Orthodontics in 3 millennia. Chapter 7: Facial analysis before the advent of the cephalometer

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The cephalometer was not invented in a vacuum. It was the culmination of centuries of efforts on the part of artists, anthropologists, and scientists to fathom nature's vicissitudes. Whereas Renaissance investigators "caged" the human face in a series of grids in an effort to find proportional relations, 20th-century orthodontists were more interested in knowing how the teeth and jaws related to the face and cranial base. Primarily a research tool, the cephalometer became a means of unmasking a patient's whole developmental pattern, becoming our most important diagnostic tool since study models. (Am J Orthod Dentofacial Orthop 2006;129:293-8)

Cephalometrics did not begin in orthodontics, but in studying human growth and the development of craniofacial anatomy.[1] The appraisal of these patterns is especially important in the treatment of Class II and Class III malocclusions, because the orthodontist must rely on the control of growth. In any case, only the cephalometric radiograph can show the relationships of the teeth to the other craniofacial structures. Historically, the human form has been measured for many reasons. One has been to aid humanity's self-portrayal in sculpture, drawing, and painting.[2] Man's face has also been studied extensively by anthropologists with an early focus on its proportional relations by a network of horizontal and vertical lines.

DEFINITIONS

Ever since Camper investigated prognathism craniometrically in 1791, *anthropologists* (those who specialize in the study of human beings) have been interested in the *ethnographic* (relating to cultures) determination of facial form and pattern. Using *anthropometrics* (the measurement of man), anthropologists found the human head a fertile source of information because of the relatively little change in the bony parts as a result of death. As a specialized part of anthropometrics, the study of the head became known as *craniometrics* (measurement of dry skulls). *Craniostats,* designed to hold the skull in an oriented position, were the forerunners of the *cephalostat*, or head holder. The cephalostat, in turn, became the forerunner of the *cephalometer*. It was only after the measurements and relationships were applied to the living subject (*cephalometrics*) that their use in the field of orthodontics was seen to be important. Certain landmarks were developed to assist the anthropologist in interpreting craniofacial relations. Today's use of the term *cephalometrics* implies *roentgenographic* cephalometrics, the end result of which is the *cephalogram* (cephalometric radiograph), called by Europeans the *tele(o)roentgenogram.*[3]

RENAISSANCE TO THE 20TH CENTURY

The analysis of facial proportions reached a climax in the studies of Leonardo da Vinci (1452-1519; Italian) (Fig 1) and Albrecht Dürer (1471-1528; German) (Fig 2). Da Vinci demonstrated the projection of a coordinate or grid system on the face of a horseman. Dürer used a coordinate system to demonstrate differences in the long, narrow face and the broad face, and showed how the proclined facial contour differed from the retroclined configuration by a change in the angle between the vertical and horizontal axes of his coordinate system (Fig 3).

Petrus Camper (1722-89; Dutch) (Fig 4), physician, anatomist, and painter, opened the door to anthropometric methods of ethnographic determination of facial form and was probably the first to employ angles in measuring the face. His *linea facialis* became the universal measurement for the study of the human face. The terms *prognathic* and *orthognathic* introduced by Retsius are tied to Camper's illustrations of facial form in man and primates beginning of scientific measurement of the human skull, which was based on Camper's facial line (a forward projection from the upper incisor tangent to the frontal bone) and facial angle (formed by the horizontal reference line [plane] and the facial line). Camper found that as the face grows downward and forward, the facial angle decreases.[4]

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Fig 1. Leonardo da Vinci, the original "Renaissance man."

Fig 2. Albrecht Dürer, regarded as greatest of German Renaissance artists, helped lay foundation for cephalometrics.

