Craniometry and Cephalometry: A History Prior to the Advent of Radiography

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Craniometry is defined in the Edinburgh Encyclopaedia of 1813 as "the art of measuring skulls of animals so as to discover their specific differences."[1]

Cephalometry is concerned with measuring the head, inclusive of soft tissues, be it living or dead.

Any person who examines lateral skull radiographs is inevitably looking at the size of the structures depicted even if they do not specifically measure them. It is particularly interesting to look at the origins of radiographic cephalometry as it is widely used now in the treatment planning for correction of skeletal and dental abnormalities.

Observations as to variations in human skull form have been recorded for many centuries. Hippocrates (460-357BC), affectionately and reverently known as "the Father of Physic," was a pioneer in physical anthropology. Although he made numerous descriptions as to the variety of skull forms, in particular commenting on macrocephalics, he did not employ measurements to distinguish between the various characteristics that he noted.[2]

The fifteenth century saw the advent of specific measurements being made to compare the features of different skulls and heads. Leonardo da Vinci (1452-1519) was probably one of the earliest people of note to apply the theory of head measurement to good effect in practice. He used a variety of lines related to specific structures in the head to assist in his study of the human form. The accompanying two illustrations of his work demonstrate his use of lines to break up the head and skull into small units, which can more easily be reproduced on a different scale at a subsequent time.[3]

In the pen and ink drawing of a skull (Fig. 1) there are four approximately horizontal lines, marked A, B, C, and D in this reproduction. The most superior line, A, is not related to any skeletal structures. The second line, B, passes through the junction of the frontal and nasal bones anteriorly and through the dorsum sellae posteriorly. This line is very close to the line sella-nasion as used today in radiographic cephalometry. The third line, C, passes through the anterior nasal spine and along the roof of the hard palate, corresponding to the current maxillary plane. The most inferior line, D, is less precise, being in contact with the skull only anteriorly at the most inferior point of the symphysis. There is no posterior locating point for this line.

In the second illustration (Fig. 2) a similar technique has been applied to a man's head. Lines that correspond to those depicted on the skull can be identified in addition to lines more appropriate to the soft tissue anatomy, such as the line running horizontally forward from the junction of the upper and lower lips. The most interesting line is that passing tangentially to the lowest point of the ala of the nose and the inferior aspect of the lobe of the ear. This is a good line that is naturally horizontal when the subject is in an upright posture looking toward the horizon. This is a recurring feature of many of the "base" lines that have been propounded since then.

From the Department of Dental Radiology, Guy's Hospital, London.

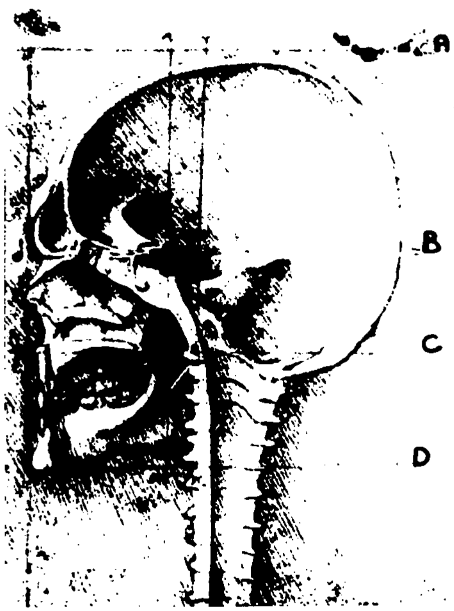

Fig. 1 Anatomical drawing of a skull in profile.

Fig. 2 Study of a man's head, squared for proportion.

Albrecht Dürer (1471-1528) used a very similar horizontal line for his base line. He published a treatise in 1528 on cranial measurements, having carried out some investigations to aid his work as an artist.[4] This treatise comprised "Vier Bücher von menschlischer Proportion" dealing with the proper proportion of the human form in the first two books, the proportions according to mathematical rules in the third book, and the human figure in motion in the fourth book. This work was the first published attempt to apply anthropometry to aesthetics.[5] Artists have always been naturally interested in the human form and it was not until some time later that other people became interested in form as their prime objective.

