Postnatal Growth of the Human Skull Base

Melvin L. Moss, D.D.S., Ph.D. and Saul N. Greenberg, D.D.S.
New York City

Introduction

The etiology of the various types of dental malocclusion is a problem of continuing interest. There is general agreement that an existing disharmony reflects, somehow, a non-coordination between the growth of all or some of the components of the skull. The orthodontist, as well as other students of cranial growth, is confronted with the problem of understanding the admittedly complex interrelation between a) the neural skeleton, b) the facial skeleton and c) the teeth and their alveolar bone.

Recent anatomical research points towards the skull base as a critical region which is concerned with the coordination of the growth of the neural and facial skeletons. The work of Hofer[1], Starck[2] and of Kummer[3, 4], indicates that these two anatomically adjacent regions have a greater degree of phylogenetic and ontogenetic independence than has previously been postulated for them by Weidenreich[5] and by Bolk[6]. The older view holds that changes in the neural skeleton are necessarily followed by coordinated changes in the facial skeleton. A correlation between the degree of cranial base flexure and the coordination of growth between the neural and facial skeletons is indicated by Bjork[7], Pankow[8, 9] and by Lindegard[10].

It will be remembered that the basicranial region of the human skull base exhibits a characteristic flexure. The axis about which this bending occurs passes transversely through the body of the sphenoid bone, dividing the skull base into pre- and post-sella components. A further topographic distinction is the delimitation of the neural and facial skeletons by the skull base. It follows then that a change in the form or position of the components of the sphenoid bone complex will greatly influence the angular relations of the skull base, affecting the maturation of both the neural and facial skeletons.

Despite the interest in these questions in many fields, knowledge of the growth of the skull base is scanty. An integration of such data as are available with the growth of the immediately adjacent structures is equally rare. The reason is not hard to find. Most current techniques of assessing craniofacial growth do not consider either the growth of the specific components of the skull base and the facial skeleton, or the spatial variations within and between these components (Broadbent,[11, 12] Brodie,[13] Bjork,[7]).

All of these cephalometric techniques are primarily directed toward problems of the growth of the dentition and its supporting osseous structures. They are not capable, as now used, of indicating morphological and spatial changes in the tissues between the selected points of reference. It is felt that a technique which used contour tracings of the actual anatomical units would be useful. In this way the changes in and between these growing units could better be studied.

This paper presents such a study of the growth of the skull base. We attempt to a) correlate the angular

* Department of Anatomy and Division of Orthodontics, College of Physicians and Surgeons and School of Dental and Oral Surgery, Columbia University, New York.

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-05-14 via free access

changes of the skull base with morphological growth, and b) integrate these data with existing information on the growth of the adjacent structures. In addition, the relations existing between cranial base flexure and certain types of dental malocclusion are examined. It is shown that one such type of malocclusion, Class III, is correlated with a deformity of the cranial base.

Materials and Methods

Lateral roentgenograms of 151 randomly selected human crania were utilized. No sexual or ethnic differentiation was made. The adult material uniformly showed obliteration of the spheno-occipital suture. The indicated age of the children is inclusive, i.e. 1-2 years includes all from one year and no months to two years and eleven months. All of the children's crania had previously been diagnosed as normal.[2] The adult material, while obtained from a neurological service,[3] did not exhibit pathological alterations of the skull base. None of this material exhibited dental malocclusion.

In addition to these, cephalometrically oriented roentgenograms of 49 adolescent cases of dental malocclusion were obtained; 28 cases of Class II, Division 1 and 21 cases of Class III.

It is important, at this point, to note divergent uses of the term prognathism. In one sense a *craniofacial* relation is described, i.e. the antero-posterior relation between the facial skeleton and neural skeleton. In another sense a *dentofacial* relation is implied, this usage referring to the antero-posterior relations of the dental arcades, with particular reference to the first molar teeth. These 49 cases were originally classified according to their dentofacial disharmonies, without reference to coexistent maxillary or mandibular craniofacial prognathism or retrusion, or to the effect which these latter skeletal conditions may or may not have had on the dentofacial condition.

