22.2
15	16.5	3.13	.78	11.1	22.0	15.9	2.45	.61	10.5	20.2	16.2	2.78	.49	10.5	22.0
16	16.3	3.58	.89	9.8	21.8	15.7	2.69	.67	10.7	19.7	16.0	3.13	.55	9.8	21.8
17	16.7	3.25	.81	11.1	20.9	16.1	2.74	.68	12.6	21.0	16.4	2.97	.52	11.1	21.0
18	16.4	3.90	.97	9.0	23.0	15.4	2.64	.66	11.6	20.0	15.9	3.31	.58	9.0	23.0

Angular measurement No. 10. (Na-S)-(Occl pl)/(58-95)-(170-162/174-166)

	Male					*Female*					*Male and female pooled*				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	21.9	3.06	1.08	16.1	26.7	19.0	2.35	.59	14.3	23.4	20.0	2.88	.59	14.3	26.7
2	21.3	3.13	.78	13.8	25.3	17.7	2.86	.72	12.3	23.1	19.5	3.47	.61	12.3	25.3
3	19.8	3.36	.84	11.7	24.5	17.8	2.78	.70	12.9	22.2	18.8	3.20	.57	11.7	24.5
4	20.8	3.42	.86	11.1	25.0	16.9	3.02	.76	10.0	22.2	18.9	3.73	.66	10.0	25.0
5	19.6	3.67	.92	14.6	27.5	17.1	2.05	.51	14.1	20.9	18.3	3.19	.56	14.1	27.5
6	20.7	3.21	.80	15.4	26.0	22.1	3.69	.92	15.0	29.6	21.4	3.47	.61	15.0	29.6
7	20.2	3.62	.91	16.1	25.8	18.2	4.85	1.21	8.9	27.2	19.2	4.32	.76	8.9	27.2
8	17.0	3.99	1.00	8.1	23.6	17.1	3.14	.78	9.8	22.6	17.0	3.53	.62	8.1	23.6
9	17.5	3.42	.86	10.8	23.0	16.8	2.99	.75	10.4	23.0	17.2	3.18	.56	10.4	23.0
10	16.8	3.71	.93	10.8	23.1	15.6	3.08	.77	10.3	22.7	16.2	3.40	.60	10.3	23.1
11	16.6	3.63	.91	10.3	22.7	15.3	3.57	.89	9.7	22.7	15.9	3.60	.64	9.7	22.7
12	16.0	3.92	1.00	8.2	20.8	15.5	2.93	.73	10.8	22.1	15.8	3.41	.60	8.2	22.1
13	15.2	3.85	.96	7.5	21.4	14.3	3.42	.85	7.9	20.4	14.8	3.61	.64	7.5	21.4
14	14.6	3.96	.99	6.5	21.6	12.6	2.64	.66	6.9	16.5	13.6	3.46	.61	6.5	21.6
15	13.8	4.06	1.01	5.3	22.2	13.6	3.10	.77	8.1	19.9	13.7	3.55	.63	5.3	22.2
16	13.6	4.34	1.08	4.8	21.3	13.1	2.59	.65	9.1	19.2	13.4	3.52	.62	4.8	21.3
17	12.3	3.94	.98	4.4	20.5	12.4	3.24	.81	5.9	18.2	12.3	3.55	.63	4.4	20.5
18	12.2	3.92	.98	4.1	18.8	13.5	2.52	.63	7.3	17.0	12.9	3.31	.58	4.1	18.8

Angular measurement No. 11. (Na-S)-(Go-Gn)/(58-95)-(144-139)

	Male					*Female*					*Male and female pooled*				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	37.2	4.08	1.44	31.0	43.9	33.5	4.26	1.06	23.9	41.0	34.7	4.49	.92	23.9	43.9
2	32.4	4.14	1.04	24.1	38.7	29.8	2.39	.60	26.3	33.9	31.1	3.59	.63	24.1	38.7
3	33.1	4.58	1.15	25.5	41.1	31.9	3.76	.94	25.0	39.8	32.5	4.17	.74	25.0	41.1
4	33.5	4.43	1.11	22.7	42.3	31.3	2.94	.74	25.9	36.4	32.4	3.87	.68	22.7	42.3
5	33.0	3.20	.80	27.5	41.2	31.1	2.34	.58	28.0	36.6	32.0	2.92	.52	27.5	41.2
6	32.4	3.29	.82	27.5	41.5	32.3	3.43	.86	26.4	38.3	32.4	3.30	.58	26.4	41.5
7	32.6	3.18	.80	27.3	40.1	31.2	2.99	.75	26.2	36.7	31.9	3.12	.55	26.2	40.1
8	31.8	3.17	.79	26.9	38.7	31.3	2.77	.69	26.7	36.5	31.6	2.94	.52	26.7	38.7
9	31.9	3.27	.82	25.8	37.7	31.2	2.59	.65	27.5	35.9	31.6	2.93	.52	25.8	37.7
10	31.4	3.31	.83	25.0	36.7	30.5	3.11	.78	25.1	36.0	31.0	3.19	.56	25.0	36.7
11	31.9	3.13	.78	26.1	37.5	30.1	3.23	.81	24.7	35.8	31.0	3.26	.58	24.7	37.5
12	31.7	3.54	.88	24.4	38.6	30.7	2.85	.71	26.7	35.7	31.2	3.20	.56	24.4	38.6
13	31.2	3.24	.81	24.2	36.4	29.3	3.10	.77	23.8	34.7	30.2	3.25	.58	23.8	36.4
14	30.9	3.61	.90	21.9	36.6	27.9	3.10	.77	22.6	33.1	29.4	3.63	.64	21.9	36.6
15	30.2	3.92	.98	21.1	38.1	29.5	2.60	.65	26.5	35.2	29.8	3.29	.58	21.1	38.1
16	29.9	4.04	1.01	21.0	38.3	28.9	2.78	.70	24.7	34.9	29.4	3.45	.61	21.0	38.3
17	28.9	3.42	.85	21.0	34.2	28.6	2.96	.74	24.0	33.8	28.8	3.15	.56	21.0	34.2
18	28.6	4.39	1.10	18.4	33.8	28.9	2.65	.66	24.1	34.2	28.8	3.57	.63	18.4	34.2

Angular measurement No. 12. Na-S-Ar/58-95-12

	Male					*Female*					*Male and female pooled*				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	118.0	7.04	2.49	109.9	127.3	116.9	7.42	1.86	101.2	129.0	117.3	7.16	1.46	101.2	129.0
2	117.8	4.60	1.15	108.4	125.6	118.5	4.61	1.15	111.0	126.4	118.2	4.55	.80	108.4	126.4
3	118.7	5.25	1.31	110.4	127.6	115.9	5.81	1.45	106.3	127.8	117.3	5.62	.99	106.3	127.8
4	121.6	5.03	1.26	111.5	130.2	119.5	5.10	1.27	111.9	128.2	120.6	5.10	.90	111.5	130.2
5	120.9	4.61	1.15	113.2	127.5	120.0	5.33	1.33	111.5	127.8	120.4	4.93	.87	111.5	127.8
6	119.8	4.84	1.21	111.4	128.9	118.8	4.55	1.14	110.4	126.9	119.3	4.66	.82	110.4	128.9
7	121.9	4.91	1.23	112.7	129.1	119.2	3.63	.91	113.7	125.4	120.6	4.46	.79	112.7	129.1
8	120.9	4.72	1.18	113.2	127.5	119.2	3.58	.90	113.9	125.4	120.0	4.20	.74	113.2	127.5
9	121.1	4.57	1.14	112.8	126.5	120.7	3.91	.98	114.1	127.3	120.9	4.19	.74	112.8	127.3
10	121.0	4.61	1.15	113.8	127.2	119.8	3.91	.98	113.8	127.2	120.4	4.26	.75	113.8	127.2
11	122.3	3.83	.96	114.9	128.8	120.4	3.03	.76	115.7	126.8	121.3	3.53	.62	114.9	128.8
12	122.5	3.76	.94	115.8	126.9	121.6	3.10	.77	116.2	129.3	122.0	3.41	.60	115.8	129.3
13	122.4	3.47	.87	116.2	128.1	121.2	2.92	.73	117.2	126.6	121.8	3.22	.57	116.2	128.1
14	121.6	4.13	1.03	114.8	127.8	121.9	3.88	.97	116.4	130.6	121.8	3.95	.70	114.8	130.6
15	122.6	4.37	1.09	112.9	129.2	121.4	3.52	.88	116.6	129.1	122.0	3.95	.70	112.9	129.2
16	123.4	4.02	1.01	116.3	129.8	121.1	4.20	1.05	113.5	128.4	122.2	4.21	.74	113.5	129.8
17	122.2	3.71	.93	113.8	127.1	121.7	5.01	1.25	114.1	130.4	121.9	4.34	.77	113.8	130.4
18	122.0	5.04	1.26	112.9	129.2	120.8	3.58	.89	115.0	128.7	121.4	4.35	.77	112.9	129.2

Angular measurement No. 13. Ar-Go-Gn/12-144-139

	Male					Female					Male and female pooled				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	134.7	4.87	1.72	128.8	143.6	132.4	3.03	.76	126.8	136.9	133.2	3.79	.77	126.8	143.6
2	134.0	3.90	.98	128.8	142.9	131.2	3.14	.78	124.2	137.6	132.6	3.76	.66	124.2	142.9
3	133.0	4.18	1.05	126.6	140.3	131.2	4.78	1.19	123.0	139.3	132.1	4.52	.80	123.0	140.3
4	132.4	4.27	1.07	127.1	142.0	130.6	3.75	.94	124.1	136.9	131.5	4.05	.72	124.1	142.0
5	130.5	3.57	.89	126.7	139.1	130.2	5.03	1.26	121.3	137.4	130.3	4.29	.76	121.3	139.1
6	130.2	3.58	.89	123.4	136.7	128.9	4.04	1.01	121.6	136.8	129.6	3.81	.67	121.6	136.8
7	128.7	2.88	.72	124.9	132.9	127.5	3.65	.91	121.7	134.7	128.1	3.29	.58	121.7	134.7
8	128.5	4.24	1.06	122.7	136.9	127.1	4.11	1.03	120.9	135.0	127.8	4.17	.74	120.9	136.9
9	128.8	4.24	1.06	121.5	137.4	127.9	4.31	1.08	120.6	133.9	128.4	4.23	.75	120.6	137.4
10	127.8	4.64	1.16	120.5	136.0	126.6	3.71	.93	119.4	133.0	127.2	4.18	.74	119.4	136.0
11	128.2	4.80	1.20	119.2	136.9	126.5	3.42	.85	120.7	133.2	127.4	4.18	.74	119.2	136.9
12	128.1	4.88	1.22	119.0	137.2	127.2	3.97	.99	120.5	135.3	127.6	4.40	.78	119.0	137.2
13	127.2	5.10	1.27	119.1	136.9	125.6	3.60	.90	120.0	131.7	126.4	4.42	.78	119.1	136.9
14	126.8	4.95	1.24	117.7	136.3	124.4	3.82	.95	119.2	132.5	125.6	4.51	.80	117.7	136.6
15	126.8	5.08	1.27	116.0	136.7	125.5	4.02	1.01	118.6	132.6	126.1	4.55	.80	116.0	136.7
16	125.2	4.72	1.18	116.1	135.9	125.1	3.73	.93	119.5	132.2	125.2	4.18	.74	116.1	135.9
17	125.0	4.86	1.21	115.7	135.6	125.1	3.89	.97	118.9	133.0	125.1	4.33	.77	115.7	135.6
18	124.9	4.34	1.09	118.4	136.8	124.8	3.87	.97	118.4	133.0	124.8	4.05	.72	118.4	136.8

Angular measurement No. 14. (PNS-ANS)-$\underline{1}$/(127-132)-(164-162)