The sixteenth century saw the first truly scientific attempt at cranial measurement and the introduction by Spigel (1578-1625) of the "lineae cephalometricae." (Spigel is the spelling customarily used in the literature, although the original spelling was Spieghel, Adrian van der.) Spigel's lineae cephalometricae consisted of four lines: the facial, occipital, frontal and sincipital lines. He described these lines as follows: *facial*—from the most inferior point of the chin to the most superior point on the forehead, *occipital*—from the crown of the head to the atlas, *frontal*—from one temple to the other, and *sincipital*—from the lowest part of the ear, in the region of the mastoid process, to the highest part of the sinciput, the sinciput being the anterior part of the head or skull, from the forehead to the crown. He propounded the theory that in a well-proportioned skull these lines should all be equal to one another.

In reporting this Aitken-Meigs writes "although these lines are evidently not sufficient for the comparative ethnography of the present day, yet it is interesting to observe that, in ascending the zoological scale, these lines approximate just in proportion as the head measured approaches the human form."[4] At this point in the development of craniometry there was little interpretation of small variations in measurements. To Spigel a skull was either well-proportioned or it was not; there were no qualifying values between the two extremes of acceptance or rejection. He did suggest that measurement could be used for expressing differences in human skull form, but he was not concerned about the interpretation of the significance of these differences.

At this time there were still some barriers that separated the study of man from that of lower species. These barriers were broken when a Cambridge physician undertook some measurements on the chimpanzee skull in 1699. As a result of his work Edward Tyson (1650-1708) proposed that there was an intermediate animal between man and monkey. He described this animal as a form of "pygmy." Unfortunately this "pygmy" was later shown to be another chimpanzee, so negating his findings.[2]

From this time onwards craniologists abounded and numerous systems of analysis were propounded. Most of the workers in the eighteenth century were in particular very interested in relating intelligence to certain measurements. They not infrequently found that their native race demonstrated a higher level of intelligence, according to their methods, than did others.[4]

The Dutchman, Pieter Camper, (1722-1789) was particularly concerned with the distinction of different races of men. He introduced the *Facial Angle,* which has been widely used since. His famous publication "Dissertation sur les variétés naturelles de la physionomie" appeared posthumously in 1791. However, his findings were of limited value as his collection of skulls was not sufficiently large, or diverse, for a systematic arrangement of the varying forms of cranium.[1]

The facial angle as he described it was formed by the intersection of a facial line and a horizontal plane. These two components can be described: 1) The facial line was a line tangential to the most prominent part of the frontal bone in the neighbourhood of the glabella, and to the slight convexity anterior to the upper teeth. In the head, the facial line passes through the point of contact of the lips, as seen in profile (this represents the most anterior point on the surface of the upper incisors) (Fig. 3). 2) The horizontal plane passes through the lower part of the nasal aperture, backwards along the line of the zygomatic arch, and through the centre of the external auditory meatus.

The facial angle obtained following Camper's method is greatest in heads such as those that were immortalised by the Greek artists in their masterpieces of sculpture in which the facial angle is about 100°. An angle greater than this is not normally found in man in whom it would result in a rather monstrous appearance. Some examples of the facial angle according to Camper are: European man 80°, Negro 70°, Orangutan 58° and Monkeys 42°.

Camper said "if it be now asked what is meant by a fine countenance, we may answer, that in which the facial line makes an angle of 100 degrees with the horizon. The ancient Greeks have consequently chosen this angle." He did not adhere strictly to his location of the posterior reference point for the horizontal plane, nor did he take into account the fact that the locating point might alter its po-