An international congress of anatomists and physical anthropologists was held in Frankfürt, Germany, in 1882, with the choice of a horizontal reference plane for orientation of skulls as an important item for the agenda. At the suggestion of Herbert Von Ihering, the *Frankfort plane*, extending from the upper rim of the external auditory meatus (porion) to the lowest point on the margin of the orbit, was adopted as the best representation of the natural orientation of the skull. However, as Krogman and others have pointed out, Frankfort horizontal and the external auditory meatus are not biologically related to growth. They are technical conveniences and little else. For that matter, there is no point, plane, dimension, or angle that during growth relates invariably to any other such landmark.[5] Photographs were also used to obtain a picture of the soft tissues; Galton, at the end of the 19th century, superimposed photos of different individuals on one another to get an average face. Unfortunately, the photograph was still only a 2-dimensional picture of a 3-dimensional object, but it did enable the observer to see the effects of treatment on the soft tissues.

The divine proportion

Is it possible to reduce beauty to numbers? The golden ratio, or divine proportion, has for centuries been thought by many to represent perfect harmony, or the most attractive proportion in almost all things. Da Vinci is said to have applied the ratio to his paintings, including the *Mona Lisa*, where not only the face, but also the rest of the body, may have been formed according to a golden rectangle (Fig 5).[6] Even today's engineering feats incorporate the "golden section." The Tacoma (Wash) Narrows bridge is being constructed so that the ratio of its main span to a side span is the same as between the whole and the main span.[7]

In the divine proportion, developed by Greek mathematicians, the length of a line is divided into two parts such that the minor part divided by the major part equals the major part divided by the total. In other words, the major part is 1.61803 times as long as the minor part. In a 1982 study, Ricketts found numerous examples of divine proportion in the faces of commercial models, in the teeth of subjects with normal excellent occlusions, and in measurements of both frontal and lateral head films, suggesting that esthetics can indeed be analyzed scientifically.[8] In the design of the human face, nature evidently translated the divine proportion into a pattern of harmonious relations between the soft and hard tissues.

EARLY 20TH CENTURY

Discovery of x-rays

Wilhelm C. Roentgen (1845-1923) a German physicist, made his discovery in 1895 when by chance he noticed that a phosphor screen near a vacuum tube through which he was passing an electric current fluoresced brightly, even when shielded by opaque cardboard. For this he received the first Nobel Prize for Physics.[9]

Influence of art

In 1900 Angle was seeking a rule for facial form that he could give his students. On approaching Edmund H. Wuerpel (1866-1958), an art teacher at the Washington University School of Fine Arts, he was told that there was no such rule; that beauty is dependent on the observer; and that the observer, in turn,

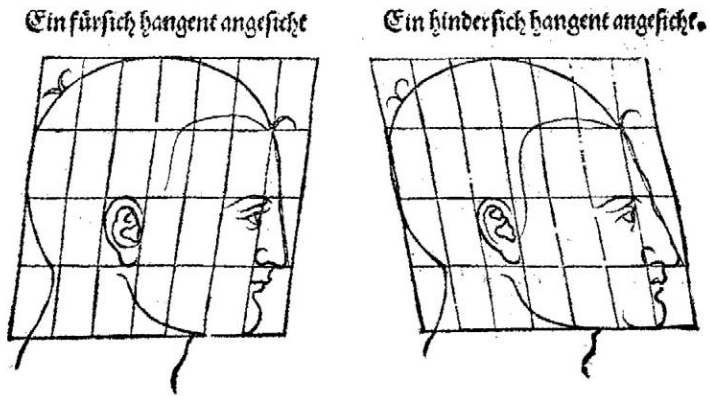

Fig 3. Dürer demonstrated how single angular measure characterizes configuration of different facial types.