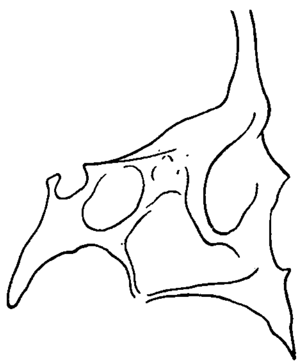
From these roentgenograms the following tracings were made (Fig. 1a): (A) the outline of the sella turcica. (B) the post-sella portion of the cranial base, from the posterior clinoid process to basion. (C) the posterior half of the orbital roof. This traced the lesser wing of the sphenoid bone as well as the posterior portion of the orbital plate of the frontal bone. (D) the hard palate, from the anterior to the posterior nasal spine. These four tracings were obtained from all age groups. In addition, the following were traced in the older specimens: (E) the jugum sphenoidale, the area of the sphenoid bone immediately anterior to the hypophyseal fossa. This tracing was impossible in the newborn, as the area did not yet exist, and in its place the inclination of the anterior wall of the sella was used. (F) the cribriform plate of the ethmoid bone. Again, this was impossible in the newborn, as ossification of the area begins after birth. In its place the ethmoidal spine of the sphenoid bone was traced, this area articulating with the now cartilaginous cribriform plate.

Upon these tracings straight lines were drawn, by inspection, which represent the mean direction of the tracings of the area. The post-sella portion was indicated by a line drawn from basion, tangential to the cerebral surface of the basi-occipital bone and the post sella portion of the sphenoid bone. This line did not include the posterior clinoid process. The lines derived from the other tracings were projected until they intersected this clival line. The angles formed by these lines were determined (fig. 1b).

The angles were designated; (A) orbital angle, formed by the roof of the orbit. (B) cribriform angle, formed by the cerebral surface of the cribriform plate of the ethmoid bone, or the ethmoidal spine of the newborn sphenoid bone. (C) the palatal angle.

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-05-14 via free access

1a



1b

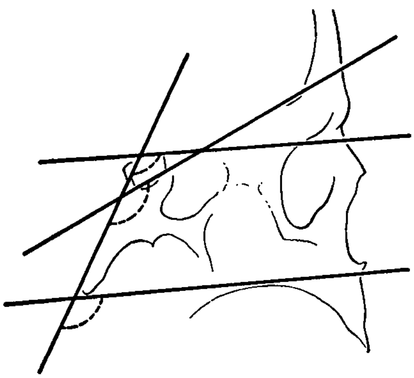


Fig. 1a. Tracing of composite lateral roentgenograms of adult skull. Note that the roof of the orbit and the cribriform plate appear to have a common origin at the anterior clinoid process.

Fig. 1b. Illustrating the method of determining the angular values of the various structures relative to the clivus. In descending order they are: a) cribriform angle; b) orbital angle: c) palatal angle.

Comparison of the computations of these angles by each author independently revealed no significant differences.

Results

The values of the various angles for the normal material are indicated in Table (1). The orbital angle gradually reaches adult values. The cribriform angle, on the other hand, remains relatively constant throughout life. No significant differences were found between age groups. Within a small range, the palatal angle is parallel to the cribriform angle, or its equivalent, in all age groups. The differences between the two angles are almost equally divided on either side of equality.

The angular values of the maloccluded material are shown in Table (2).

Despite the existence of a dental disharmony only one angle, the cribriform in the Class III cases showed a significant difference, at the .01 level, from the dentally normal material. The cribriform plate in this group showed a greater downward inclination relative to the clivus. The significance of this observation will be brought out in the following section.

Discussion

It is possible to correlate the observed postnatal angular changes of the skull base with definitive morphological alterations. The essential uniformity of

TABLE 1.

Representative Angular Values in Degrees of Dentally Normal Individuals.*

Age	*Newborn*	*1-2 years*	*5-6-7 years*	*Adult*
Orbital angle	152.24±94	143.9±1.2	141.0±1.4	138.1±1.2
	N=29	N=34	N=27	N=28
Cribriform angle	121.3±2.02	119.1±1.1	117.0±1.6	120.5±1.1
	N=16	N=34	N=27	N=61
Cribriform-Palatal angle differences	1.8	4.4	5.2	3.5

* All values are recorded as the mean plus or minus the standard error of the mean, calculated for small samples.