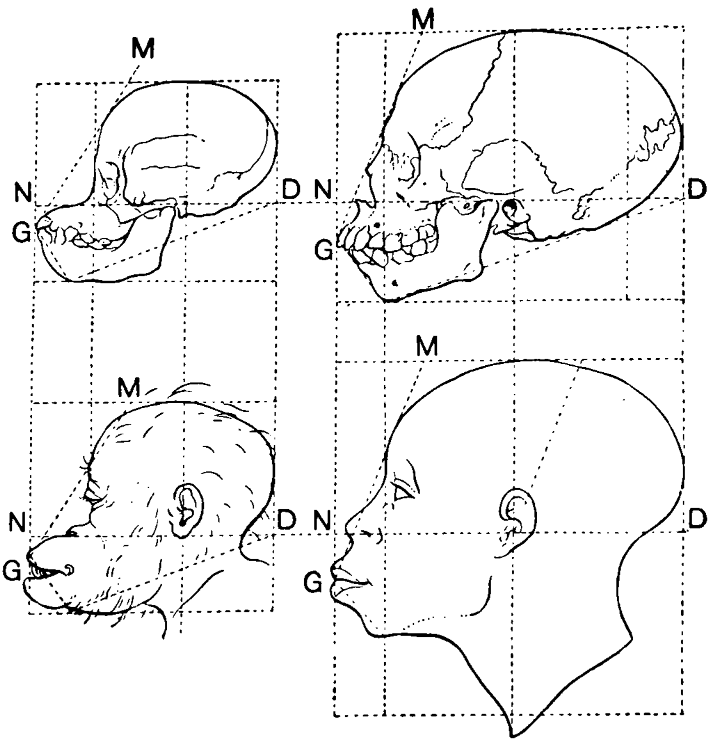

Fig. 3 Drawings of the head and skull of a young orangutan and of a negro, to show the method of determining the facial angle of Camper. (Reproduced in Duckworth's *Morphology and Anthropology*, from Camper's original memoir.)

sition relevant to other bony structures with advancing years, thus making direct comparisons of skulls of different ages impossible.[1] This is of interest because in radiographic cephalometric analysis we use many reference points which change their relative positions with age. One of the problems that challenges researchers is to discover points that remain stable throughout growth.

One of the major drawbacks to the use of Camper's facial angle is that it ignores the contribution made by the lower jaw to facial forms. It is possible for races exhibiting widely differing cranial forms to share a common facial angle and, conversely, for skulls from the same race to demonstrate a variety of facial angles resulting from the normal range of facial characteristics.

Shortly after Camper introduced this angle, Deschamps (1740-1824) introduced the cephalic triangle. This was made up of the facial, coronal and occipital angles. He described the facial angle as being made up of a horizontal line that passed from the external auditory meatus to the base of the nose, which crossed a profile line, the lesser angle formed by this intersection being the facial angle. This is essentially the same as Camper's method. Fortunately, the majority of the earlier workers used the external auditory meatus as a reference point, so enabling at least rough comparisons to be made between different skulls.[4] Craniologists such as Doornik, Spix, Oken and many others, all put forward their individual methods of analysing human and animal skulls. All had one common motivating

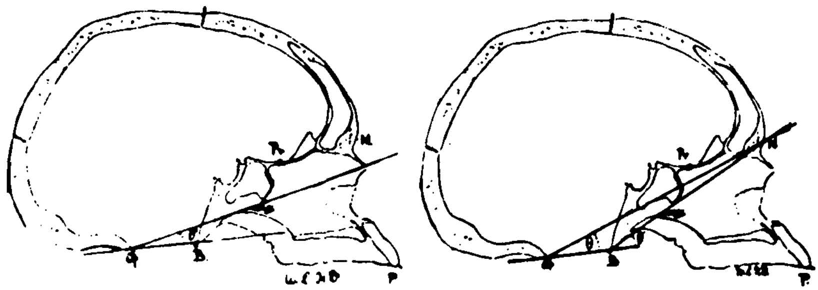

Fig. 4 Illustration of Daubenton's angle (left) and Broca's occipital angles. (From Duckworth.)

force: the desire to learn how men differ from each other and from animals, and why.[1]

In the same period as Pieter Camper there was a Frenchman producing some novel ideas of his own. Daubenton (1716-1799) was very concerned with the relative position of the foramen magnum in man and in lower animals. He undertook various measurements using "new" angles including the occipital angle (Fig. 4). His measurements were not very reliable but the angle is of interest as a similar angle was later used by Pierre Broca.

Skulls, sectioned in the midsagittal plane, were often used to measure given angles. The two illustrations (Fig. 4) are taken from the same sectioned skull. In both cases the base line is drawn along the level of the opening of the foramen magnum, from the inial edge of the foramen, along the surface of the occipital condyle and anteriorly for a short distance. Daubenton's second line passes from the posterior margin of the foramen magnum to the tip of the nasal spine. This use of the tip of the nasal spine must have posed problems in those many cases in which it would be found fractured. Broca uses two different lines giving alternative angles, originating from the posterior and anterior margins of the foramen magnum and passing anteriorly through the junction of the frontal and nasal bones.[5] If the occipital angle is used for comparing species, the magnitude of the angle decreases as the habitual posture of the animal tends more towards the upright.