	Male					Female					Male and female pooled				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	96.0	8.50	3.00	83.8	106.9	93.9	6.59	1.65	84.2	104.2	94.6	7.17	1.46	83.8	106.9
2	98.5	5.08	1.27	89.0	106.1	99.6	4.52	1.13	91.9	108.0	99.0	4.77	.84	89.0	108.0
3	96.8	5.00	1.25	89.3	104.8	96.8	5.33	1.33	83.4	104.2	96.8	5.08	.90	83.4	104.8
4	95.7	4.99	1.25	87.8	102.8	97.1	4.82	1.21	87.7	104.8	96.4	4.88	.86	87.7	104.8
5	97.8	5.31	1.33	88.7	105.8	97.0	5.56	1.39	87.8	112.5	97.4	5.36	.95	87.8	112.5
6	99.0	7.09	1.77	84.8	114.9	96.6	6.93	1.73	89.4	113.2	97.8	7.00	1.24	84.8	114.9
7	102.9	10.47	2.62	83.5	121.8	106.1	10.02	2.51	90.0	120.3	104.5	10.22	1.81	83.5	121.8
8	110.8	5.21	1.30	104.9	121.3	110.2	4.77	1.19	101.7	118.0	110.5	4.92	.87	101.7	121.3
9	110.3	5.06	1.27	97.5	118.2	110.0	4.89	1.22	101.9	121.4	110.2	4.90	.87	97.5	121.4
10	109.8	5.50	1.37	97.3	116.8	110.3	4.75	1.19	102.2	120.2	110.1	5.06	.89	97.3	120.2
11	109.4	5.57	1.39	97.1	119.3	110.3	4.12	1.03	103.2	117.1	109.8	4.84	.86	97.1	119.3
12	109.0	6.18	1.54	90.8	117.2	110.1	3.02	.76	106.4	117.1	109.6	4.81	.85	90.8	117.2
13	109.8	7.04	1.76	91.3	122.4	109.9	5.46	1.36	98.5	116.3	109.8	6.20	1.10	91.3	122.4
14	109.4	6.73	1.68	94.2	119.2	109.8	4.92	1.23	99.3	116.4	109.6	5.80	1.03	94.2	119.2
15	110.9	5.97	1.49	98.6	122.0	111.7	3.69	.92	104.7	117.1	111.3	4.90	.87	98.6	122.0
16	109.9	6.14	1.53	96.7	117.6	108.5	5.24	1.31	99.2	115.7	109.2	5.65	1.00	96.7	117.6
17	109.4	6.91	1.73	96.8	122.9	109.0	5.68	1.42	100.6	116.8	109.2	6.23	1.10	96.8	122.9
18	108.2	5.84	1.46	96.4	118.1	108.4	4.72	1.18	98.5	116.6	108.3	5.22	.92	96.4	118.1

Angular measurement No. 15. (S-Na)-$\underline{1}$/(95-58)-(164-162)

	Male					Female					Male and female pooled				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	89.2	9.86	3.49	75.5	102.4	89.3	6.95	1.74	80.9	102.4	89.2	7.82	1.60	75.5	102.4
2	91.3	5.68	1.42	80.0	100.9	95.6	3.52	.88	88.7	101.1	93.4	5.14	.91	80.0	101.1
3	90.4	4.50	1.12	83.5	98.5	92.6	5.04	1.26	82.1	99.9	91.5	4.83	.85	82.1	99.9
4	88.0	4.51	1.13	79.5	94.6	91.9	3.87	.97	83.0	98.1	90.0	4.57	.81	79.5	98.1
5	89.9	5.43	1.36	80.6	101.2	91.7	5.20	1.30	83.6	104.6	90.8	5.31	.94	80.6	104.6
6	92.0	6.83	1.71	77.4	102.2	90.1	6.75	1.69	81.0	105.2	91.1	6.75	1.19	77.4	105.2
7	95.2	10.49	2.62	76.6	111.6	99.5	10.09	2.52	83.8	114.3	97.4	10.36	1.83	76.6	114.3
8	103.5	4.90	1.22	96.1	114.5	103.5	4.21	1.05	96.3	111.5	103.5	4.49	.79	96.1	114.5
9	102.3	5.62	1.41	89.1	109.9	103.0	4.15	1.04	97.3	113.7	102.6	4.88	.86	89.1	113.7
10	101.9	6.03	1.51	89.1	110.8	103.8	4.17	1.04	97.7	112.5	102.8	5.20	.92	89.1	112.5
11	101.6	5.99	1.50	88.7	109.6	103.2	4.39	1.10	96.0	111.7	102.4	5.23	.92	88.7	111.7
12	100.9	7.35	1.84	82.4	108.2	102.6	2.59	.65	99.4	108.1	101.8	5.50	.97	82.4	108.2
13	101.6	7.32	1.83	83.4	111.5	103.0	5.53	1.38	93.5	111.5	102.3	6.42	1.13	83.4	111.5
14	101.3	6.61	1.65	87.0	109.5	103.5	4.73	1.18	96.4	110.9	102.4	5.76	1.02	87.0	110.9
15	102.6	5.54	1.39	89.4	110.2	104.0	3.44	.86	97.7	110.2	103.3	4.60	.81	89.4	110.2
16	101.1	7.16	1.79	85.0	112.2	101.8	5.27	1.32	92.1	110.4	101.4	6.19	1.09	85.0	112.2
17	101.5	7.04	1.76	86.2	115.2	102.1	5.75	1.44	90.4	111.1	101.8	6.33	1.12	86.2	115.2
18	99.6	6.58	1.64	85.7	109.0	100.7	4.76	1.19	91.8	107.7	100.2	5.68	1.00	85.7	109.0

Angular measurement No. 16. (ANS-PNS)-(Go-Gn)/(132-127)-(144-139)

	Male					Female					Male and female pooled				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	30.4	3.89	1.38	26.4	39.1	28.9	4.87	1.22	20.7	37.0	29.4	4.54	.93	20.7	39.1
2	25.2	3.52	.88	19.4	33.7	25.7	2.92	.73	21.3	29.9	25.4	3.20	.57	19.4	33.7
3	26.6	3.94	.98	20.5	33.8	27.6	3.79	.95	22.1	34.5	27.1	3.83	.68	20.5	34.5
4	25.8	3.42	.85	20.4	32.4	26.0	2.98	.75	21.0	30.3	25.9	3.16	.56	20.4	32.4
5	25.1	3.50	.87	18.1	30.8	25.8	3.00	.75	21.9	30.6	25.4	3.22	.57	18.1	30.8
6	25.3	3.08	.77	19.1	29.9	25.8	3.23	.81	20.6	32.3	25.6	3.11	.55	19.1	32.3
7	24.8	2.96	.74	20.6	29.7	24.6	3.02	.75	20.1	31.3	24.7	2.95	.52	20.1	31.3
8	24.5	3.26	.81	18.5	30.2	24.6	3.34	.83	19.2	31.2	24.5	3.25	.57	18.5	31.2
9	23.9	3.60	.90	16.3	30.3	24.2	2.31	.58	19.7	28.1	24.0	2.98	.53	16.3	30.3
10	23.5	4.00	1.00	15.9	31.7	24.0	3.01	.75	18.3	30.1	23.8	3.49	.62	15.9	31.7
11	24.1	3.43	.86	18.9	28.9	23.0	3.24	.81	18.0	29.6	23.6	3.32	.59	18.0	29.6
12	23.4	3.48	.87	17.5	28.9	23.2	2.65	.66	17.6	27.1	23.3	3.05	.54	17.5	28.9
13	23.0	3.61	.90	16.7	29.0	22.4	3.42	.86	17.2	28.9	22.7	3.47	.61	16.7	29.0
14	22.7	4.08	1.02	16.9	29.2	21.6	3.64	.91	16.4	28.8	22.2	3.85	.68	16.4	29.2
15	21.9	4.21	1.05	15.8	29.7	21.8	2.97	.74	16.1	25.7	21.8	3.58	.63	15.8	29.7
16	21.1	3.69	.92	13.6	26.2	22.1	2.92	.73	15.9	27.5	21.6	3.31	.58	13.6	27.5
17	20.9	4.13	1.03	15.5	30.3	21.6	3.30	.82	15.6	28.0	21.2	3.69	.65	15.5	30.3
18	20.0	5.05	1.26	9.6	28.2	21.3	2.65	.66	16.4	25.8	20.6	4.02	.71	9.6	28.2

Angular measurement No. 17. (S-Na)-Ī/(95-58)-(166-168)

	Male					Female					Male and female pooled				
Age	M	SD	SE	Min	Max	M	SD	SE	Min	Max	M	SD	SE	Min	Max
1	50.8	5.71	2.02	44.4	61.0	57.2	6.65	1.66	48.2	74.7	55.1	6.95	1.42	44.4	74.7
2	58.9	4.78	1.20	50.6	64.9	63.8	5.07	1.27	53.8	71.8	61.4	5.44	.96	50.6	71.8
3	59.3	5.94	1.48	44.6	67.3	62.0	5.70	1.43	53.0	69.9	60.6	5.90	1.04	44.6	69.9
4	60.7	6.10	1.53	48.8	70.4	63.6	6.14	1.54	54.6	73.4	62.2	6.21	1.10	48.8	73.4
5	61.6	6.82	1.70	47.6	76.9	62.3	6.39	1.60	56.0	81.1	62.0	6.51	1.15	47.6	81.1
6	60.7	5.54	1.39	49.1	71.7	60.7	6.16	1.54	50.9	73.5	60.7	5.76	1.02	49.1	73.5
7	58.8	7.91	1.98	43.7	74.6	60.6	7.19	1.80	48.9	73.8	59.7	7.49	1.32	43.7	74.6
8	56.7	7.20	1.80	43.3	69.9	57.1	6.06	1.51	48.1	68.1	56.9	6.55	1.16	43.3	69.9
9	56.4	6.15	1.54	43.2	68.9	58.5	6.25	1.56	49.6	69.9	57.4	6.19	1.09	43.2	69.9
10	56.2	7.09	1.77	45.5	70.7	58.5	6.58	1.65	48.6	73.3	57.4	6.83	1.21	45.5	73.3
11	55.1	5.95	1.49	45.7	65.6	58.3	6.96	1.74	48.4	76.5	56.7	6.58	1.16	45.7	76.5
12	56.3	5.82	1.46	48.5	67.2	57.8	3.39	.85	52.3	65.2	57.0	4.75	.84	48.5	67.2
13	55.8	6.41	1.60	46.5	68.3	58.0	6.60	1.65	49.5	78.8	56.9	6.50	1.15	46.5	78.8
14	56.6	5.97	1.49	47.9	68.8	59.6	7.12	1.78	46.0	76.7	58.1	6.65	1.18	46.0	76.7
15	57.6	6.13	1.53	49.7	68.3	60.0	4.08	1.02	50.6	66.9	58.8	5.27	.93	49.7	68.3
16	57.5	5.59	1.40	50.8	70.9	60.1	5.89	1.47	51.0	75.5	58.8	5.80	1.03	50.8	75.5
17	59.4	6.04	1.51	51.1	71.8	60.7	4.80	1.20	52.9	72.4	60.0	5.40	.95	51.1	72.4
18	60.7	6.63	1.66	51.2	72.4	60.6	5.93	1.48	51.2	77.6	60.6	6.19	1.09	51.2	77.6

Angular measurement No. 18. (Go-Gn)-Ī/(144-139)-(168-166)