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-05-14 via free access

TABLE 2

REPRESENTATIVE ANGULAR VALUES OF DENTALLY ABNORMAL INDIVIDUALS*

	Class II	*Class III*
Orbital angle	139.5±1.6	138.5±1.6
	N=28	N=21
Cribriform angle	118.3±1.4	114.2±1.5
	N=28	N=21
Cribriform-Palatal angle differences	2.7	3.3

* All values are recorded as the mean, plus or minus the standard error of the mean, calculated for small samples.

the cribriform angle indicated that the median structures of the anterior cerebral fossa are more stable than the more lateral structures. These latter are indicated by the orbital angle, which undergoes prolonged and progressive alterations. These observed postnatal angular changes are a completion of a fetal process by which the degree of human basal flexure is attained (see Kummer,[3] Pankow,[8] for fetal data).

Cribriform angle.

This angle remains unchanged despite an extension medialward of the lesser wings of the sphenoid bone above the anterior part of the body of the sphenoid bone. These two medial extensions fuse with each other to form the jugum sphenoidale during the first postnatal year (Fig. 2).

Correlated growth of the sphenoid bone.

Little data are to be found concerning the absolute or relative growth of the sphenoid bone. The length of the pre- and post-sella portions of this bone are fairly stable at five years of age (Brodie,[13]). The dimensions of the sella turcica are relatively constant from the third to the twelfth year (Rochlin,[14] Bergerhoff and Hobler,[15]). Prior to the third year, the vertical growth of the posterior clinoid process is greater than that of the anterior clinoid process, relative to a given horizontal line. Data covering the prenatal stages are presented by Kummer[3]. The present material demonstrates the continuation of this growth tendency during the first

Fig. 2a. Newborn sphenoid bone, with left greater wing detached. Note especially the non-union of the lesser wings at the midline, allowing the ethmoid spine to be glimpsed below. (1.2 X)

Fig. 2b. Adult sphenoid bone, in situ. Note the relation of the jugum sphenoidale to the site of the unformed area mentioned above. (Natural size)

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-05-14 via free access

two postnatal years. Here the vertical growth of the posterior clinoid process is twice as great as that of the anterior process, relative to the palatal line. Growth of the sphenoid bone in the first three years is not due to the expansion of the sphenoidal sinus (Schaeffer,[16]).

In summary, the body and wings of the sphenoid bone change markedly in form during the first several years. This accompanies angular changes of the two components of the skull base. The sphenoid bone grows upwards and backwards relative to the splanchnocranium. Confirmation of this change of position is graphically given by Broadbent[17]. The absolute vertical growth of the sphenoid bone is accentuated by the relative downgrowth of the floor of the laterally situated middle cerebral fossa (Dabelow[18], Stadtmuller[19]). Alizarin studies of animal material gives substantial support to this hypothesis (Brash[20]). It is emphasized that while the sphenoid bone is changing markedly in form and somewhat in position, the cribriform angle remains constant. It is shown below that a corresponding downward growth is demonstrated by the visceral structures immediately below the sphenoid bone.

Orbital angle.

The change in this angle is caused by an upgrowth of the roof of the orbit, raising the cerebral surface of the lesser wings of the sphenoid bone and the posterior portion of the orbital plate of the frontal bone, relative to the jugum sphenoidale. This implies greater addition in vertical height of the apex of the orbit relative to its base.

Correlated growth of the orbit.

The morphological changes occurring in the growth of the orbit during the first several years of life are of interest in studying the growth of the skull base. Decisive quantitative evidence of the *vertical* upgrowth of the posterior orbital roof, relative to the medial line is presented by Stadtmuller[19]. This upgrowth is apparently associated with the change in the angle of the optic foramen, from a horizontal position in the newborn to a forward declivity of some 15-20 degrees in the adult (Whitnall[21]). The present paper indicates this change to be essentially completed before the fifth year. After this time, the volume and dimensions of the bulb and its extrinsic musculature are constant until puberty, having increased during the first five years (Weiss[22]).

The vertical upgrowth of the orbital apex is coordinated, in time, with a *transverse* growth of the greater wing of the sphenoid bone, which forms the posterior half of the lateral wall of the orbit. This transverse growth is relatively greater than that of the external orbital margin in the same plane (Pallin[23]).

