The Road to Three-Dimensional Imaging in Orthodontics

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This paper examines the origins of 3-dimensional craniofacial measurement. It briefly tracks the development of measurement methods from the plaster casts and facial moulages of the early 20th century to the cone beam computed tomographic scanners of today. The fundamental difference in design between cone beam scanners and conventional computed tomography scanners is described in their difference in primary function; cone beam scanners are optimized for the location of hard tissue structures, such as teeth and bone, whereas computed tomography scanners were originally optimized for the detection of subtle distinctions in the radiopacity of different bodily soft tissues under different conditions of health and disease. The advantages and limitations of several attempts at quantitative measurement of the skull and face in 3 dimensions are noted. (Semin Orthod 2011; 17:2-12.) © *2011 Elsevier Inc. All rights reserved.*

Recent advances in cone beam computed tomography (CBCT) represent the potential for important further developments in craniofacial imaging. At radiation doses considerably lower than those of classical computed tomography (CT) imaging, they permit the rapid visualization of the spatial relationships between oral and cranial structures in 3 dimensions. As recently as 2001, when *Seminar in Orthodontics* produced an issue on 3-dimensional (3D) craniofacial measurement guest edited by the present author, it still seemed necessary to make the case that 3D measurement of the craniofacial complex was desirable.[1] Now that argument is moot, and the desirability of 3D craniofacial measurement is obvious. This issue of *Seminars in Orthodontics* reports several early applications in a burgeoning field, and a brief review of the origins of that field seems an appropriate place to begin.

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The original interest in 3D craniofacial mapping was part of a groundswell of interest in the study of human growth that took place among anatomists and physical anthropologists in the second half of the 19th century. Cross-sectional studies based on the examination of dried skulls had been started earlier in several parts of the world, but longitudinal studies capable of detecting "growth spurts" were not possible because information from only one time point was available from any one individual. Moreover, it was difficult to distinguish normal from pathologic specimens because the skulls that became available for growing subjects were clearly not the results of "normal" biological events.

In the early years of the 20th century, van Loon in the Netherlands and Simon in Germany became interested in monitoring the relationship of the teeth and jaws to the bony skull by the use of physical 3D systems.[2,3] Simon's system (Fig 1) dates mainly from the early 1920s and thus antedates by several years the development of practical systems for generating 3D skull x-ray films. Like that of his predecessor van Loon, Simon's approach was mechanical. It included the use of a maxillary clutch and frame, which resembled in function the later face bows of Hanau, McCollum, Stewart, and others.[4-6]

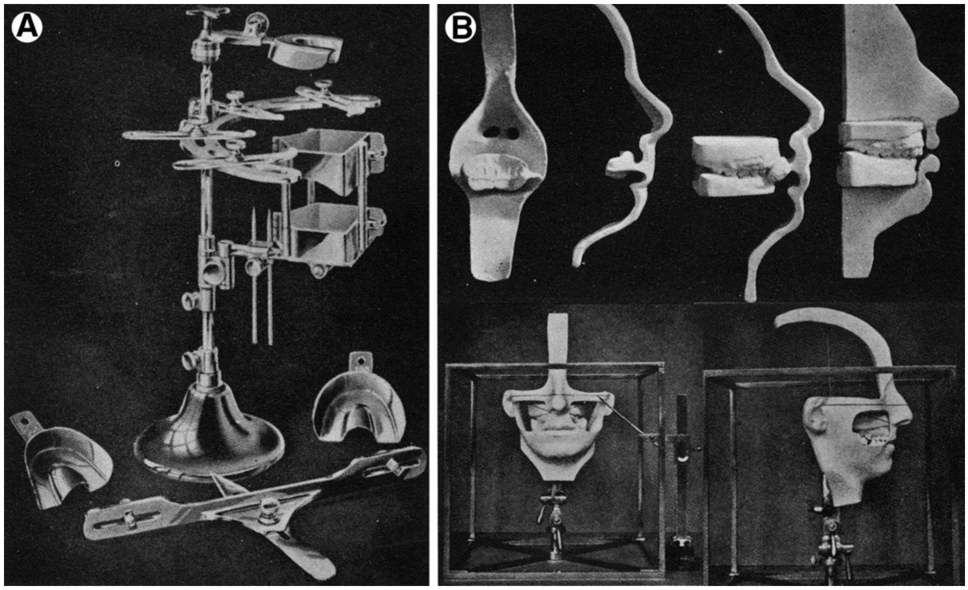

Figure 1. (A) Components of Simon's "gnathostatic" cast mounting system. These include upper and lower impression trays, upper and lower study cast formers, a face bow, and a vertical mounting stand. (B) 2D and 3D plaster cast assemblies of the jaws and face made using these devices. (Images courtesy of WM Krogman, PhD, and V Sassouni, DDS, DSc.)

As part of these systems, a physical plaster cast of the facial surface (called a moulage) was frequently used. A face bow registration made it possible to mount the moulage and plaster casts of the upper and lower jaws relative to Frankfort plane. This synthesis of separate physical transforms, taken in total, represented the configuration of the head at a single time point.

To the extent that the physical procedures of cast fabrication and instrument registration were correct, Simon's method was capable of orienting the dentition within the skull in 3 dimensions. Note, however, that as in other syntheses, the question of registering the individual plaster transforms with respect to each other presented technical difficulties, such as occur in all "bottom up" synthetic systems in which several separate components are assembled to form a larger whole.

Simon's system is especially important to us in that it focused sharply on the location within the skull of the teeth and alveolar processes which support them—the anatomical structures that interest dentists most. In fact, its focus on representation of the dentition within the skull was more anatomically correct than the current orthodontic method of convenience which ignores Frankfort and orients the occlusal plane parallel to the tabletop.

Meanwhile, in the last years of the 19th century and the first years of the 20th, a profoundly new method of viewing the skull was made possible by Roentgen's discovery of x-rays in 1885 (Fig 2). Dentists on both sides of the Atlantic quickly made use of this new technology. Not only individual films but paired stereoscopic x-ray images were captured and used by physicians and dentists for diagnostic purposes before 1900. However, it was not realized that one could make quantitative measurements of depth from x-ray stereopairs and their use never became popular, largely because their use was physiologically taxing for the viewer. As frequently happens with new diagnostic technologies, the early use of dental x-rays was not entirely positive; overinterpretation of the morbidity of periapical lesions revealed by x-ray but formerly hidden from view lead to misguided fears of "focal infection". This resulted in a wave of promiscuous extraction of salvageable teeth that did not completely subside for the next 40 years.[7]

By 1925 skull x-rays of living subjects had become feasible and the stage was set for the classic work of Broadbent in America (Fig 3) and Hofrath in Europe.[8,9] Both approaches involved the interpretation of 2 images taken nearly simultaneously from a pair of x-ray tubes so ori-