	Male					Female					Male and female pooled				
Age	M	SD	SE	Min	Max	M	SD	SE	Min	Max	M	SD	SE	Min	Max
1	92.0	5.34	1.89	81.9	99.5	89.3	4.84	1.21	79.7	94.8	90.2	5.06	1.03	79.7	99.5
2	88.7	4.64	1.16	81.0	97.2	86.5	5.01	1.25	78.4	94.1	87.6	4.88	.86	78.4	97.2
3	87.7	3.80	.95	80.8	94.4	86.1	5.46	1.37	76.8	98.4	86.9	4.70	.83	76.8	98.4
4	85.8	5.00	1.25	75.7	93.5	85.1	5.64	1.41	75.5	94.4	85.5	5.26	.93	75.5	94.4
5	85.4	5.56	1.39	74.2	92.1	86.6	5.70	1.42	70.9	94.9	86.0	5.57	.98	70.9	94.9
6	86.9	4.52	1.13	75.9	97.3	86.9	5.41	1.35	77.3	92.6	86.9	4.91	.87	75.9	97.3
7	88.7	6.61	1.65	76.1	99.7	88.2	6.02	1.50	76.4	99.5	88.5	6.22	1.10	76.1	99.7
8	91.5	5.91	1.48	78.3	100.6	91.6	4.16	1.04	84.9	98.0	91.5	5.02	.89	78.3	100.6
9	91.7	5.74	1.43	79.9	101.8	90.4	5.33	1.33	81.1	98.2	91.0	5.49	.97	79.9	101.8
10	92.4	6.49	1.62	78.7	102.4	91.1	5.12	1.28	79.9	98.2	91.7	5.80	1.02	78.7	102.4
11	93.0	5.60	1.40	85.7	106.4	91.6	5.42	1.36	78.1	100.2	92.3	5.47	.97	78.1	106.4
12	92.1	6.20	1.55	82.8	104.4	91.5	4.35	1.09	82.3	96.1	91.8	5.28	.93	82.3	104.4
13	93.1	6.03	1.51	82.7	104.2	92.7	5.66	1.42	77.4	99.9	92.9	5.76	1.02	77.4	104.2
14	92.6	5.91	1.48	85.1	102.1	92.4	5.43	1.36	80.0	102.7	92.5	5.58	.99	80.0	102.7
15	92.2	6.36	1.59	83.4	102.8	90.4	4.22	1.05	84.7	98.6	91.3	5.38	.95	83.4	102.8
16	92.6	5.50	1.37	84.3	100.3	91.0	4.79	1.20	79.8	100.6	91.8	5.14	.91	79.8	100.6
17	91.7	6.11	1.53	82.4	101.0	90.8	3.98	1.00	83.5	99.1	91.2	5.09	.90	82.4	101.0
18	90.7	6.32	1.58	81.5	102.1	90.5	5.36	1.34	78.4	100.9	90.6	5.77	1.02	78.4	102.1

Angular measurement No. 19. (Occl pl)-$\bar{1}$/(170-162/174-166)-(166-168)

			Male					*Female*					*Male and female pooled*		
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	72.6	5.50	1.94	66.6	83.8	76.2	6.02	1.50	69.8	90.6	75.0	5.98	1.22	66.6	90.6
2	80.2	4.57	1.14	72.1	88.5	81.4	5.27	1.32	72.9	89.1	80.8	4.90	.87	72.1	89.1
3	79.1	4.66	1.16	69.1	87.2	79.9	5.49	1.37	69.1	89.8	79.5	5.02	.89	69.1	89.8
4	81.5	5.06	1.26	72.6	90.1	80.6	6.60	1.65	70.9	92.5	81.0	5.80	1.03	70.9	92.5
5	81.2	6.44	1.61	69.8	94.6	79.4	6.35	1.59	72.0	96.0	80.3	6.36	1.12	69.8	96.0
6	81.5	6.60	1.65	67.7	90.9	82.8	6.51	1.63	75.5	96.5	82.1	6.48	1.15	67.7	96.5
7	78.9	7.92	1.98	65.5	90.9	78.8	9.02	2.25	63.4	95.5	78.9	8.35	1.48	63.4	95.5
8	73.6	4.89	1.22	63.9	81.5	74.2	4.91	1.27	66.1	82.7	73.9	4.83	.85	63.9	82.7
9	73.9	4.96	1.24	64.4	81.0	75.2	6.31	1.58	65.0	84.7	74.6	5.62	.99	64.4	84.7
10	73.0	6.34	1.58	60.1	81.5	74.1	6.66	1.67	64.6	87.1	73.5	6.42	1.13	60.1	87.1
11	71.6	6.28	1.32	60.6	80.2	73.6	6.63	1.66	65.1	89.4	72.6	5.98	1.06	60.6	89.4
12	72.3	5.28	1.32	61.5	83.4	73.3	3.88	.97	68.3	81.4	72.8	4.59	.81	61.5	83.4
13	71.0	5.84	1.46	57.8	80.4	72.3	7.05	1.76	63.5	92.9	71.6	6.40	1.13	57.8	92.9
14	71.1	5.47	1.37	59.1	80.6	72.2	6.38	1.60	62.5	88.5	71.7	5.87	1.04	59.1	88.5
15	71.4	5.52	1.38	60.3	79.0	73.6	3.16	.79	66.7	79.0	72.5	4.57	.81	60.3	79.0
16	71.0	5.00	1.25	60.7	78.7	73.2	5.51	1.38	66.0	86.7	72.1	5.29	.94	60.7	86.7
17	71.7	5.51	1.38	61.3	81.0	73.1	4.72	1.18	65.4	82.5	72.4	5.10	.90	61.3	82.5
18	72.9	6.09	1.52	60.5	82.2	74.1	5.54	1.38	66.1	89.3	73.5	5.75	1.02	60.5	89.3

Angular measurement No. 20. S-Na-A/95-58-133

			Male					*Female*					*Male and female pooled*		
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	82.2	2.82	1.00	78.4	87.2	83.5	4.10	1.02	76.7	89.8	83.1	3.71	.76	76.7	89.8
2	81.7	2.61	.65	78.2	87.5	84.0	3.85	.96	78.9	93.5	82.8	3.44	.61	78.2	93.5
3	81.3	4.23	1.06	69.7	87.6	84.4	3.75	94	78.6	93.2	82.8	4.23	.75	69.7	93.2
4	80.7	3.91	.98	71.5	88.1	82.1	2.87	.72	76.1	86.4	81.4	3.45	.61	71.5	88.1
5	80.7	3.65	.91	71.6	84.2	82.3	2.68	.67	77.3	86.6	81.5	3.26	.58	71.6	86.6
6	81.4	3.83	.96	72.0	86.1	83.2	2.49	.62	76.8	86.6	82.3	3.31	.58	72.0	86.6
7	80.4	3.65	.91	72.0	84.5	83.6	1.89	.47	80.1	87.4	82.0	3.28	.58	72.0	87.4
8	81.0	3.60	.90	72.3	85.5	83.1	2.29	.57	78.7	86.7	82.1	3.16	.56	72.3	86.7
9	81.8	3.48	.87	73.1	85.4	82.5	2.44	.61	77.3	85.4	82.2	2.98	.53	73.1	85.4
10	81.7	3.60	.90	73.6	87.0	83.3	2.22	.56	78.8	87.3	82.5	3.05	.54	73.6	87.3
11	81.9	3.56	.89	75.8	87.6	83.7	2.07	.52	80.5	88.0	82.8	3.00	.53	75.8	88.0
12	82.0	3.38	.84	75.8	87.0	82.5	1.65	.41	79.2	84.7	82.3	2.63	.46	75.8	87.0
13	83.0	2.90	.72	76.9	87.9	84.0	2.38	.59	79.4	88.4	83.5	2.66	.47	76.9	88.4
14	83.2	2.85	.71	77.6	88.4	84.5	2.74	.68	78.1	88.4	83.9	2.82	.50	77.6	88.4
15	83.1	3.10	.77	76.8	89.9	83.2	2.24	.56	78.5	86.7	83.1	2.66	.47	76.8	89.9
16	83.1	2.86	.71	77.6	87.0	84.3	2.38	.59	80.4	88.2	83.7	2.65	.47	77.6	88.2
17	83.7	3.49	.87	76.8	88.0	84.3	2.48	.62	80.6	89.7	84.0	2.99	.53	76.8	89.7
18	84.0	2.92	.73	77.2	88.3	83.9	1.92	.48	80.0	86.6	83.9	2.43	.43	77.2	88.3

Angular measurement No. 21. S-Na-B/95-58-137

	Male					*Female*					*Male and female pooled*				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	74.9	2.90	1.02	70.4	79.0	76.6	3.90	.98	70.4	83.1	76.0	3.64	.74	70.4	83.1
2	76.4	2.44	.61	72.0	80.9	78.6	2.78	.70	74.0	84.3	77.5	2.82	.50	72.0	84.3
3	76.6	3.66	.91	67.5	81.9	79.3	3.00	.75	75.3	85.5	78.0	3.58	.63	67.5	85.5
4	76.0	3.49	.87	67.4	83.9	78.7	2.32	.58	75.1	82.3	77.3	3.23	.57	67.4	83.9
5	76.6	2.66	.67	70.3	80.7	78.8	1.94	.49	74.9	81.8	77.7	2.56	.45	70.3	81.8
6	77.6	3.42	.86	69.2	81.5	79.1	2.17	.54	74.6	82.7	78.3	2.92	.52	69.2	82.7
7	76.7	3.13	.78	69.4	81.0	79.4	1.93	.48	75.2	82.0	78.1	2.89	.51	69.4	82.0
8	77.7	3.13	.78	70.5	82.6	79.4	1.73	.43	75.3	81.7	78.6	2.63	.47	70.5	82.6
9	78.2	3.17	.79	71.4	82.9	79.4	1.70	.43	76.0	82.1	78.8	2.58	.46	71.4	82.9
10	78.3	3.13	.78	72.6	84.0	80.2	1.64	.41	77.5	83.4	79.2	2.66	.47	72.6	84.0
11	78.5	3.10	.78	73.1	83.5	80.5	1.79	.45	76.6	84.0	79.5	2.69	.48	73.1	84.0
12	78.4	3.20	.80	72.7	83.9	80.0	1.67	.42	77.4	82.8	79.2	2.64	.47	72.7	83.9
13	79.1	2.65	.66	74.2	83.9	81.2	2.26	.57	77.3	84.6	80.2	2.65	.47	74.2	84.6
14	79.7	2.88	.72	75.2	84.6	81.9	2.07	.52	78.1	84.8	80.8	2.69	.48	75.2	84.8
15	80.3	2.92	.73	75.1	86.1	81.2	1.86	.46	78.0	83.8	80.7	2.45	.43	75.1	86.1
16	79.9	3.03	.76	74.5	83.7	81.9	2.11	.53	78.3	85.0	80.9	2.77	.49	74.5	85.0
17	80.8	3.23	.81	74.7	85.4	82.1	2.17	.54	78.3	85.3	81.4	2.79	.49	74.7	85.4
18	81.0	3.22	.81	74.5	85.3	81.4	1.96	.49	77.9	83.9	81.2	2.63	.47	74.5	85.3