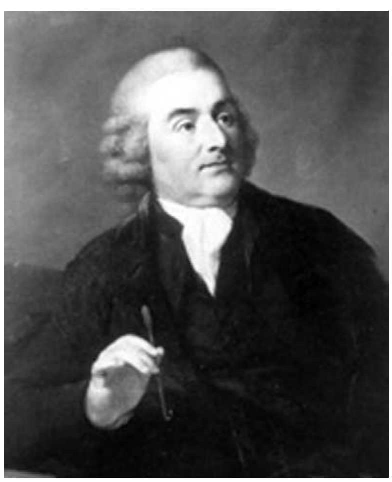

Fig 4. Camper's facial angle, based on comparative anatomy, had profound influence on esthetics and anthropology.

was influenced by race, color, culture, and background. Angle asked Wuerpel to tell this to his students. This he did for the rest of Angle's teaching life and remained one of Angle's closest friends.[10]

Justus A.W. van Loon, physician, dentist, and lecturer in orthodontics at the University of Utrecht, was probably the first (1915) to introduce cephalometrics into orthodontics when he applied anthropometric procedures in analyzing facial growth by making plaster casts of the face into which he inserted oriented casts of the dentition.[3]

Beginning in the 1920s, several investigators began laying the groundwork for modern cephalometry. Hellman, drawing on his experience as a research associate at the American Museum of Natural History, introduced craniometric measurements, thereby adapting techniques of physical anthropology to orthodontic research and diagnosis.

August J. Pacini, MD (1888-?) recognized that roentgenographic cephalometry was more accurate than the anthropometric methods then in use. His method, which was rather primitive, involved a large, fixed distance from the x-ray source to the cassette, with the median sagittal plane of the subject's head parallel to the film. Thus, as early as 1921 a rather well-thought-out procedure for oriented lateral skull roentgenography was in use for anthropologic purposes and standardized head radiography.[3]

Gnathostatics

Fortunately, the economic chaos of Weimar Germany did not stunt the growth of a new crop of orthodontic researchers—Hofrath, Korkhaus, and Kantorowicz, to name a few—that was to help put Europe back on the orthodontic map after a comparative absence since the mid-19th century. One of the first of these was Paul W. Simon (1883-1957). After receiving his DMD degree at the University of Berlin in 1907, Simon went to work at the Berlin Polyclinic. During World War I he was an army dental surgeon. In 1924 he was asked to present his dissertation on *gnathostatics* at the AAO meeting in Kansas City.

Using anthropological methods, he related the denture to the face and cranium in three planes of space: Frankfort, orbital, and midsagittal (Fig 6). In 1923 he wrote *On the Norm Concept in Orthodontics,* wherein he espoused the tenet that norms do not exist in external nature, but are created by man's mind to create order in a complex world. His gnathostatic and photostatic research gave him the basis for contradicting Angle's dogma of the first maxillary molar and key ridge as the diagnostic criteria for sagittal discrepancies.[11]

Fig 5. Calipers set to a constant ratio of 1.6:1 are used to demonstrate divine proportion in faces (drawings by Leonardo Da Vinci).

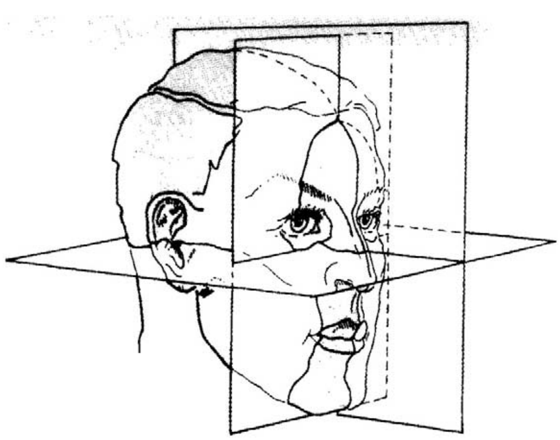

Fig 6. Paul Simon insisted that every diagnosis be based on 3 dimensions.

Although Simon's theories were rejected by Broadbent and others, gnathostatics played an important role in making the orthodontist more conscious of basal relationships, facial balance and harmony, cant of the occlusal plane, inclination of the mandibular plane, and arch asymmetries.[12] Only recently has 3-D imaging technology enabled Simon's vision to materialize.