Growth of the orbit in the third plane, *antero-posteriorly,* is also rapid during the first few years. In addition, the morphological change of the optic canal occurs in the first year, changing from a foramen to a canal some 4 mm. in length. This is associated with the formation of the jugum sphenoidale noted above (Wolff,[24]). In summary the evidence indicates that the resultant direction of all this growth is upwards and backwards.

Growth of the nose.

The parallelism between the cribriform line and the palatal line demonstrates the stability of the upper splanchnocranium relative to the clival line. The medial area between these lines within this region is occupied by the nose. Study of the growth of this organ is revealing (Disse[25], Rosenberger[26], Richter[27]). In the midline the respiratory portion of the nose grows faster than the olfactory portion, and is

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-05-14 via free access

less completely developed at birth. Laterally, the inferior meatus is formed only after birth, becoming functional in the third year. The vertical growth of the median labyrinthine wall is not caused by growth of the vertical plate of the ethmoid bone, which is cartilaginous at birth, but of the area immediately below it. It is the vertical growth and expansion of the middle concha, situated below the superior meatus that is responsible. The vertical increase of the posterior portion of the nose is greater than the anterior, especially during the first year.

Antero-posterior growth of this splanchnocranial area is indicated by the fact that the opening of the pharyngotympanic (Eustachian) tube moves backwards, postnatally, from beneath the sella to the site of the spheno-occipital synchondrosis. Seemingly this movement parallels the relative growth of the sella turcica alluded to above. A parallel backwards growth of the maxilla is reported by Diamond[28]. This antero-posterior growth is correlated with the opening of the nasopharynx.

It is emphasized, therefore, that the growth of the splanchnocranium is not concerned merely with the maintenance of infantile relationships between structures. Within fairly broad limits, morphological and spatial alterations occur. That is, these growth processes and their resultant alterations occur in a region whose upper and lower limits remain parallel (cribriform and palatal lines). Indeed, the proportion of the total facial height which the nose occupies, about 43%, is constant throughout life (Herzberg and Holic[29]). This figure is corroborated by our analysis of the data of Young[30] and of Smyth and Young[31].

Relation to growth dysharmonies.

The picture which emerges from the foregoing is one which supplements that of Brodie[13, 32] who finds *individual* angular consistency between his tracings of skull base, floor of the nose (our palatal line), occlusal plane and lower border of the mandible during the first eighteen years of life.

The stability of these planes occurs within a growing, shifting complex of bone, cartilage and soft tissue, the growth of which is integrated and correlated. The stability of the cranial base in its middle region and of the medial facial skeleton is not found in the more laterally placed structures. The relative elevation of the anterior cerebral fossa and the consequent lowering of the middle cerebral fossa, together with an absolute growth of the sphenoid bone itself results in morphological, spatial, and angular changes of the skull base components. This growth is shown to be closely related to that of adjacent organs, in all three planes.

Moreover, the greatest part of these correlated growth changes occurs during the first several years of life, after which a great degree of individual stability is attained.

It follows, then, that dentofacial and craniofacial growth disharmonies become evident, but not necessarily incurred, during these early years. One area of disharmonic growth will then cause subsequent disharmonies in regions and structures correlated with it (Todd[31]).

The relation existing between the development of the brain and the cranial base must be mentioned. No doubt a basic correlation does exist, phylogenetically, between the development of the brain and basal flexure (see: Hofer[1]; van der Klaauw[34, 35]; Schuchardt[36, 37]). Indeed the normal development of this basal flexure does depend on the presence of at least, a normal midbrain (Hammer[38]).

However, apparently the most common types of dentofacial disharmony may exist without apparent disturbance

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-05-14 via free access

of the skull base. This finding merely restates the thesis that a great degree of independence exists between the neural and facial skeleton. The finding of median basal distortions in one type of malocclusion, Class III, however, pin points a region which may, in fact, be considered to be more nearly the area of functional interconnection between these two regions of the skull.