Angular measurement No. 22. A-Na-B/133-58-137

	Male					*Female*					*Male and female pooled*				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	7.4	1.79	.63	4.8	9.1	6.8	2.03	.51	3.7	11.5	7.0	1.93	.39	3.7	11.5
2	5.4	1.58	.40	2.9	7.6	5.4	1.87	.47	1.8	9.2	5.4	1.71	.30	1.8	9.2
3	4.7	1.73	.43	2.1	8.2	5.0	1.62	.40	3.1	8.0	4.9	1.65	.29	2.1	8.2
4	4.7	1.69	.42	1.6	7.5	3.4	1.25	.31	.7	4.8	4.0	1.61	.28	.7	7.5
5	4.0	1.77	.44	1.4	7.2	3.4	1.65	.41	− .9	6.4	3.7	1.71	.30	− .9	7.2
6	3.9	1.90	.47	.8	7.9	4.1	1.08	.27	2.1	6.0	4.0	1.52	.27	.8	7.9
7	3.7	2.03	.51	.4	7.1	4.2	1.40	.35	2.4	7.2	3.9	1.73	.31	.4	7.2
8	3.3	1.65	.41	1.1	6.2	3.7	1.42	.35	1.7	6.1	3.5	1.53	.27	1.1	6.2
9	3.6	1.77	.44	1.4	6.6	3.1	1.26	.32	1.3	5.3	3.4	1.53	.27	1.3	6.6
10	3.5	1.76	.44	.7	6.5	3.1	1.11	.28	1.1	4.9	3.3	1.46	.26	.7	6.5
11	3.4	2.03	.51	.7	7.8	3.2	1.36	.34	.6	5.3	3.3	1.70	.30	.6	7.8
12	3.6	1.94	.49	.9	6.9	2.5	1.29	.32	.4	5.5	3.1	1.71	.30	.4	6.9
13	3.9	1.91	.48	1.3	7.2	2.8	1.95	.49	− .1	6.3	3.3	1.97	.35	− .1	7.2
14	3.5	1.82	.45	.7	6.4	2.6	1.81	.45	−1.4	5.4	3.1	1.84	.32	−1.4	6.4
15	2.8	1.50	.38	.6	6.0	2.0	1.65	.41	−1.3	5.1	2.4	1.61	.28	−1.3	6.0
16	3.2	1.69	.42	.5	6.7	2.3	1.56	.39	− .9	4.8	2.8	1.66	.29	− .9	6.7
17	2.9	2.05	.51	− .4	6.6	2.2	1.54	.39	−1.1	4.4	2.6	1.82	.32	−1.1	6.6
18	3.0	1.54	.39	.9	5.9	2.5	1.23	.31	.5	4.9	2.7	1.39	.25	.5	5.9

Angular measurement No. 23. Na-A-Pogo/58-133-138

	Male					Female					Male and female pooled				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	165.0	3.24	1.15	160.6	169.9	166.4	4.70	1.18	155.7	173.1	165.9	4.25	.87	155.7	173.1
2	169.0	3.25	.81	162.2	174.6	169.3	3.79	.95	162.4	174.8	169.2	3.48	.62	162.2	174.8
3	170.0	3.78	.94	161.7	176.1	169.0	4.04	1.01	160.5	176.0	169.6	3.88	.69	160.5	176.0
4	170.4	3.62	.91	163.4	177.0	172.5	2.97	.74	167.6	179.4	171.4	3.43	.61	163.4	179.4
5	171.6	4.06	1.01	164.0	178.9	172.8	2.79	.70	165.5	177.5	172.2	3.48	.62	164.0	178.9
6	172.2	4.26	1.06	163.2	179.6	171.3	3.08	.77	165.0	176.7	171.7	3.68	.65	163.2	179.6
7	173.1	4.44	1.11	165.6	179.8	171.9	3.49	.87	164.7	176.8	172.5	3.98	.70	164.7	179.8
8	174.6	3.59	.90	168.2	179.6	173.2	3.62	.91	166.4	179.0	173.9	3.61	.64	166.4	179.6
9	173.5	3.83	.96	166.9	179.2	175.3	3.16	.79	168.5	170.0	174.4	3.57	.63	166.9	179.2
10	174.1	3.73	.93	166.7	179.5	175.3	2.87	.72	169.4	179.5	174.7	3.34	.59	166.7	179.5
11	173.9	4.04	1.01	163.7	178.9	175.0	3.39	.85	169.0	179.8	174.5	3.71	.66	163.7	178.8
12	173.9	4.01	1.00	166.3	179.5	176.6	2.92	.73	169.9	180.0	175.2	3.72	.66	166.3	180.0
13	173.5	3.79	.95	166.8	179.4	175.0	3.67	.92	166.8	179.8	174.3	3.74	.66	166.8	179.8
14	174.1	3.64	.91	167.7	179.8	175.7	2.77	.69	170.7	179.0	174.9	3.28	.58	167.7	179.8
15	175.6	2.96	.74	169.7	179.5	177.0	2.52	.63	170.3	179.5	176.3	2.79	.49	169.7	179.5
16	175.6	3.10	.78	170.6	179.6	176.6	2.31	.58	172.1	179.4	176.1	2.73	.48	170.6	179.6
17	175.3	302	.75	169.6	179.7	176.8	2.09	.52	172.2	179.2	176.1	2.65	.47	169.6	179.7
18	175.8	2.28	.57	171.2	179.5	176.5	2.10	.53	172.4	179.7	176.2	2.19	.39	171.2	179.7

Angular measurement No. 24. (Na-Pogo)-(B-A)/(58-138)-(137-133)

	Male					Female					Male and female pooled				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	7.1	1.94	.69	3.4	9.1	6.9	1.97	.49	3.5	11.9	7.0	1.92	.39	3.4	11.9
2	7.7	2.56	.64	4.1	11.9	7.0	2.40	.60	1.6	10.5	7.4	2.47	.44	1.6	11.9
3	6.8	2.54	.64	3.0	11.1	6.2	2.06	.52	3.0	9.9	6.4	2.29	.41	3.0	11.1
4	6.8	2.60	.65	2.9	12.1	4.5	1.88	.47	1.2	7.3	5.6	2.51	.44	1.2	12.1
5	6.1	2.80	.70	1.1	10.7	5.3	2.35	.59	−1.0	8.2	5.7	2.57	.46	−1.0	10.7
6	5.8	3.14	.79	1.9	13.8	6.0	1.59	.40	2.5	8.2	5.9	2.45	.43	1.9	13.8
7	6.2	3.00	.75	1.2	11.2	6.3	1.99	.50	3.3	11.6	6.2	2.50	.44	1.2	11.6
8	5.8	2.43	.61	2.0	10.7	6.1	1.82	.45	2.3	9.4	6.0	2.12	.37	2.0	10.7
9	6.5	2.91	.73	1.9	11.6	5.8	2.00	.50	2.3	9.2	6.2	2.48	.44	1.9	11.6
10	6.3	2.88	.72	1.4	11.4	5.5	1.58	.40	1.8	7.9	5.9	2.32	.41	1.4	11.4
11	6.1	3.54	.89	1.3	13.0	5.8	1.96	.49	2.6	10.7	6.0	2.82	.50	1.3	13.0
12	6.7	3.58	.90	2.0	13.6	5.1	1.99	.50	1.4	9.3	5.9	2.97	.52	1.4	13.6
13	7.3	3.40	.85	3.0	13.8	5.8	3.36	.84	1.1	13.5	6.6	3.41	.60	1.1	13.8
14	6.6	3.40	.85	1.8	13.0	5.3	2.76	.96	−1.5	11.0	6.0	3.12	.55	−1.5	13.0
15	6.1	2.87	.72	2.4	13.8	4.3	2.44	.61	− .9	8.1	5.2	2.77	.49	− .9	13.8
16	6.8	3.50	.88	1.7	14.4	4.8	2.62	.66	− .8	9.5	5.8	3.22	.57	− .8	14.4
17	6.3	3.86	.96	1.0	14.9	4.8	2.46	.61	− .6	8.2	5.6	3.27	.58	− .6	14.9
18	6.6	2.98	.74	3.2	13.6	5.4	1.63	.41	2.6	8.3	6.0	2.44	.43	2.6	13.6

Angular measurement No. 25. (Na-A)-$\underline{1}$/(58-133)-(164-162)

			Male					Female					Male and female pooled		
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	7.0	8.13	2.88	−5.6	17.5	5.9	6.70	1.68	−5.3	16.5	6.2	7.05	1.44	−5.6	17.5
2	9.5	4.84	1.21	− .9	17.2	11.6	5.70	1.42	− .8	22.3	10.6	5.30	.94	− .9	22.3
3	9.1	5.59	1.40	1.8	23.0	8.2	6.10	1.52	−2.2	19.8	8.6	5.77	1.02	−2.2	23.0
4	7.3	6.32	1.58	−2.3	20.4	9.8	4.50	1.13	3.8	18.8	8.6	5.54	.98	−2.3	20.4
5	9.2	5.64	1.41	.3	17.0	9.4	5.93	1.48	−3.0	23.3	9.3	5.69	1.01	−3.0	23.3
6	10.6	8.04	2.01	−4.4	30.2	6.9	7.13	1.78	−4.0	23.3	8.8	7.71	1.36	−4.4	30.2
7	14.8	10.90	2.73	−3.2	31.6	15.9	10.15	2.54	1.8	29.3	15.4	10.38	1.83	−3.2	31.6
8	22.5	5.35	1.34	16.1	33.7	20.3	4.34	1.08	12.5	27.0	21.4	4.91	.87	12.5	33.7
9	20.5	4.79	1.20	9.9	28.9	20.5	4.67	1.17	12.6	29.0	20.5	4.65	.82	9.9	29.0
10	20.2	6.16	1.54	8.8	30.8	20.5	3.74	.94	15.4	28.1	20.4	5.02	.89	8.8	30.8
11	19.7	5.83	1.46	7.2	26.3	19.5	3.74	.93	14.0	24.6	19.6	4.82	.85	7.2	26.3
12	18.8	7.10	1.77	.9	26.8	20.1	2.60	.65	15.9	24.5	19.4	5.30	.94	.9	26.8
13	18.6	7.23	1.81	1.0	29.9	18.9	5.31	1.33	10.2	25.3	18.8	6.24	1.10	1.0	29.9
14	18.0	6.02	1.51	5.4	25.3	19.0	4.74	1.19	11.1	26.6	18.5	5.36	.95	5.4	26.6
15	19.5	5.84	1.46	7.2	26.9	20.9	4.52	1.13	11.3	26.8	20.2	5.19	.92	7.2	26.9
16	18.0	6.61	1.65	3.9	28.2	17.5	5.57	1.39	8.4	26.4	17.8	6.02	1.06	3.9	28.2
17	17.8	6.65	1.66	5.2	29.8	17.8	6.50	1.62	7.3	28.6	17.8	6.47	1.14	5.2	29.8
18	15.6	5.80	1.45	5.5	23.5	16.8	5.49	1.37	8.0	25.2	16.2	5.59	.99	5.5	25.2

Angular measurement No. 26. (Na-B)-$\bar{1}$/(58-137)-(166-168)

			Male					Female					Male and female pooled		
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	24.0	6.80	2.40	9.3	31.5	19.4	5.81	1.45	8.4	29.0	21.0	6.40	1.31	8.4	31.5
2	17.4	3.89	.97	11.5	24.3	14.8	4.44	1.11	9.6	21.3	16.1	4.32	.76	9.6	24.3
3	17.3	3.80	.95	10.0	23.7	17.3	4.66	1.16	8.5	24.2	17.3	4.18	.74	8.5	24.2
4	15.2	4.15	1.04	8.2	22.4	15.0	5.08	1.27	6.8	23.9	15.1	4.57	.81	6.8	23.9
5	15.0	5.69	1.42	2.4	22.6	16.5	6.04	1.51	− .9	22.6	15.8	5.83	1.03	− .9	22.6
6	16.8	4.65	1.16	9.8	28.5	18.4	5.64	1.41	7.4	28.1	17.6	5.14	.91	7.4	28.5
7	18.0	6.89	1.72	4.6	28.6	18.8	6.51	1.63	7.6	27.9	18.4	6.61	1.17	4.6	28.6
8	21.0	5.33	1.33	10.1	30.0	22.3	5.60	1.40	12.7	32.4	21.6	5.42	.96	10.1	32.4
9	21.8	4.78	1.20	14.0	29.3	21.0	5.57	1.39	10.9	29.9	21.4	5.12	.91	10.9	29.9
10	22.0	5.62	1.40	10.4	31.3	21.8	6.18	1.55	8.5	31.5	21.9	5.81	1.03	8.5	31.5
11	23.5	4.91	1.23	13.6	34.1	22.2	6.54	1.64	5.8	31.2	22.8	5.72	1.01	5.8	34.1
12	22.1	5.09	1.27	13.5	31.7	22.2	3.33	.83	13.1	25.9	22.1	4.23	.75	13.1	31.7
13	23.4	5.73	1.43	12.2	33.5	23.2	5.82	1.46	5.0	31.4	23.3	5.68	1.00	5.0	33.5
14	23.2	4.84	1.21	14.2	31.3	22.2	6.18	1.55	7.1	32.5	22.7	5.48	.97	7.1	32.5
15	22.6	5.26	1.31	14.6	31.0	21.1	3.38	.85	15.0	27.9	21.9	4.41	.78	14.6	31.0
16	22.4	4.74	1.18	12.4	29.6	21.8	5.43	1.36	7.7	29.2	22.1	5.02	.89	7.7	29.6
17	21.3	5.18	1.30	11.8	29.3	21.4	3.93	.98	11.7	26.4	21.4	4.52	.80	11.7	29.3
18	20.3	5.26	1.31	11.8	29.4	20.8	4.76	1.19	6.2	27.0	20.5	4.94	.87	6.2	29.4

