The History of Articulators: From Facebows to the Gnathograph, a Brief History of Early Devices Developed for Recording Condylar Movement: Part I

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WILLIAM G.A. BONWILL described the forward movement of the condyles when he introduced his concept of occlusion and his articulator to the profession in 1864. However, because he placed little importance on the influence of the condyles on articulation of the teeth, he made no attempt to determine the character of the condylar paths.[1]

On June 4, 1866, Francis H. Balkwill made an historic presentation to the Odontological Society of Great Britain.[2] His descriptions of maxillo-mandibular movement and relationships were extraordinarily accurate and detailed, even by today's standards. It is noteworthy that Balkwill believed that it was impractical to measure the angle of the condylar inclination in the living subject. However, he introduced an instrument for measuring "the angle formed between the plane of two lines drawn from the articulating surfaces of the condyles to the [incisor point] and the [occlusal plane] which is near enough to use." He estimated this angle, now known as "Balkwill's Angle," to be an average of 26 degrees. Balkwill also revealed that he had constructed a "bite frame," by means of which (using the angle and measurements) "the lower model can be placed in the same position relative to the center of the hinge."[2]

What were the characteristics of Balkwill's "bite frame"? Was it adjustable, and if so, to what extent? Was the instrument that he introduced a facebow or some other type of measuring device? Did it record anatomic relationships or just measure distances? These are intriguing questions, but unfortunately, the answers may remain a mystery. Rowland Fereday's 1994 account[3] of Balkwill's incredible contributions to dentistry, published in the British Dental Journal, reported that, inexplicably, no examples, illustrations, or descriptions of these devices remain in existence. It is truly regrettable that these important dental artifacts appear to have been lost to the profession.

The Earliest Mandibular Facebows

From the late 1880s until about 1910, as transfer or positional facebows were beginning to find their way into dental offices, investigators struggled to determine the character of condylar paths and what influence those paths might have on the design and use of articulators. These investigators soon discovered that to be successful, they must not only reproduce the movement of the condyle on an articulator, but also create a permanent graphic record of the condyles' complex and variable movements that could be retained for future reference. After George Snow introduced his innovative version of the facebow in 1899, many clinicians and investigators agreed that it was an instrument well suited for anatomically orienting the casts to the condylar axis of an articulator. Why, then, could not such a device be modified to record the movements of the jaw or measure the condylar paths? Charles E. Luce had developed a type of facebow apparatus for his study a *decade* before Snow produced his!

Luce's "Photographic" Method

In 1889, Luce had reported the results of an investigation that he had conducted at Harvard Medical School under the direction of Prof. Henry P. Bowditch. This landmark study of mandibular movement was not well known to dentists because it had appeared in a medical journal and was not well publicized to the dental profession.[4]

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Luce was probably the first to use a mandibular facebow to reproduce the movements of the mandible and to specifically trace the individual condylar pathways. Luce used what he called the "photographic" method to record the relative movements of 3 points on the mandible: the condyle, angle, and symphysis. Luce described his apparatus as a "light framework. . .securely fastened to the lower incisors. . .that reached around the face almost to the ears."[4] With the use of adjusting rods, the device held highly polished silver beads that could be placed directly over the condyle, angle, and symphysis (Fig 1*A*). For this "photographic method," the subject was placed in bright sunlight so that the silver beads would reflect into a camera lens as bright spots. The camera was placed so as to capture a direct profile exposure, and the film was exposed for each entire sequence of mandibular movement. Each sequence appeared on the negative as a solid white line.[4]

Luce's results corroborated Balkwill's findings that the condyles moved downward and forward, and, in addition, he found that the condylar paths were curved and that there was considerable individual variation in the relative movements of the condyle, angle, and symphysis (Fig 1*B*). Luce believed that the condyles frequently advanced to the summit of the glenoid ridge and beyond. He was also convinced that the condyles moved forward simultaneously with the opening of the mandible. Luce criticized several anatomists and physiologists who claimed otherwise.[4] The idea that the condyles only rotate with translation, even during the initial opening of the mandible, prevailed for many years, and was reflected in the articulator designs of Walker and Gysi.[5]* It is interesting that such scientists as Walker and Gysi failed to recognize that the mandibular condyles were capable of pure rotation.