IMPACT OF THE CEPHALOMETER

Development

The forerunner of the cephalometer—the Reserve craniostat (after Western Reserve University)—was developed by T. Wingate Todd (1885-1938), who did more than any other nondentist of modern times to advance orthodontics. Born in Sheffield, England, Todd began his career as a surgeon and demonstrator, but became interested in anatomy, especially skeletal development. In 1912 he was called to the US to become professor of anatomy at Western Reserve University Medical School. In 1920 he was appointed director of the Hamann Museum of Comparative Anthropology and Anatomy in Cleveland.

In 1926, assisted by Broadbent, Todd undertook a growth study of children on a more exact basis than the prevailing basis of weight and stature, x-raying more than 4,500 children throughout the whole of their growth periods, thus establishing standards of normal growth and development at any period of childhood. He developed an index of maturation for the hand and wrist (*Atlas of Skeletal Maturation*) and brought attention to the influence of the first molar in facial morphology and to the existence of growth spurts. In short, he elevated anatomy from a static discipline to a dynamic study of growth and development.[13]

While studying roentgenography of the face under Atkinson at the Angle School in 1922, it occurred to B. Holly Broadbent Sr. (1884-1977; Angle School, 1923) that these facial pictures could be superimposed on certain base lines, thereby disclosing more clearly the changes in the teeth and jaws during orthodontic treatment. After Broadbent completed his training with Angle, he received an appointment as research fellow in the Western Reserve Department of Anatomy under Todd.

Thanks to his earlier experience in a machine shop, within a year Broadbent was able to make a contribution to Todd's apparatus. Together they designed a roentgenographic craniostat that made possible precise standardization of cranial x-rays of dry skulls. The next step was to adapt the device to the heads of living subjects: the roentgenographic cephalometer.[14] As a result of his work, Broadbent was assigned to research, under Todd, the cephalic development of 800 children in a study sponsored by the Brush Foundation.

The same year that Broadbent published his technique in the first issue of the *Angle Orthodontist*, Herbert Hofrath (1899-1952) came out, in the German literature, with "The Importance of Teleroentgenograms for Diagnosis of Jaw Abnormalities." However, it was not accepted as the standard technique because

- there was little mention of a frontal view,
- the path of the central ray was not fixed in relation to the head,
- no plan was suggested for superimposition of subsequent films, and
- considerable emphasis was placed on the recording of soft tissue.

For the first time, investigators were able to follow longitudinally the orofacial developmental pattern and the intricacies of tooth formation, eruption, and adjustment. No longer did they have to depend on dried skulls of unknown history and of dubious ethnic origin, age, and health backgrounds.[11]

Roentgenographic cephalometry made it possible to measure growth in the same person. Until 1931, diagnosis was performed using a clinical exam, models, and facial photographs as tools. After the Broadbent-Bolton cephalometer was introduced in 1931, no diagnosis would be complete without it.[15] But it would be many years before cephalometrics would become a standard clinical tool.

CRANIOFACIAL GROWTH STUDIES

In the early years, the cephalometer was primarily a research tool. Through the medium of serially produced and accurately oriented cephalograms, orthodontists could now see the total development pattern, or they could study changes in one or more parts of the face over a circumscribed length of time.[16] It gave investigators an extension of their senses so they could see what was "inside."

Gustav Korkhaus (1885-1978) (Fig 7), internationally revered scientist and patriarch of German orthodontics, even before the advent of roentgenographic cephalometry, believed that profile analysis formed the most reliable basis for a diagnosis and developed an evaluation of head films not unlike our present analytical tracing.[17] In addition to teaching, Korkhaus researched the origin of dental malformations and the genetics of occlusion in twins. He built the Bonn clinic into one of the most modern teaching and research institutes of its time and founded the *Journal of Orofacial Orthopedics*.