Linear measurement No. 1A. PNS-ANS/127-132

	Male					*Female*					*Male and female pooled*				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	39.0	1.66	.59	36.4	40.8	38.7	1.52	.38	36.4	41.4	38.8	1.54	.31	36.4	41.4
2	40.7	1.87	.47	37.4	44.4	41.2	1.60	.40	38.4	43.8	41.0	1.72	.30	37.4	44.4
3	43.1	1.86	.47	39.2	46.0	43.2	1.74	.43	39.6	45.2	43.2	1.77	.31	39.2	46.0
4	44.7	1.88	.47	41.2	49.0	44.3	2.05	.51	40.4	48.0	44.5	1.95	.34	40.4	49.0
5	46.1	1.85	.46	41.0	47.6	45.5	1.75	.44	42.6	49.2	45.8	1.79	.32	41.0	49.2
6	47.1	1.61	.40	44.4	50.2	46.8	1.80	.45	44.4	50.2	47.0	1.69	.30	44.4	50.2
7	48.5	2.10	.52	44.8	53.8	47.8	2.49	.62	44.4	52.2	48.2	2.30	.41	44.4	53.8
8	49.5	1.79	.45	45.6	51.6	49.1	2.68	.67	43.2	52.8	49.3	2.25	.40	43.2	52.8
9	50.2	1.19	.30	47.4	52.2	50.1	2.02	.50	46.4	53.8	50.2	1.63	.29	46.4	53.8
10	50.8	1.53	.38	48.4	53.4	50.2	2.04	.51	46.8	53.8	50.5	1.80	.32	46.8	53.8
11	52.0	1.54	.38	48.6	54.4	51.9	2.40	.60	47.0	55.8	52.0	1.98	.35	47.0	55.8
12	53.6	1.79	.45	50.8	57.4	52.3	2.78	.69	46.8	58.4	53.0	2.39	.42	46.8	58.4
13	54.1	2.13	.53	51.0	59.6	53.3	3.22	.80	47.0	58.2	53.7	2.72	.48	47.0	59.6
14	55.8	2.00	.50	52.0	60.2	54.0	3.31	.83	46.8	58.8	54.9	2.83	.50	46.8	60.2
15	56.6	2.29	.57	52.6	59.4	54.1	2.61	.65	49.0	58.6	55.4	2.73	.48	49.0	59.4
16	58.0	2.12	.53	54.4	60.4	54.6	3.10	.78	48.8	58.2	56.3	3.14	.55	48.8	60.4
17	57.7	3.18	.79	52.0	62.0	55.0	2.63	.66	48.8	58.0	56.4	3.19	.56	48.8	62.0
18	58.5	2.01	.50	54.8	61.2	55.2	2.69	.67	49.6	59.2	56.8	2.88	.51	49.6	61.2

Linear measurement No. 1B. (A-Pogo)-$\underline{1}$ tip/(133-138)-162

	Male					*Female*					*Male and female pooled*				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	2.9	2.15	.76	.2	5.7	2.5	1.58	.40	.1	4.6	2.7	1.76	.36	.1	5.7
2	3.2	1.14	.28	1.7	5.9	3.9	1.35	.34	2.2	7.6	3.6	1.27	.23	1.7	7.6
3	2.8	1.53	.38	.8	6.2	2.9	1.57	.39	.6	6.5	2.8	1.53	.27	.6	6.5
4	2.4	1.22	.30	.5	5.0	2.6	.94	.23	1.2	4.7	2.5	1.07	.19	.5	5.0
5	2.4	1.43	.36	.2	5.8	2.1	.82	.21	.0	3.2	2.2	1.16	.21	.0	5.8
6	2.3	1.20	.30	.5	5.2	1.7	1.00	.25	.0	3.5	2.0	1.13	.20	.0	5.2
7	2.9	1.86	.46	.0	6.0	2.2	1.38	.35	.2	4.6	2.6	1.65	.29	.0	6.0
8	3.8	1.61	.40	1.2	6.1	3.4	1.44	.36	.8	5.7	3.6	1.51	.27	.8	6.1
9	4.5	1.53	.38	1.7	7.0	3.7	1.38	.35	1.2	5.7	4.1	1.48	.26	1.2	7.0
10	4.6	1.64	.41	2.4	7.6	4.6	1.41	.35	2.2	7.2	4.6	1.50	.27	2.2	7.6
11	4.9	1.59	.40	2.0	7.5	4.4	1.55	.39	2.0	7.6	4.6	1.56	.28	2.0	7.6
12	5.1	1.73	.43	1.0	7.8	4.1	.79	.20	2.7	5.4	4.6	1.43	.25	1.0	7.8
13	4.8	2.06	.51	1.7	8.2	3.9	1.79	.45	.1	7.5	4.4	1.95	.34	.1	8.2
14	4.7	1.84	.46	2.1	7.8	4.2	1.77	.44	.5	7.7	4.4	1.79	.32	.5	7.8
15	4.8	2.07	.52	1.3	8.4	3.9	.81	.20	1.7	4.9	4.4	1.60	.28	1.3	8.4
16	4.3	2.27	.57	1.4	8.6	3.7	1.79	.45	.8	7.9	4.0	2.04	.36	.8	8.6
17	4.0	2.19	.55	1.0	9.3	3.6	1.89	.47	.4	8.3	3.8	2.02	.36	.4	9.3
18	3.2	1.98	.50	.1	6.5	3.4	1.51	.38	.1	5.9	3.3	1.73	.31	.1	6.5

Linear measurement No. 2B. (Na-A)-$\underline{1}$ tip/(58-133)-162

			Male					Female					Male and female pooled		
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	1.6	1.22	.43	.1	3.4	1.5	1.05	.26	.2	3.3	1.6	1.08	.22	.1	3.4
2	.9	.90	.22	.1	3.2	1.4	1.03	.26	.0	3.7	1.2	.99	.17	.0	3.7
3	1.5	1.15	.29	.2	4.9	1.4	1.21	.30	.2	3.9	1.4	1.16	.21	.2	4.9
4	1.5	1.05	.26	.1	3.4	.9	.69	.17	.2	2.9	1.2	.92	.16	.1	3.4
5	1.2	.90	.23	.0	3.0	.8	.67	.17	.0	2.1	1.0	.81	.14	.0	3.0
6	1.4	1.09	.27	.1	3.7	1.3	1.00	.25	.1	3.7	1.4	1.03	.18	.1	3.7
7	2.3	1.09	.27	.3	3.7	1.4	1.03	.26	.3	4.5	1.8	1.12	.20	.3	4.5
8	2.1	1.68	.42	.0	5.5	1.8	1.20	.30	.0	3.9	2.0	1.44	.26	.0	5.5
9	2.6	1.62	.41	.2	5.6	2.3	1.34	.34	.1	5.0	2.4	1.48	.26	.1	5.6
10	2.9	1.75	.44	.3	6.9	3.1	1.14	.28	1.3	4.8	3.0	1.45	.26	.3	6.9
11	3.2	1.71	.43	.0	5.7	2.8	1.19	.30	.6	4.6	3.0	1.46	.26	.0	5.7
12	3.6	1.60	.40	.5	6.2	3.0	1.11	.28	1.4	5.1	3.3	1.39	.25	.5	6.2
13	3.2	1.66	.42	.3	6.7	3.0	1.69	.42	.0	5.7	3.1	1.65	.29	.0	6.7
14	3.1	1.82	.45	.1	6.5	3.1	1.88	.47	.2	6.3	3.1	1.82	.32	.1	6.5
15	3.8	1.95	.49	.4	7.5	3.3	1.56	.39	.2	6.5	3.6	1.76	.31	.2	7.5
16	3.4	2.06	.52	.5	7.5	2.8	1.82	.46	.4	5.7	3.1	1.93	.34	.4	7.5
17	3.4	2.28	.57	.4	8.7	3.0	1.94	.48	.6	6.5	3.2	2.09	.37	.4	8.7
18	2.6	1.41	.35	.4	5.0	2.7	1.78	.45	.7	6.2	2.6	1.58	.28	.4	6.2

Linear measurement No. 3B. (Na-B)-$\overline{1}$ tip/(58-137)-166

			Male					Female					Male and female pooled		
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	3.0	1.32	.47	.1	4.3	2.0	1.49	.37	.0	5.5	2.5	1.49	.30	.0	5.5
2	1.9	.74	.18	1.0	3.2	2.0	1.11	.28	.4	4.0	2.0	.93	.16	.4	4.0
3	1.8	1.05	.26	.3	4.0	2.0	1.22	.30	.3	4.1	1.9	1.12	.20	.3	4.1
4	1.6	.99	.25	.1	3.3	1.4	.76	.19	.3	2.6	1.5	.87	.15	.1	3.3
5	1.5	1.31	.33	.0	4.1	1.8	1.19	.30	.0	3.9	1.6	1.25	.22	.0	4.1
6	1.6	1.12	.28	.5	4.2	1.7	.92	.23	.1	3.9	1.6	1.01	.18	.1	4.2
7	2.1	1.41	.35	.5	4.6	2.0	1.41	.35	.1	4.4	2.0	1.39	.25	.1	4.6
8	2.9	1.50	.38	.5	5.6	2.8	1.49	.37	.5	5.5	2.8	1.47	.26	.5	5.6
9	3.3	1.55	.39	.7	5.8	2.7	1.31	.33	.4	5.4	3.0	1.45	.26	.4	5.8
10	3.3	1.61	.40	.1	5.7	3.2	1.71	.43	.1	6.2	3.2	1.63	.29	.1	6.2
11	3.8	1.55	.39	.5	6.5	3.5	1.59	.40	.2	5.9	3.6	1.56	.28	.2	6.5
12	3.7	1.40	.35	1.1	5.9	3.2	1.02	.25	1.7	5.0	3.4	1.24	.22	1.1	5.9
13	4.1	1.92	.48	.8	6.7	3.6	1.37	.34	1.2	5.9	3.8	1.66	.29	.8	6.7
14	4.0	1.88	.47	.9	6.7	3.6	1.79	.45	.6	6.4	3.8	1.82	.32	.6	6.7
15	4.1	1.95	.49	.5	7.8	3.1	1.11	.28	1.6	5.0	3.6	1.64	.29	.5	7.8
16	4.3	1.93	.48	.5	8.6	3.4	1.63	.41	1.0	6.2	3.8	1.81	.32	.5	8.6
17	4.1	1.97	.49	.4	8.3	3.2	1.45	.36	.7	6.4	3.6	1.75	.31	.4	8.3
18	3.4	1.71	.43	.1	6.3	3.3	1.41	.35	.2	5.3	3.4	1.55	.27	.1	6.3