Daubenton's interest in the position of the foramen magnum was shared by Sir Charles Bell (1744-1842). He was interested, inter alia, in the balance of the head and in the reasoning behind the diversity in shape between the Negroid and European heads. He argued that as the head is movable on a pivot, then it must always be balanced. If it were heavier behind, then it would be inclined forward to relieve the muscles and maintain the balance of the head. But, being heavier in front in the negro skull and thus falling forward naturally, it is thrown backward to poise it and relieve the muscles which support it behind.[6]

To test this hypothesis William Gibson (1788-1868) in 1809, when a medical student, undertook some investigations. He placed Negroid and European skulls in front of him resting on their occipital condyles. The European skull fell forward and the Negroid skull backward. This was quite the opposite result from that expected according to Bell. Samuel Soemmerring (1755-1830) had noted this same point in 1785, and came to the same conclusion as Gibson that it was a peculiarity of negroid crania to fall backward. In keeping with the current trend they linked this phenomenon with the idea that the white man was of a superior nature to the negro, a rather suspect belief, but one widely held at that time.

Camper had one great antagonist, Johann Friedrich Blumenbach (1752-1840). Blumenbach rejected the method of lines and angles as a test of national characteristics and proposed instead a more minute survey of the skull in general and in particular the frontal and maxillary bones.[6] In 1795 he described a method of positioning the cranium to be measured in a standard, reproducible manner. This is a most important point if findings are to gain both respect and acceptance from fellow workers. His method was simple, consisting of resting the skull on its base and looking down vertically upon its vault, that is, at its norma verticalis. The points worthy of recording were the projection of the maxillae anterior to the frontal arch, the direction of the jaws and cheek bones (outward, forward, etc.) and the proportional breadth or narrowness of the head. He completely rejected the idea of viewing the head in norma lateralis, but in spite of this he introduced some important features that demonstrate variability in the coronal outline and the breadth of the face.[4] It would have been very interesting if Camper and Blumenbach had pooled resources and devised a grand joint system.

A correlation of these two schemes was attempted by Anders Retzius (1796-1860), as a result of which he provided the basis for the methods of craniology used today. We also have him to thank for the cephalic index, the ratio of the breadth of the skull to its length, expressed as a percentage.

John Barclay (1758-1826) proposed two new angles and for the first time incorporated the mandible into his measurements. His superior basifacial angle was not dissimilar to Camper's facial angle. The superior basifacial line is drawn along the basilar surface of the superior maxillary bone and his inferior basifacial line along the base of the lower jaw (from a point at the level of the angles to the base of the symphysis). He used a custom-made goniometer (supplied by a Dr. Leach) to measure the angle formed by the superior line and a profile line.[1]

The nineteenth century produced three very great men in the history of craniology: Huxley, Broca, and Topinard.

Thomas Huxley (1825-1895) wrote in 1876, "the so-called facial angle, in fact, does not simply express the development of the jaws in relation to the face, but is the product of two factors, a facial and a cranial, which vary independently. The face remaining the same, prognathism may be indefinitely increased, or diminished, by rotation of the frontal region of the skull, backwards or forwards, upon the anterior end of the basi-cranial axis."[7] Huxley felt that the sphenomaxillary angle which he described was a preferable measurement to Camper's angle, when comparing the degree of prognathism in different skulls. He also derived the sphenoethmoidal angle, using certain points in the skull to divide the cranial base into anterior, middle and posterior bases (Fig. 5).

The sphenoethmoidal angle, as illustrated, tends to be less than 180° in man. The sphenomaxillary angle, which is not illustrated, is included by the lines drawn from basion and prosthion respectively to the prosphenion.[5]

Broca founded the Paris Society of Anthropology and was featured often in the Bulletins as well as Topinard,

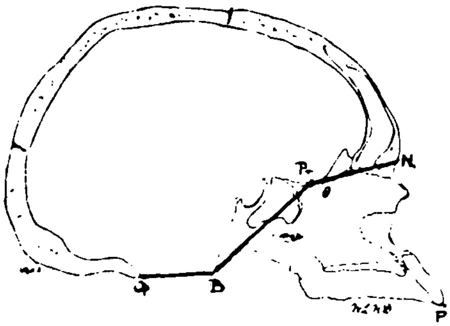

Fig. 5 An illustration of a medial section of the skull of an aborigine of Australia showing the three divisions of the cranial base: Pr-N; B-Pr; Op-B; and the spheno-ethmoidal angle. N, nasion; Pr, prosphenion; B, basion; Op, opisthion; P, prosthion. (From Duckworth, 1904).