Fig 7. Gustav Korkhaus (left, with Viggo Andresen) founded Germany's first orthodontic journal, but his influence on orthodontics was worldwide.

Wilton M. Krogman (1903-87), who obtained his PhD at the University of Chicago, was not a dentist, but a physical anthropologist who made invaluable contributions to cephalometry. As early as 1931 he was superimposing tracings of anthropoid skulls, using porion as a registration point to recognize the development of a growth pattern, thereby establishing standards for growth and development.[18]

He was founder and director of the Philadelphia Center for Research in Child Growth (1947), the first of its kind. Many thousands of normal Philadelphia school children were assessed as part of establishing the first longitudinal studies of physical and craniofacial growth in this region. The center has become a widely used resource for the diagnosis of unusually complicated growth disorders.[19]

Broadbent's studies

The cephalometer was not wholeheartedly accepted by the profession when it was introduced. Hellman called adherents "pseudo-anthropologists." However, Broadbent, convinced of the ultimate value of records made through its use and able to work independently of Todd, proceeded in 1929 to establish the Bolton Study.

By a stroke of fortune, the mother of one of his patients, Congresswoman Frances Payne Bolton, became interested in Broadbent's project and set up a fund to continue the study. After maturing, her son, Charles Bingham Bolton, took an active part. The study eventually included 4,309 children and led to the finest serial collection of standardized cephalograms available.[18]

In 1937 Broadbent published his findings based on an analysis of a 5-year accumulation of films on more than 1,000 cases. The most striking revelation was that the face of the normal child develops downward and forward in an orderly fashion. Other important findings were: (1) the pattern of the head and face is established at a very early age (about 3 years) and undergoes little if any change thereafter, and (2) the so-called bimaxillary protrusion is due more to retarded development of the facial skeleton than to the denture being too far forward in relation to the cranial base.[20]

Under the direction of Broadbent's son, B. Holly Jr, the collection continues to be a mine of investigative material. In 1970 all materials were combined in 1 center, to be called the Bolton-Brush Growth Study Center.[14] The completion of Update 2000 will make the Bolton Collection a cradle-to-grave study of normal dentofacial growth.[21]

Allan G. Brodie

As a fellow alumnus of the Pasadena school, Brodie was likely following Broadbent's work with great interest. Brodie at once recognized the application of the cephalometer to research and, when his department was established in 1929, insisted on the installation of a Broadbent-Bolton cephalometer. While Broadbent was starting the Herculean task of accumulating serial records in Cleveland, the University of Illinois was using the cephalometer largely for the study of clinical patients and unusual cases. By 1938, Brodie's group had something to show for their efforts. In "A Cephalometric Appraisal of Orthodontic Results: a Preliminary Report," they found that, first, there was a definite correlation between success in treatment and good facial growth; second, the orthodontist is able to move teeth without markedly disturbing their axial inclinations; and third, changes accompanying orthodontic treatment seemed to be restricted to the alveolar bone—a far cry from the earlier belief in "bone-growing."[22]

After 10 years at the helm of the country's most respected orthodontic program, Brodie felt inadequate with only an MS degree. The outcome was a PhD thesis, based largely on Broadbent's collection, wherein he stated that the mandibular rest position was established before eruption of the teeth and was not later influenced by their presence.[23,24] "Steve" Brodie's special achievement was his systematic and imaginative approach to the study of growth and development and his ability to relate laboratory findings to the daily, practical problems of orthodontics.[18]

The list of pioneers in cephalometric radiography would not be complete without the name of L. Bodine Higley (1899-1990). At the University of Iowa, Higley employed standardized profile roentgenograms as early as 1931. He pioneered TMJ radiography and reproduction of hard and soft tissues in profile roentgenography. In 1936, he invented a cephalometric head positioner and cassette holder, a design now widely used. His early theories on temporomandibular articulation, at the time controversial, were validated many years later.[25]

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