Linear measurement No. 4B. (Na-B)-Pogo/(58-137)-138

	Male					Female					Male and female pooled				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	1.1	.90	.32	.1	2.5	1.2	.62	.15	.0	2.6	1.2	.71	.14	.0	2.6
2	.6	.34	.08	.0	1.1	.7	.62	.15	.1	2.0	.6	.49	.09	.0	2.0
3	.9	.85	.21	.1	3.5	1.1	.99	.25	.0	3.5	1.0	.91	.16	.0	3.5
4	.7	.55	.14	.1	1.7	.9	.82	.21	.1	3.1	.8	1.42	.25	.1	3.1
5	.9	.72	.18	.1	2.5	.6	.61	.15	.0	2.1	.8	.67	.12	.0	2.5
6	.9	.49	.12	.3	2.1	.9	1.01	.25	.0	3.8	.9	.78	.14	.1	3.8
7	1.1	.72	.18	.1	3.0	.8	.48	.12	.1	1.6	1.0	.62	.11	.1	3.0
8	1.4	.97	.24	.1	3.0	1.2	.68	.17	.0	2.4	1.3	.83	.15	.0	3.0
9	1.5	1.20	.30	.1	4.7	1.5	.95	.24	.1	3.4	1.5	1.06	.19	.1	4.7
10	1.7	1.17	.29	.6	4.4	1.6	1.03	.26	.1	3.5	1.6	1.09	.19	.1	4.4
11	1.6	1.17	.29	.0	4.6	1.8	1.23	.31	.1	3.9	1.7	1.19	.21	.0	4.6
12	1.9	1.21	.30	.2	5.3	1.9	.79	.20	.6	4.0	1.9	1.00	.18	.2	5.3
13	2.2	1.48	.37	.3	6.0	2.2	1.22	.31	.4	4.9	2.2	1.33	.24	.3	6.0
14	1.9	1.16	.29	.3	4.8	2.4	1.36	.34	.3	4.7	2.2	1.27	.22	.3	4.8
15	2.8	1.47	.37	1.2	6.3	2.3	.78	.20	1.0	4.5	2.6	1.20	.21	1.0	6.3
16	3.0	1.56	.39	.7	6.1	2.3	1.15	.29	.3	4.4	2.6	1.39	.25	.3	6.1
17	3.1	1.68	.42	.3	6.9	2.5	1.00	.25	.1	4.1	2.8	1.40	.25	.1	6.9
18	3.7	1.83	.46	.4	6.3	2.9	1.33	.33	1.7	6.6	3.3	1.63	.29	.4	6.6

Linear measurement No. 5B. (Na-Pogo)-1 tip/(58-138)-162

	Male					Female					Male and female pooled				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	6.3	2.33	.82	2.7	9.7	5.2	2.33	.58	.6	9.5	5.6	2.34	.48	.6	9.7
2	5.4	1.37	.34	4.0	7.9	6.0	1.67	.42	4.3	10.1	5.7	1.53	.27	4.0	10.1
3	5.0	1.81	.45	2.6	9.3	5.2	2.10	.52	1.6	11.1	5.1	1.93	.34	1.6	11.1
4	4.7	1.49	.37	2.5	8.3	4.3	1.37	.34	1.8	6.9	4.5	1.42	.25	1.8	8.3
5	4.4	1.95	.49	.5	8.1	3.7	1.36	.34	.8	5.9	4.0	1.69	.30	.5	8.2
6	4.1	1.62	.41	1.6	7.0	3.7	1.57	.39	1.2	7.5	3.9	1.59	.28	1.2	7.5
7	4.6	2.19	.55	1.3	9.0	4.1	1.78	.44	.5	7.1	4.4	1.98	.35	.5	9.0
8	5.2	2.01	.50	1.1	7.7	5.2	1.75	.44	2.4	8.6	5.2	1.85	.33	1.1	8.6
9	6.0	1.92	.48	2.8	9.6	4.9	1.75	.44	1.5	7.9	5.4	1.88	.33	1.5	9.6
10	6.0	2.10	.52	3.0	9.7	5.8	1.97	.49	2.7	9.5	5.9	2.00	.35	2.7	9.7
11	6.3	1.98	.49	2.5	9.8	5.7	2.26	.57	1.5	10.0	6.0	2.12	.37	1.5	10.0
12	6.6	1.93	.48	2.9	9.4	4.9	1.33	.33	2.7	7.6	5.8	1.85	.33	2.7	9.4
13	6.4	2.55	.64	1.8	10.5	4.9	2.38	.60	.8	10.0	5.6	2.53	.45	.8	10.5
14	6.3	2.20	.55	2.1	9.8	5.1	2.40	.60	.9	10.6	5.7	2.35	.42	.9	10.6
15	5.7	2.50	.63	1.0	9.0	4.4	1.38	.35	2.0	6.9	5.0	2.10	.37	1.0	9.0
16	5.4	2.44	.61	.7	9.6	4.4	2.24	.56	.6	9.5	4.9	2.36	.42	.6	9.6
17	4.9	2.50	.63	.7	9.8	4.1	2.27	.57	.2	9.7	4.5	2.39	.42	.2	9.8
18	4.0	2.58	.65	.5	8.0	4.1	1.73	.43	.6	6.6	4.0	2.16	.38	.5	8.0

Linear measurement No. 1C. Na-ANS/58-132

	Male					Female					Male and female pooled				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	32.5	1.20	.43	31.6	34.6	30.6	1.34	.34	28.2	33.4	31.3	1.56	.32	28.2	34.6
2	36.2	2.06	.52	32.8	40.2	34.0	1.49	.37	31.4	36.2	35.1	2.09	.37	31.4	40.2
3	38.4	2.21	.55	35.2	43.2	35.9	1.45	.36	33.8	38.6	37.2	2.22	.39	33.8	43.2
4	40.3	2.44	.61	36.6	44.4	37.9	1.66	.41	34.2	40.8	39.1	2.37	.42	34.2	44.4
5	42.0	1.96	.49	39.8	46.0	39.8	1.41	.35	37.2	43.0	40.9	2.01	.36	37.2	46.0
6	43.0	2.00	.50	40.4	46.8	42.0	2.10	.53	37.8	46.0	42.5	2.07	.37	37.8	46.8
7	45.0	1.87	.47	42.2	48.6	43.2	2.14	.53	38.8	46.4	44.1	2.19	.39	38.8	48.6
8	46.2	2.20	.55	43.2	50.2	44.6	2.29	.57	40.8	48.2	45.4	2.34	.41	40.8	50.2
9	47.3	2.23	.56	44.2	52.2	46.4	2.47	.62	41.4	50.6	46.8	2.36	.42	41.4	52.2
10	48.5	2.39	.60	45.8	54.0	46.5	2.21	.55	42.4	50.0	47.5	2.49	.44	42.4	54.0
11	49.2	1.95	.49	46.0	54.6	48.3	2.45	.61	44.0	52.6	48.8	2.23	.39	44.0	54.6
12	50.5	2.33	.58	46.8	56.8	49.6	2.51	.63	45.6	55.0	50.0	2.42	.43	45.6	56.8
13	51.8	2.06	.52	48.6	56.8	49.8	2.11	.53	46.2	53.0	50.8	2.29	.41	46.2	56.8
14	53.4	1.96	.49	50.0	57.6	49.8	2.04	.51	46.2	53.0	51.6	2.72	.48	46.2	57.6
15	55.0	2.48	.62	51.4	60.8	50.9	2.49	.62	47.0	56.6	53.0	3.19	.56	47.0	60.8
16	55.8	2.26	.56	52.0	60.8	50.7	2.04	.51	46.0	53.2	53.2	3.31	.59	46.0	60.8
17	55.4	1.93	.48	52.0	58.6	50.8	2.39	.60	45.2	54.4	53.1	3.18	.56	45.2	58.6
18	57.0	2.55	.64	51.8	60.6	51.6	2.10	.53	46.8	55.4	54.3	3.58	.63	46.8	60.6

Linear measurement No. 2C. ANS-Me/132-140

	Male					Female					Male and female pooled				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	43.2	4.49	1.59	40.0	54.0	41.8	2.90	.73	37.6	47.0	42.3	3.49	.71	37.6	54.0
2	42.6	2.99	.75	38.4	47.8	43.2	2.52	.63	39.6	46.6	42.9	2.74	.48	38.4	47.8
3	46.8	2.47	.62	43.0	50.6	46.2	2.47	.62	42.0	50.0	46.5	2.45	.43	42.0	50.6
4	48.3	2.71	.68	45.1	55.0	47.9	2.39	.60	44.2	51.8	48.1	2.52	.45	44.2	55.0
5	50.1	3.01	.75	45.8	56.2	49.4	2.42	.61	46.2	54.6	49.8	2.71	.48	45.8	56.2
6	51.6	2.81	.70	47.8	58.4	50.8	3.10	.77	47.2	57.4	51.2	2.93	.52	47.2	58.4
7	53.2	2.96	.74	48.8	59.4	52.3	3.14	.78	47.8	58.2	52.8	3.03	.54	47.8	59.4
8	55.2	3.67	.92	49.8	62.8	53.1	3.37	.84	48.0	59.6	54.2	3.63	.64	48.0	62.8
9	55.3	3.67	.92	49.4	63.2	54.1	2.92	.73	49.8	59.0	54.7	3.32	.59	49.4	63.2
10	56.2	3.55	.89	50.0	62.8	55.9	4.03	1.01	49.8	64.6	56.0	3.74	.66	49.8	64.6
11	57.9	3.03	.76	53.2	62.8	56.8	4.33	1.08	50.6	67.0	57.4	3.72	.66	50.6	67.0
12	59.0	3.41	.85	53.2	65.0	58.5	3.86	.96	51.8	66.0	58.8	3.59	.63	51.8	66.0
13	60.3	3.51	.88	52.8	65.4	59.4	3.72	.93	52.4	64.2	59.8	3.58	.63	52.4	65.4
14	61.7	3.77	.94	54.2	66.4	61.3	4.54	1.13	53.2	71.6	61.5	4.11	.73	53.2	71.6
15	64.4	3.98	.99	57.0	68.8	61.7	3.86	.96	55.0	68.8	63.0	4.09	.72	55.0	68.8
16	65.6	4.04	1.01	59.6	71.0	62.1	3.99	1.00	55.6	68.6	63.8	4.33	.76	55.6	71.0
17	67.4	3.78	.95	60.6	73.8	62.5	4.04	1.01	55.2	68.6	65.0	4.58	.81	55.2	73.8
18	67.7	4.63	1.16	59.4	74.2	63.2	4.31	1.08	56.2	70.2	65.4	4.96	.88	56.2	74.2