who was curator of the Society museum. Broca (1824-1880) believed that the great variability of cranial form constituted a principal difficulty for the craniologist.[8] He was the first craniologist to institute a precise and accurate technique which could be used to compare crania. His goal was to acquire sufficient descriptions and measurements to make it possible to discriminate between the variations in racial types among human skulls. In his first paper, published in 1859, he discussed the collection and preservation of skulls, the anatomical features, craniometric instruments, definitions of points and planes, methods of graphical representation, qualitative descriptive characters and other matters of anthropological importance.[9] He introduced a new base line, his "plan alvéolo-condylien," which passes through the alveolar point and tangential to the inferior surfaces of the two occipital condyles.[8]

To obtain reproducible results he developed a craniostat, mainly constructed of wood for positioning the skull (Fig. 6). In the centre is a small block of wood on which the occipital condyles rest to position the plane horizontally. To prevent the skull from overbalancing backwards there is a wooden wedge fitted behind it. Holding the skull in one hand, the other is used for positioning the anterior locating rod in the alveolar point, in which position it is fixed. The horizontal plane is determined on purely anatomical grounds.[8]

It was generally accepted at this time that angles were best determined on projected drawings of the skull. A simple method was to trace the outline of the skull onto a piece of paper. Broca elaborated on this by fixing the skull in question in a craniostat. A drawing board with paper attached is positioned parallel to the midsagittal plane, and a pencil is held in a frame perpendicular to the paper.[5] The resultant tracing is equivalent to a tracing of peripheral structures as depicted on a lateral skull radiograph. The system of using median longitudinal sections of a skull has already been mentioned.

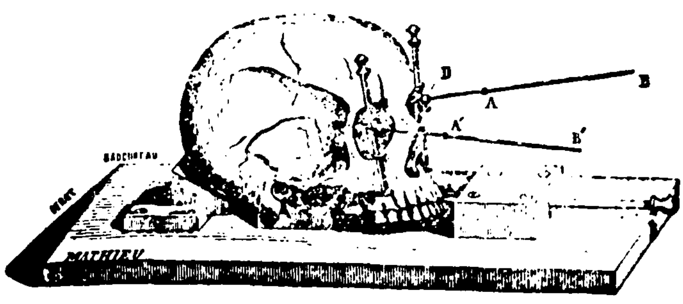

Fig. 6 Illustration of Broca's craniostat.

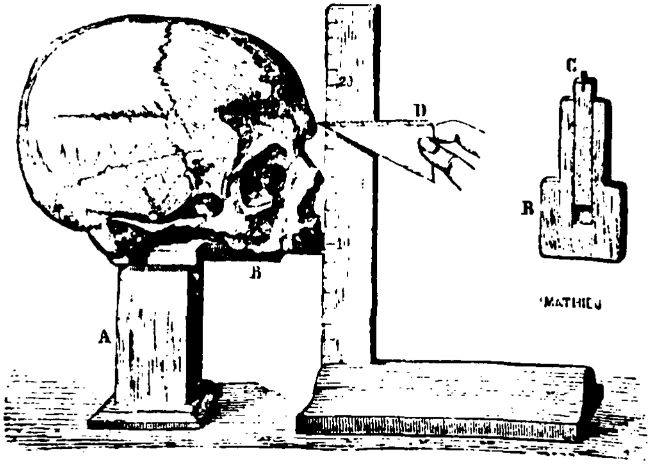

Fig. 7 Illustration of Topinard's craniostat.

Paul Topinard (1830-1912) used a similar craniostat with some additional modifications (Fig. 7). He used a pedestal and shelf arrangement, the skull being placed on the shelf. Within the shelf is a sliding portion which can be moved out to support the maxilla (see inset). Perpendicular to the shelf is a graduated rule with a sliding triangle that is used to locate a specific point. The alveolocondylar plane is always a fixed distance from the table. If the skull showed a tendency to fall backwards, Topinard placed lead shot in the orbits.[10]

Topinard wrote in 1890 "the Craniometer substitutes mathematical data for the uncertain data founded on judgment and opinion. It studies the skeleton of the head in its ensemble, the cranium and the face separately and then each of its parts, by methods which take the head in its natural attitude, accept certain central points of more or less physiological importance, or have to do directly with absolute measurements apart from all pre-conceived theory. One of its systems is specially fertile, namely, the comparison of methods under the form of indices; but it requires a large number of skulls in which individual marks of variation are effaced. Characteristics hitherto left to chance investigation also come within its province. It shows that the eye may be deceived and analyses as far as possible those variable impressions which we term the beautiful. Although at first, and even now, encumbered with materials many of which ought to be eliminated, it has enabled us to recognize human types which without it would have remained undetermined and it bids fair one day to furnish a solid basis for the classification of races into genera and species." With the advent of radiography we are now able to classify individuals taking into consideration many more features than the early craniologists had access to.