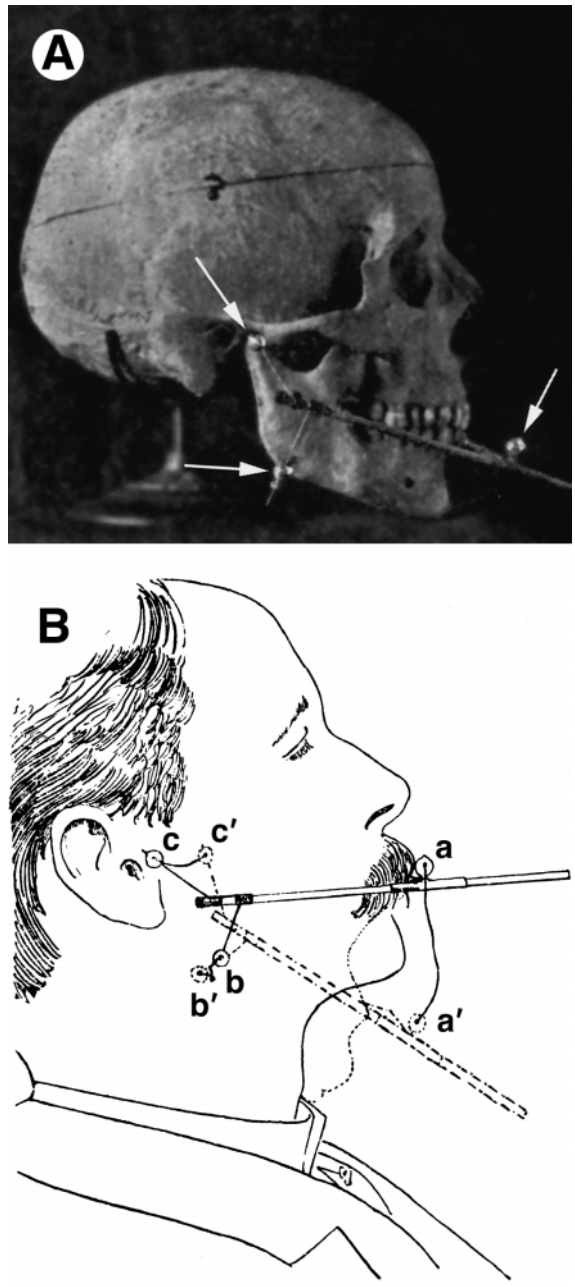

Figure 1. (*A*) Luce's facebow recording device mounted on a skull. The arrows identify the positions of the polished silver beads at the symphysis, angle, and the condyle. (Reprinted from Luce, p 8.[4]) (*B*) A composite drawing of the movement of the silver beads showing the change in the relative positions of the condyle, angle, and symphysis of the mandible. a to a′ demonstrates the downward motion of the chin, b to b′ the downward and backward motion of the angle, and c to c′ the forward and downward curve of the condylar path. (Reprinted from Luce, p 9.[4])

*Charles Luce did not produce an articulator until over 20 years later. When he received a patent for his articulator in 1911,[6] he had not developed a facebow or any other similar device based on the 1889 Harvard Study. Instead, the controls of the articulator were custom molded in modeling plastic, using a functionally generated path technique. Nevertheless, this was consistent with his interest in reproducing the unique character of each individual's mandibular movements. He probably concluded that an articulator with mechanical controls could not imitate these movements.

Walker's Facial Clinometer: A Missed Opportunity?

In 1896, William E. Walker produced the first adjustable condyle articulator. This instrument featured adjustable controls for recording the variability of the downward as well as forward movements of the individual condyles and controls for variable lateral and vertical rotation centers. He called the instrument his "physiological" articulator. Walker was not concerned with reproducing the exact anatomic curvatures of the condylar paths, only the angles that these paths formed with the facial line and the alveolar (or occlusal) plane† and the distances that the condyles traveled. To make these measurements on the patient, he invented a device that he called the "facial clinometer." This was the first instrument devised to determine the individual relationships and movements of the mandible for the purpose of constructing mechanisms for imitating these movements.[8,9] Undoubtedly, using the "facial clinometer" *was* complicated (Fig 2*A*). Walker's method for registering the angles of the condyle paths and the distances that the condyles traveled was highly complicated. Specifically, along with the facial clinometer, Walker designed 2 auxiliary measurement devices that were secured in the mouth by the teeth or alveolar ridge. After the measurements were made, however, the devices were set aside and neither became a part of the basic clinometer. The mandibular facebow device (see Fig 2*B*) recorded the individual *condylo-facial* angles as well as the distance traveled by each condyle. The second device (see Fig 2*C*) recorded the *occluso-facial* angle. Walker determined that "the mathematical difference between the *condylo-facial* angle and the *occluso-facial* angle [is calculated to be] the *condylo-occlusal* angle. . .to which I set the adjustable angle of my 'physiological' articulator."[9]