Linear measurement No. 3C. Na-Me/58-140

			Male					*Female*					*Male and female pooled*		
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	75.8	5.26	1.86	71.8	88.2	72.4	2.60	.65	69.2	78.6	73.5	3.93	.80	69.2	88.2
2	78.8	3.43	.86	73.6	84.0	77.2	2.26	.57	73.8	81.2	78.0	2.97	.52	73.6	84.0
3	85.2	3.58	.89	80.4	90.0	82.1	2.40	.60	78.8	86.0	83.6	3.38	.60	78.8	90.0
4	88.6	3.61	.90	83.2	96.0	85.8	3.02	.76	78.4	90.2	87.2	3.56	.63	78.4	96.0
5	92.0	3.22	.81	86.2	97.4	89.2	2.70	.67	86.2	94.8	90.6	3.25	.57	86.2	97.4
6	94.5	2.93	.73	90.0	99.2	92.8	3.95	.99	85.0	101.4	93.6	3.52	.62	85.0	101.4
7	98.2	3.59	.90	93.0	104.4	95.5	4.20	1.05	86.6	102.0	96.8	4.09	.72	86.6	104.4
8	101.4	3.95	.99	94.8	108.0	97.7	4.15	1.04	89.2	104.2	99.6	4.40	.78	89.2	108.0
9	102.6	3.78	.95	96.6	108.6	100.5	4.17	1.04	91.2	107.0	101.6	4.06	.72	91.2	108.6
10	104.6	3.48	.87	99.0	110.0	102.3	5.05	1.26	92.4	112.4	103.4	4.42	.78	92.4	112.4
11	107.1	3.84	.96	101.4	113.6	105.0	5.42	1.35	94.6	116.2	106.0	4.73	.84	94.6	116.2
12	109.5	4.15	1.04	103.6	117.0	108.0	4.46	1.11	97.4	116.4	108.8	4.30	.76	97.4	117.0
13	112.1	4.26	1.07	104.8	117.4	109.2	4.05	1.01	101.0	115.8	110.6	4.34	.77	101.0	117.4
14	115.1	4.68	1.17	106.6	120.8	111.0	5.07	1.27	103.0	121.4	113.0	5.24	.93	103.0	121.4
15	119.4	5.31	1.33	109.2	128.4	112.6	3.97	.99	106.0	120.4	116.0	5.75	1.02	106.0	128.4
16	121.3	5.25	1.31	112.2	130.0	112.8	4.06	1.02	106.2	119.2	117.0	6.32	1.12	106.2	130.0
17	122.7	4.29	1.07	115.0	128.6	113.2	4.20	1.05	106.6	120.8	118.0	6.39	1.13	106.6	128.6
18	124.7	5.05	1.26	116.6	132.6	114.8	4.83	1.21	107.4	122.8	119.8	7.00	1.24	107.4	132.6

Linear measurement No. 1D. S-Na/95-58

			Male					*Female*					*Male and female pooled*		
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	56.3	1.98	.70	52.8	58.6	54.4	2.20	.55	50.6	57.6	55.0	2.28	.47	50.6	58.6
2	59.9	1.80	.45	56.6	62.5	57.9	2.15	.54	53.0	61.6	58.9	2.21	.39	53.0	62.5
3	62.4	1.91	.48	60.0	65.4	59.8	2.78	.70	54.6	64.2	61.1	2.71	.48	54.6	65.4
4	63.6	1.82	.45	61.5	67.2	61.8	1.99	.50	58.9	65.6	62.7	2.08	.37	58.9	67.2
5	65.0	2.01	.50	62.2	68.5	63.4	1.94	.48	61.2	67.0	64.2	2.12	.38	61.2	68.5
6	66.0	2.52	.63	62.4	70.8	63.4	1.75	.44	60.9	67.5	64.7	2.52	.44	60.9	70.8
7	67.2	2.41	.60	62.6	71.8	64.4	1.92	.48	62.2	68.5	65.8	2.55	.45	62.2	71.8
8	68.3	2.51	.63	64.4	72.8	65.2	1.95	.49	62.6	69.3	66.8	2.70	.48	62.6	72.8
9	68.6	2.87	.72	65.0	73.7	65.9	1.84	.46	63.6	69.6	67.2	2.74	.48	63.6	73.7
10	69.5	2.74	.68	65.8	74.6	66.8	2.08	.52	63.6	71.0	68.2	2.77	.49	63.6	74.6
11	69.8	2.79	.70	66.0	75.7	67.6	2.34	.59	64.2	72.7	68.7	2.77	.49	64.2	75.7
12	70.9	2.93	.73	66.9	76.4	68.4	2.04	.51	65.8	72.4	69.6	2.79	.49	65.8	76.4
13	71.4	2.87	.72	67.3	76.8	69.2	2.38	.60	65.7	73.9	70.3	2.83	.50	65.7	76.8
14	72.3	2.31	.58	67.6	75.5	69.5	2.32	.58	66.4	73.8	70.9	2.67	.47	66.4	75.5
15	73.8	2.79	.70	68.3	79.4	69.7	2.33	.58	66.0	73.6	71.8	3.25	.58	66.0	79.4
16	74.0	2.79	.70	68.5	79.7	69.5	2.57	.64	64.2	74.6	71.8	3.51	.62	64.2	79.7
17	75.1	2.83	.71	69.7	80.6	69.5	2.13	.53	64.9	73.4	72.3	3.77	.67	64.9	80.6
18	75.4	2.52	.63	71.0	80.2	70.1	2.96	.74	64.2	74.9	72.8	3.79	.67	64.2	80.2

Linear measurement No. 2D. S-Ba/95-13

			Male					*Female*					*Male and female pooled*		
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	31.4	1.77	.62	28.2	34.2	29.9	2.30	.58	26.7	34.7	30.4	2.22	.45	26.7	34.7
2	33.6	2.07	.52	30.0	37.4	33.1	2.06	.52	27.2	36.4	33.4	2.05	.36	27.2	37.4
3	35.2	1.60	.40	31.9	37.9	35.0	1.23	.31	33.0	37.9	35.1	1.41	.25	31.9	37.9
4	35.7	1.84	.46	33.5	39.2	35.9	1.56	.39	32.9	39.3	35.8	1.68	.30	32.9	39.3
5	37.5	2.15	.54	34.1	42.2	36.5	2.30	.58	32.2	41.1	37.0	2.25	.40	32.2	42.2
6	38.4	2.21	.55	33.5	42.5	38.4	2.16	.54	34.7	43.1	38.4	2.15	.38	33.5	43.1
7	39.4	2.34	.58	36.5	43.9	39.1	1.65	.41	36.7	42.4	39.2	2.00	.35	36.5	43.9
8	41.4	2.09	.52	38.3	45.3	40.2	1.91	.48	37.3	44.8	40.8	2.07	.37	37.3	45.3
9	42.1	3.12	.78	35.8	46.7	42.1	1.70	.42	38.3	45.1	42.1	2.47	.44	35.8	46.7
10	43.1	2.86	.71	38.5	47.7	42.4	2.24	.56	37.6	46.3	42.8	2.56	.45	37.6	47.7
11	43.6	2.66	.67	39.3	47.8	43.3	2.20	.55	40.4	47.8	43.4	2.41	.43	39.3	47.8
12	44.6	2.85	.71	40.3	49.1	44.1	1.80	.45	40.6	46.8	44.4	2.36	.42	40.3	49.1
13	45.2	2.73	.68	40.0	49.9	44.3	2.10	.53	40.6	47.1	44.8	2.44	.43	40.0	49.9
14	45.8	2.98	.74	41.7	52.3	44.4	2.20	.55	39.5	48.1	45.1	2.66	.47	39.5	52.3
15	47.2	2.53	.63	41.6	51.0	44.9	1.65	.41	41.9	47.4	46.0	2.41	.43	41.6	51.0
16	47.0	3.48	.87	38.2	52.3	45.0	2.22	.55	39.7	49.1	46.0	3.05	.54	38.2	52.3
17	47.0	3.26	.81	41.3	52.2	45.3	2.07	.52	41.2	48.4	46.2	2.83	.50	41.2	52.2
18	48.1	3.27	.82	39.7	52.7	44.9	2.77	.69	39.4	50.4	46.5	3.40	.60	39.4	52.7

Linear measurement No. 3D. S-Gn/95-139

			Male					*Female*					*Male and female pooled*		
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	83.3	5.16	1.83	76.5	93.3	80.9	3.02	.75	75.6	86.2	81.7	3.92	.80	75.6	93.3
2	88.1	4.02	1.01	81.0	97.5	87.4	3.44	.86	80.1	92.7	87.7	3.70	.65	80.1	97.5
3	93.8	3.88	.97	87.8	102.6	92.2	3.32	.83	84.5	97.1	93.0	3.63	.64	84.5	102.6
4	96.4	4.06	1.02	90.3	102.9	94.9	3.03	.76	88.8	99.2	95.7	3.61	.64	88.8	102.9
5	100.4	3.66	.91	94.6	106.1	99.2	3.21	.80	94.1	106.4	99.8	3.44	.61	94.1	106.4
6	103.3	3.75	.94	96.9	110.5	101.9	3.49	.87	95.7	110.7	102.6	3.64	.64	95.7	110.7
7	105.9	4.55	1.14	100.1	113.0	104.8	3.67	.92	98.1	112.2	105.4	4.10	.73	98.1	113.0
8	109.8	4.63	1.16	104.0	115.8	107.3	3.87	.97	100.8	114.8	108.6	4.38	.78	100.8	115.8
9	111.2	4.62	1.15	104.4	118.8	109.6	4.35	1.09	103.8	118.8	110.4	4.49	.79	103.8	118.8
10	113.3	4.93	1.23	106.1	121.4	112.4	4.99	1.25	106.0	124.1	112.8	4.90	.87	106.0	124.1
11	115.5	4.69	1.17	108.5	123.8	115.0	5.31	1.33	107.0	126.9	115.2	4.93	.87	107.0	126.9
12	117.8	4.92	1.23	110.0	126.0	117.3	3.95	.99	110.2	122.9	117.5	4.39	.78	110.0	126.0
13	120.7	4.98	1.24	111.7	128.4	119.5	4.64	1.16	112.9	129.4	120.1	4.77	.84	111.7	129.4
14	124.2	5.47	1.37	113.8	134.6	122.0	5.48	1.37	115.5	133.3	123.1	5.50	.97	113.8	134.6
15	129.1	5.34	1.34	118.5	139.2	122.4	3.27	.82	115.9	127.9	125.7	5.53	.98	115.9	139.2
16	130.2	4.86	1.21	122.2	138.1	123.4	5.01	1.25	114.1	132.3	126.8	5.95	1.05	114.1	138.1
17	132.9	5.28	1.32	124.0	144.1	124.1	5.05	1.26	115.6	133.5	128.5	6.78	1.20	115.6	144.1
18	135.4	5.36	1.34	125.5	145.5	125.1	5.24	1.31	115.7	134.0	130.3	7.39	1.31	115.7	145.5

Linear measurement No. 4D. Go-Pogo/144-138

	Male					*Female*					*Male and female pooled*				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	48.6	1.22	.43	46.9	50.0	47.9	1.86	.47	43.7	50.5	48.2	1.68	.34	43.7	50.5
2	52.1	2.54	.64	46.2	55.4	53.4	2.93	.73	46.8	57.9	52.8	2.77	.49	46.2	57.9
3	55.7	1.99	.50	51.9	58.8	55.9	2.60	.65	51.3	60.5	55.8	2.28	.40	51.3	60.5
4	58.1	2.53	.63	53.2	61.9	58.1	3.06	.77	54.0	63.9	58.1	2.76	.49	53.2	63.9
5	60.9	2.41	.60	56.5	64.8	60.9	3.58	.90	55.9	66.7	60.9	3.00	.53	55.9	66.7
6	62.9	2.46	.62	58.8	67.0	62.7	2.67	.67	58.1	67.4	62.8	2.53	.45	58.1	67.4
7	65.5	2.79	.70	60.7	70.0	64.6	2.73	.68	59.0	69.4	65.0	2.75	.49	59.0	70.0
8	67.5	2.89	.72	63.0	72.0	66.7	2.96	.74	62.0	73.1	67.1	2.90	.51	62.0	73.1
9	69.2	3.08	.77	64.3	75.1	68.4	2.91	.73	63.6	73.9	68.8	2.97	.53	63.6	75.1
10	70.7	3.35	.84	65.6	77.3	70.4	3.39	.85	64.4	75.8	70.6	3.32	.59	64.4	77.3
11	72.1	3.26	.81	67.7	78.9	72.1	3.66	.91	65.7	78.5	72.1	3.41	.60	65.7	78.9
12	73.6	3.38	.84	68.5	80.4	72.5	2.54	.63	68.4	77.2	73.0	2.99	.53	68.4	80.4
13	75.5	3.78	.95	69.7	81.2	75.0	3.95	.99	67.7	82.2	75.2	3.81	.67	67.7	82.2
14	76.9	3.34	.84	71.6	84.5	76.3	3.71	.93	69.1	83.3	76.6	3.49	.62	69.1	84.5
15	79.7	3.96	.99	74.2	86.7	75.7	2.88	.72	70.4	80.9	77.7	3.97	.70	70.4	86.7
16	80.5	3.39	.85	75.0	86.9	76.3	3.34	.83	70.3	81.4	78.4	3.92	.69	70.3	86.9
17	81.6	3.67	.92	76.0	89.9	76.8	2.92	.73	70.4	81.2	79.2	4.08	.72	70.4	89.9
18	82.7	3.55	.89	76.5	89.8	76.9	3.62	.90	70.8	84.3	79.8	4.59	.81	70.8	89.8