The median portion of the skull base, the basioccipital, the body of the sphenoid bone and the median portion of the ethmoid bone define this area. In the Class III malocclusion, the pre-sella portion of the medial area of the skull base, indicated by the cribriform angle, has a greater downward inclination relative to the clivus. Whether this is primarily a defect in the maturation of the early fetal chondrocranium, or primarily associated with a spatial malrelation of the anterior portions of the brain cannot be decided as yet. There is some evidence, drawn from the study of much more severe cranial growth disharmonies, such as acrocephaly and cranial dysostosis, which favors the primacy of the cartilaginous defect. The implications of this finding receives independent support from the recent work of Lindegard[39]. He uses osteological material for a study of the relationship between the upper alveolar process and the cranial base. He reports that as the declination of the alveolar plane increases, in the same direction as we describe above for the Class III material, this alveolar plane moves under the cranial base.

As a result of this process, he finds that the anterior portion of the alveolar plane moves downward and back and the posterior portion of this same plane moves up and back. In effect, the maxillary incisor and cuspid teeth are displaced down and back and the molar teeth up and back, the alveolar process pivoting, as it were, about the premolars. This position of the anterior dentition in the cases in which the alveolar plane has shifted as described by Lindegard bears a striking similarity to the description of the Class III malocclusion.

Finally, it should be noted that the use of a cribriform plane as a diagnostic aid had recently been reported. This work of de Coster[40] has, so far, been only of an exploratory nature.

Conclusions

The postnatal growth of the human skull base is studied with the use of lateral roentgenograms. From these, tracings are made of the contour of selected anatomical areas and the angular relations of these areas are described.

It is shown, in normal material, that the medial areas of the skull base are essentially stable while the lateral areas undergo prolonged change. The correlated morphological alterations accompanying these angular relations are described.

Two types of dental malocclusion, Class II Division I and Class III, are studied with this technique. The evidence indicates that the Class III group show significant alterations from the normal in the spatial relations of the medial pre-sella portion of the skull base. The effect of such alterations on the production of the malocclusion are discussed.

1 The work reported was carried out under the tenure of a Lederle Medical Faculty Award.

2 Material kindly supplied by Dr. John Caffey, Department of Roentgenology, Babies Hospital, New York.

3 Thanks to the courtesy of Dr. Juan Taveras, Department of Roentgenology, Neurological Institute, New York.

Bibliography:

1. Hofer, H. The alteration in shape of the skulls of mammals and birds; with special consideration to the type of flexion and to the skull base. *Anat. Anz.*, 99: 102-113. 1952.
2. Starck, D. Shape and formation of the skull base in Chiroptern. Verhandl. d. Anat. Gesselsch, 114-121. in *Anat. Anz.*, 99: 1952.