The drawing of the facial clinometer on a patient (Fig 2*A*) appeared in Carl Christensen's 1901 article[10] and is based on Walker's original photograph. It is probably the best available view of this instrument. Walker's use of this image to illustrate his theories and methods probably added to the confusion. The artist's rendition (with 1 major exception) is faithful to the original image. Unfortunately, the photographer's perspective has obscured the spatial relationships of the components, making interpretation of its function difficult.

It is not surprising that the dentists of that period would have found the process confusing and the facial clinometer difficult to use. In addition, patients may have found the instrument frightening.

Walker may have come close to choosing a much more "user friendly" device to study condylar movement, that is, a graphic facebow, although it would not have been nearly as dramatic as the clinometer. Of course, it is only speculation, but the opportunity certainly was "staring him in the face." When E.C. Kirk, editor of the *Dental Cosmos*, informed him of Luce's 1889 Harvard study, Walker commented that he was gratified to learn that Luce had, while using widely different methods, arrived at many of the same conclusions that he had.[11] To confirm Luce's results, Walker constructed a facebow device of much the same design as the one used at the Harvard laboratories and produced similar photographic images. However, to "further verify" these observations, he replaced the "bright beads" with a "small point of pencil lead to trace the movements of the condyle on a sheet of stiff paper held against the side of the face, with the edge parallel to the facial line." Walker reported that he could "trace a large number of cases in the same time required to photograph and develop the negative of a single case."[11] Why, then, did Walker choose to continue with his facial clinometer rather than with the graphic facebow that he developed while seeking to improve on Luce's method? It is obvious that Walker had confidence in the facial clinometer as a research tool, and he may not have recognized that it had little practical clinical value, as his graphic facebow idea certainly would have. Nevertheless, it may be safe to assume that John B. Parfitt and Alfred Gysi *did* take note of this innovation, even though Walker did not pursue it.

†Walker's "facial line" likely referred to an imaginary vertical line from the most prominent point of the forehead to the alveolar border of the maxilla or anterior teeth (after Broomell[7]). The terms "occlusal" (or "occluso-") and "alveolar" (or "alveolo-") were used by Walker interchangeably throughout his descriptions of his methods.

Johan Ulrich's Study of the Human Temporomandibular Joint

For his 1896 Doctorate in Medicine, Johan Ulrich[12] of Copenhagen, Sweden conducted a comprehensive study of the movements of the temporoman-