During the nineteenth century the need for standardization of methods used in craniometry became an important issue, and since then many bodies have met to better define those points and planes in use. The most important meeting as far as the dental profession is concerned was held in Frankfurt-am-Maine in August 1882. This was the 13th General Congress of the German Anthropological Society and it is to this Congress that the Frankfurt Horizontal Plane owes its name. Prior to this conference, others had been held in Munich in 1877 and Berlin in 1880 in an attempt to agree on a common method of measuring skulls. Finally at the Frankfurt meeting the proposals made previously were agreed and accepted.

J. G. Garson (19th century) translated the Agreement and together with some critical remarks of his own published this in the *Journal of the Anthropological Institute,* 1885.

The horizontal plane was central to the total system of the analysis. Von Baer, a Russian craniologist, in 1859 suggested a plane that followed the zygomatic arches. Von Ihering (1850-1930) then defined the plane more precisely as a line drawn from the centre of each auditory meatus to the lowest point on the inferior margin of each orbit. The Frankfurt Agreement modified Von Ihering's definition so that the plane passes through the upper borders of the bony meati vertically above their centres. There has been much dispute in the past about the horizontal plane being used as a base plane for subsequent measurements, and although this is now a widely accepted plane, it is difficult to find a plane in the intact skull that is easier to reproduce than Broca's condyloalveolar plane. Garson wrote that "in drawing up any code of craniometrical measurements the extensive researches of Broca must be taken as the basis, this being the system which has been adopted by anthropologists generally over the whole world."[11]

Subsequent to the Agreement the definition of the Horizontal Plane has been altered so that it is now taken as passing through right and left porion and left orbitale. This reduces the problems incurred by asymmetrical skulls. The same con-

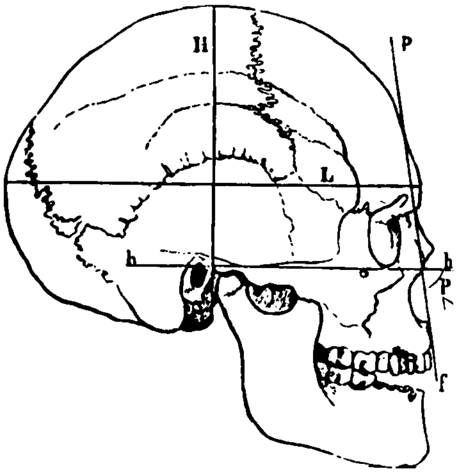

Fig. 8 Cranial measurements, hh, Frankfurt plane; L, horizontal length of cranium; Pf, profile line; H, total height. (Journal of the Anthropological Institute, Vol. XIV.)

vention applies to defining this plane on lateral skull radiographs, when it is a frequent practice to use the image of the orbit lying closest to the film for determining orbitale.

Great importance was attached to the desirability of making several measurements of the skull in relation to the horizontal plane. Some cranial measurements on the skull positioned in norma lateralis, according to the Frankfurt Agreement, are illustrated (Fig. 8).

Following the Frankfurt Agreement very little change of note has occurred in the definition of points and planes. In 1914 Rudolf Martin (1864-1925) published the "Lehrbuch der Anthropologie in Systematischer Darstellung mit besonderer Berücksichtigung der anthropologischen Methodoen." This is still renowned as a fine reference book on physical anthropology giving very detailed craniometric instructions including alternative methods of measurement.[9]

By this time X-rays had been discovered by Professor Wilhelm Conrad Roentgen in 1895 and were being widely used in the field of medicine. It was clear that the use of X-rays provided the means of obtaining a different perspective on the arrangement and relations of bones, thus expanding the horizons of craniometry and cephalometry. As with analysis using direct measurements, the problem of accurately reproducible, and thus comparable, results was paramount and it was not until 1931 that two dentists simultaneously published details of their inventions. Hofrath in Düsseldorf and Broadbent in Cleveland, had separately perfected apparatus for positioning the head in relation to the X-ray source and to the film, prior to exposing the film.

The field was now ripe for the development of cephalometric radiography.

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