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-05-14 via free access

3. Kummer, B. Researches on the ontogenetic development of human skull base angles. *Zeit.f.Morph.u.Anthrop.*, 43: 331-360, 1952.
4. Ibid. Analysis of the origin of skull base form in man and primates. Verhandl.d.Anat. Gesellsch., 122-126. in: *Anat. Anz.*, 99: 1952.
5. Weidenreich, F. The brain and its role in the phylogenetic transformation of the human skull. *Trans. Amer. Phil. Soc.*, 31: 321-442. 1941.
6. Bolk, L. The problem of human evolution. 25th. *Versam. d. Anat. Gesellsch.*, 1926.
7. Bjork, A. The face in profile. *Svensk. Tandl.-Eidskr.*, 40: 1-180. 1947.
8. Pankow, G. Researches on the flexion of the human skull base. *Z.menschl. Vereb.-u.Konstit. Lehre.*, 29: 69-139. 1948.
9. Ibid. On the regularity of growth of the skull base during human ontogenesis. *Anat. Nachricht.*, 1: 243-248. 1951.
10. Lindegard, B. Variation in human body build. *Acta Psych. et Neurol.*, Suppl. 86: 1-163. 1953.
11. Broadbent, B. H. The face of the normal child. *Angle Orthodontist*, 7: 183-208. 1937.
12. Ibid. Bolton standards and techniques in orthodontic practice. *Angle Orthodontist*, 7: 209-233, 1937.
13. Brodie, A. G. On the growth pattern of the human head from the third month to the eighth year of life. *Am. J. Anat.*, 68: 209-262. 1941.
14. Rochlin, D. G. Radio-Anthropology. *L'-Anthrop.*, 45: 33-47. 1935 in: Krogman, W. M. *Tab. Biol.*, 20: 605. 1941.
15. Bergerhoff, W. and W. Hobler. Measurement of angles and lines in X-rays of skulls of children and adolescents. *Geb.d.Röntgenstr.*, 78: 190-195, 1953.
16. Schaeffer, J. P. *The nose, paranasal sinuses, nasolacrimal passageways and olfactory organ in man.* Blakiston Co., Phila., 1920.
17. Broadbent, B. H. Ontogenetic development of occlusion. in: *Development of occlusion.* Phila. Univ. of Penn. Press.
18. Dabelow, A. On correlation in the phylogenetic development of skull form. 2. The relation between the brain and the form of the skull base in mammals. *Morph.Jb.*, 67: 84-133. 1931.
19. Stadtmuller, F. Concerning conflicting formative phenomenon in the development of the skull capsule and its contents with special regard to the temporal bone. *Arch. f. Ohr. u. Kehlkophhk.*, 1952: 110-140. 1943.
20. Brash, J. C. Some problems in the growth and developmental mechanics of bone. *Edinb. Med. J.*, 41: 305-319, 363-387. 1934.
21. Whitnall, S. E. *The anatomy of the human orbit.* Frowde and Hodder, and Stoughton. London. 1921.
22. Weiss, L. On the growth of the human eyes. *Anat. Hefte.*, 8: 193-248. 1897.
23. Pallin, P. Researches on the human orbit at different ages. *Acta Soc. Med. Suenc.*, 63: 1-107. 1937.
24. Wolff, E. *The anatomy of the orbit.* 3rd. Ed., Blakiston Co., Phila. 1948.
25. Disse, J. The formation of the nasal cavity after birth. *Arch. f. Anat. u. Physiol.*, Suppl. bd. 29-54. 1889.
26. Rosenberger, H. C. Growth and development of the naso-respiratory area in childhood. *Ann. Otol. Rhin. Laryng.*, 43: 495-512. 1934.
27. Richter, H. On the development and form of the nasal conchae. *Arch. Ohr. Nas. u. Kehlkopfheilk.*, 163: 318-323. 1953.
28. Diamond, M. Posterior growth of the maxilla. *Am. J. Ortho. and Oral Surg.*, 32: 359-364. 1946.
29. Herzberg, F. and R. Holic. An anthropological study of face height. *Am. J. Ortho. and Oral Surg.*, 29: 90-100. 1943.
30. Young, M. Normal facial growth in children. *J. Anat.*, 71: 458-470. 1927. in. Krogman, W. M. *Tab Biol.*, 20: 619. 1941.
31. Smyth, C. and M. Young. Facial growth in children with special reference to dentition. *Med. Res. Council.* Special Rep., 171: 1-83. 1932.
32. Brodie, A. G. Late growth changes in the human face. *Angle Orthodontist*, 23: 146-157. 1953.
33. Todd, T. W. Integral growth of the face. *Interntl. J. Ortho. and Oral Surg.*, 22: 321-334. 1936.
34. van der Klaauw, C. J. Cerebral skull and facial skull. A contribution to the knowledge of skull structure. *Arch. Neerl. d'Zool.*, 7: 16-37. 1946.
35. Ibid. Size and position of the functional components of the skull. A contribution to the knowledge of the architecture of the skull, based on data in the literature. *Arch. Neerl. d'Zool.*, 9: 1-556. 1948-1952.
36. Schuchardt, E. The median skull base index in phylogenesis. *Verhandl.. d. Anat. Gesellsch.*, 118-120. in: *Anat. Anz.*, 97: 1951.
37. Ibid. Concerning the growth relations between the skull and brain of mammals in ontogenesis and phylogenesis. *Zeit. f. Morph. u. Anthrop.*, 45: 73-134. 1952.
38. Hammer, E. On the influence of brain development on the facial skeleton. *Beitr. z. path. Anat.*, 91: 570-593. 1933.
39. Lindegard, B. On the relationship between the upper alveolar process and the cranial base. *Kungl. Fysiograf. Sällsk. Lund Förhndl.*, 22: 1-10. 1952.
40. de Coster, L. A new reference line for the study of dentofacial deformations. *Anal. Esp. d. Odontoestomol.*, 11: 564-577. 1952.

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-05-14 via free access