Linear measurement No. 5D. Ar-Go/12-144

	Male					*Female*					*Male and female pooled*				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	30.0	2.68	.95	26.6	34.2	29.4	2.09	.52	26.1	32.6	29.7	2.26	.46	26.1	34.2
2	32.1	3.29	.82	28.0	38.8	31.6	1.83	.46	28.6	35.5	31.8	2.63	.47	28.0	38.8
3	33.9	2.81	.70	29.5	40.4	32.9	2.30	.57	27.5	36.7	33.4	2.58	.46	27.5	40.4
4	35.1	2.46	.61	31.0	39.6	34.7	2.60	.65	29.9	40.5	34.9	2.50	.44	29.9	40.5
5	36.3	2.39	.60	32.8	41.0	36.6	2.90	.73	32.1	41.9	36.4	2.62	.46	32.1	41.9
6	36.7	1.88	.47	33.9	40.9	36.0	2.31	.58	32.5	40.4	36.4	2.10	.37	32.5	40.9
7	37.8	2.13	.53	35.1	43.6	37.9	2.47	.62	34.9	43.0	37.8	2.27	.40	34.9	43.6
8	39.5	3.02	.76	35.7	47.1	38.0	2.52	.63	32.5	42.0	38.8	2.83	.50	32.5	47.1
9	38.8	2.24	.56	35.0	43.8	38.6	1.85	.46	35.2	42.0	38.7	2.03	.36	35.0	43.8
10	39.7	1.97	.49	35.8	44.8	40.0	2.51	.63	36.8	46.5	39.8	2.22	.39	35.8	46.5
11	40.7	2.17	.54	36.1	45.7	41.3	2.42	.60	37.8	46.9	41.0	2.28	.40	36.1	46.9
12	41.6	2.35	.59	37.8	47.2	43.1	3.16	.79	39.1	49.1	42.4	2.83	.50	37.8	49.1
13	43.4	2.65	.66	38.5	47.0	44.1	3.00	.75	39.4	48.8	43.8	2.81	.50	38.5	48.8
14	45.0	3.49	.87	37.1	50.1	46.4	3.05	.76	41.5	53.7	45.7	3.30	.58	37.1	53.7
15	47.8	2.78	.70	42.3	52.3	46.0	3.18	.80	40.9	52.0	46.9	3.08	.55	40.9	52.3
16	49.1	2.92	.73	42.2	53.7	46.5	2.97	.74	41.9	52.1	47.8	3.19	.56	41.9	53.7
17	51.2	2.73	.68	43.5	54.6	47.3	2.77	.69	43.4	52.0	49.2	3.35	.59	43.4	54.6
18	52.1	2.89	.72	46.1	57.0	47.7	2.88	.72	42.8	52.7	49.9	3.63	.64	42.8	57.0

Linear measurement No. 6D. Ar-Na/12-58

	Male					*Female*					*Male and female pooled*				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	68.7	2.33	.82	64.4	70.9	66.6	3.48	.87	60.3	74.6	67.3	3.26	.66	60.3	74.6
2	74.0	3.04	.76	70.2	79.0	72.5	2.65	.66	67.6	76.7	73.2	2.90	.51	67.6	79.0
3	77.7	2.89	.72	73.6	82.5	73.8	3.36	.84	67.0	79.5	75.8	3.66	.65	67.0	82.5
4	80.3	3.00	.75	75.1	86.3	77.4	3.59	.90	71.8	84.6	78.8	3.57	.63	71.8	86.3
5	82.4	2.81	.70	78.6	87.3	79.9	3.36	.84	75.5	87.1	81.2	3.29	.58	75.5	87.3
6	84.1	3.94	.98	78.6	91.2	80.4	2.50	.63	77.1	85.3	82.2	3.76	.66	77.1	91.2
7	86.5	3.29	.82	81.6	93.4	82.1	2.41	.60	78.4	87.8	84.3	3.59	.64	78.4	93.4
8	88.1	3.62	.90	82.1	94.6	83.7	2.63	.66	79.7	88.5	85.9	3.84	.68	79.7	94.6
9	89.4	3.97	.99	83.9	97.5	86.1	2.95	.74	81.0	91.0	87.8	3.83	.68	81.0	97.5
10	90.6	3.78	.94	85.7	98.1	86.6	3.21	.80	82.3	93.5	88.6	4.01	.71	82.3	98.1
11	91.7	3.90	.98	87.0	99.5	88.4	3.21	.80	84.8	95.0	90.0	3.89	.69	84.8	99.5
12	93.6	4.01	1.00	88.8	101.4	90.0	3.22	.80	85.5	97.1	91.8	4.01	.71	85.5	101.4
13	94.5	4.01	1.00	89.7	101.9	90.7	3.60	.90	85.0	97.2	92.6	4.24	.75	85.0	101.9
14	95.7	2.73	.68	92.0	101.9	91.9	3.41	.85	86.1	97.9	93.8	3.60	.64	86.1	101.9
15	98.6	3.66	.92	93.2	107.9	92.0	3.42	.86	86.6	99.4	95.3	4.85	.86	86.6	107.9
16	99.2	3.53	.88	94.3	108.0	91.8	2.88	.72	86.6	97.1	95.5	4.94	.87	86.6	108.0
17	99.8	3.77	.94	93.3	109.4	92.1	2.37	.59	87.8	95.7	96.0	4.99	.88	87.8	109.4
18	100.8	3.29	.82	94.5	109.2	92.6	3.44	.86	87.8	99.6	96.7	5.31	.94	87.8	109.2

Linear measurement No. 7D. Bo-S/14-95

	Male					*Female*					*Male and female pooled*				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	46.2	2.11	.74	43.3	50.2	45.2	2.13	.53	41.6	48.8	45.5	2.13	.44	41.6	50.2
2	49.3	2.54	.64	45.8	55.0	48.8	2.48	.62	44.2	54.2	49.0	2.48	.44	44.2	55.0
3	51.4	2.98	.74	47.8	57.8	50.8	1.89	.47	48.2	54.1	51.1	2.47	.44	47.8	57.8
4	52.4	2.65	.66	48.6	59.2	52.1	2.37	.59	45.9	56.5	52.2	2.48	.44	45.9	59.2
5	54.0	2.60	.65	50.6	60.3	53.3	2.22	.56	48.7	58.0	53.6	2.40	.42	48.7	60.3
6	56.4	4.00	1.00	50.3	66.0	54.9	2.75	.69	51.1	60.8	55.6	3.46	.61	50.3	66.0
7	56.4	2.97	.74	52.2	63.3	55.7	2.28	.57	52.8	61.1	56.0	2.63	.46	52.2	63.3
8	57.9	2.68	.67	53.2	64.7	56.7	2.72	.68	53.8	63.2	57.3	2.73	.48	53.2	64.7
9	58.7	3.44	.86	53.7	66.4	58.2	2.78	.70	55.0	63.7	58.4	3.09	.55	53.7	66.4
10	59.5	3.35	.84	53.7	66.6	58.8	2.78	.70	54.7	64.6	59.2	3.05	.54	53.7	66.6
11	60.3	2.83	.71	55.3	63.8	59.7	2.75	.69	56.3	65.2	60.0	2.76	.49	55.3	65.2
12	61.1	2.66	.67	56.1	66.1	60.1	2.41	.60	56.3	65.7	60.6	2.56	.45	56.1	66.1
13	61.4	2.95	.74	56.6	66.2	60.7	2.73	.68	55.9	65.8	61.0	2.81	.50	55.9	66.2
14	61.8	2.59	.65	56.6	66.0	61.2	2.82	.71	56.1	66.6	61.5	2.68	.47	56.1	66.6
15	63.4	2.33	.58	60.3	67.5	60.5	2.07	.52	56.9	64.6	62.0	2.61	.46	56.9	67.5
16	63.5	2.61	.65	59.5	68.8	60.9	2.27	.57	56.1	65.2	62.2	2.74	.48	56.1	68.8
17	64.2	2.24	.56	60.5	68.4	61.0	2.21	.55	55.2	64.2	62.6	2.70	.48	55.2	68.4
18	65.0	2.77	.69	61.0	70.9	60.0	2.01	.50	55.5	63.4	62.5	3.45	.61	55.5	70.9

Linear measurement No. 8D. Bo-Na/14-58

	Male					*Female*					*Male and female pooled*				
Age	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*	*M*	*SD*	*SE*	*Min*	*Max*
1	97.5	2.65	.94	94.1	102.9	94.7	2.99	.75	87.8	99.4	95.7	3.12	.64	87.8	102.9
2	103.7	3.40	.85	97.6	110.3	101.0	3.39	.85	95.6	107.3	102.4	3.61	.64	95.6	110.3
3	108.2	4.16	1.04	100.1	114.3	104.7	3.13	.78	99.5	111.5	106.5	4.04	.71	99.5	114.3
4	110.8	3.80	.95	104.8	117.5	108.7	2.96	.74	102.6	113.2	109.8	3.51	.62	102.6	117.5
5	113.6	3.97	.99	107.1	121.3	111.1	3.02	.76	105.9	116.0	112.4	3.70	.65	105.9	121.3
6	116.6	5.67	1.42	109.8	129.0	112.4	3.31	.83	106.0	119.7	114.5	5.04	.89	106.0	129.0
7	117.9	4.39	1.10	111.8	126.4	113.8	3.11	.78	108.1	120.5	115.8	4.29	.76	108.1	126.4
8	120.0	4.41	1.10	113.2	128.7	115.4	3.58	.89	109.2	122.3	117.7	4.58	.81	109.2	128.7
9	121.0	5.26	1.31	113.4	130.6	117.4	3.30	.82	113.0	124.9	119.2	4.70	.83	113.0	130.6
10	122.5	5.43	1.36	114.1	133.5	118.7	3.68	.92	112.0	125.8	120.6	4.96	.88	112.0	133.5
11	123.6	5.06	1.27	115.3	133.6	120.1	3.74	.94	114.4	128.8	121.9	4.72	.83	114.4	133.6
12	125.5	5.00	1.25	118.3	135.3	121.9	3.75	.94	116.8	130.3	123.7	4.72	.83	116.8	135.3
13	126.0	5.16	1.29	117.8	137.5	123.0	3.78	.95	116.2	130.6	124.5	4.71	.83	116.2	137.5
14	126.9	3.97	.99	117.4	130.9	123.5	3.75	.94	118.0	131.7	125.2	4.18	.74	117.4	131.7
15	130.0	4.48	1.12	122.8	141.1	123.5	3.50	.87	117.8	129.9	126.7	5.15	.91	117.8	141.1
16	130.5	4.76	1.19	124.9	142.6	123.3	3.20	.80	119.3	129.6	126.9	5.42	.96	119.3	142.6
17	131.9	4.45	1.11	125.9	143.7	123.5	3.12	.78	118.2	129.0	127.7	5.72	1.01	118.2	143.7
18	132.5	4.27	1.07	126.2	142.9	122.9	3.48	.87	118.6	131.2	127.7	6.19	1.10	118.6	142.9

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