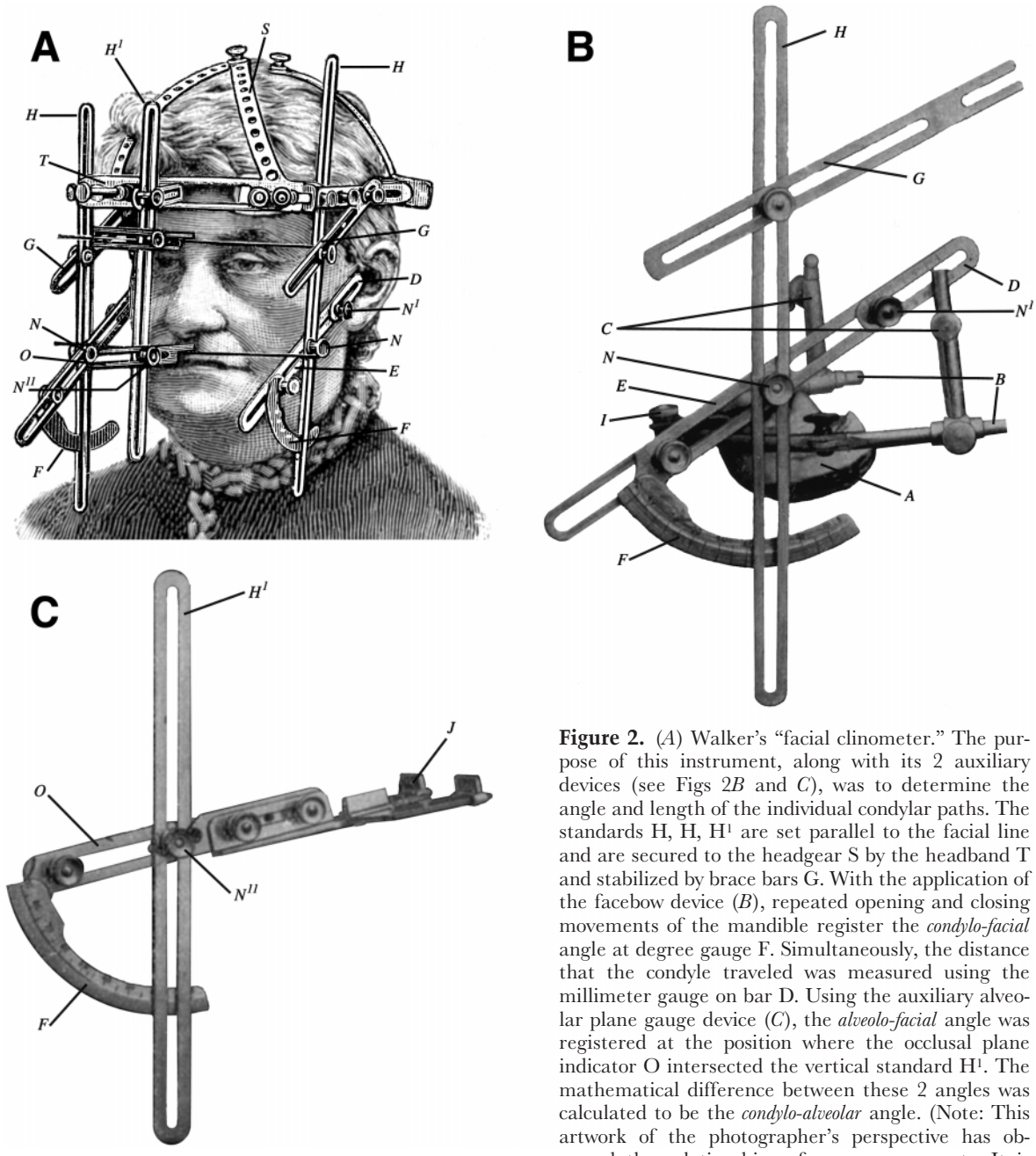

Figure 2. (*A*) Walker's "facial clinometer." The purpose of this instrument, along with its 2 auxiliary devices (see Figs 2*B* and *C*), was to determine the angle and length of the individual condylar paths. The standards H, H, H^1 are set parallel to the facial line and are secured to the headgear S by the headband T and stabilized by brace bars G. With the application of the facebow device (*B*), repeated opening and closing movements of the mandible register the *condylo-facial* angle at degree gauge F. Simultaneously, the distance that the condyle traveled was measured using the millimeter gauge on bar D. Using the auxiliary alveolar plane gauge device (*C*), the *alveolo-facial* angle was registered at the position where the occlusal plane indicator O intersected the vertical standard H^1. The mathematical difference between these 2 angles was calculated to be the *condylo-alveolar* angle. (Note: This artwork of the photographer's perspective has obscured the relationships of some components. It is especially noticeable with regard to the 3 standards. The angle gauges F are shown to enter the slots from the front, whereas the lock screws N and N^{11} enter from the side. The relative position of right standard H to standard H^1 is ambiguous because of their relationships to the structures at the levels of the headband T, the connections at G, and the occlusal plane O.) (Reprinted from Christensen, p 413.[10]) (*B*) Auxiliary facebow device for Walker's "facial clinometer." This device was used to set the *condylo-facial* angle. A is a vulcanite rubber clutch in a mandibular impression tray, the handle of which is secured to facebow B by setscrew I. At each end of the facebow B are adjustable vertical posts C that have lateral end knobs that move in the slots of bar D. The upper end of bar D is placed over the condyle (as determined by palpation). With repeated opening and closing movements of the mandible, the relative positions of bars D and E (pivoting around lock screw N) to the vertical standard H (facial line) are determined at angle gauge F. The distance that the condyle travels is determined by measuring the markings on bar D. (Reprinted from Walker, p 797.[9]) (*C*) Attachment for Walker's facial clinometer. This device was used to measure the *occluso-facial* angle. Stabilizing clutch J is placed in the mouth to contact the teeth or the alveolar ridge evenly. Extending from the handle of the clutch is part O that is set parallel to the occlusal plane. It intersects with standard H^1 (facial line) at setscrew N^{11} where it is set. The *occluso-facial angle* is measured with degree gauge F. (Reprinted from Walker, p 799.[9])

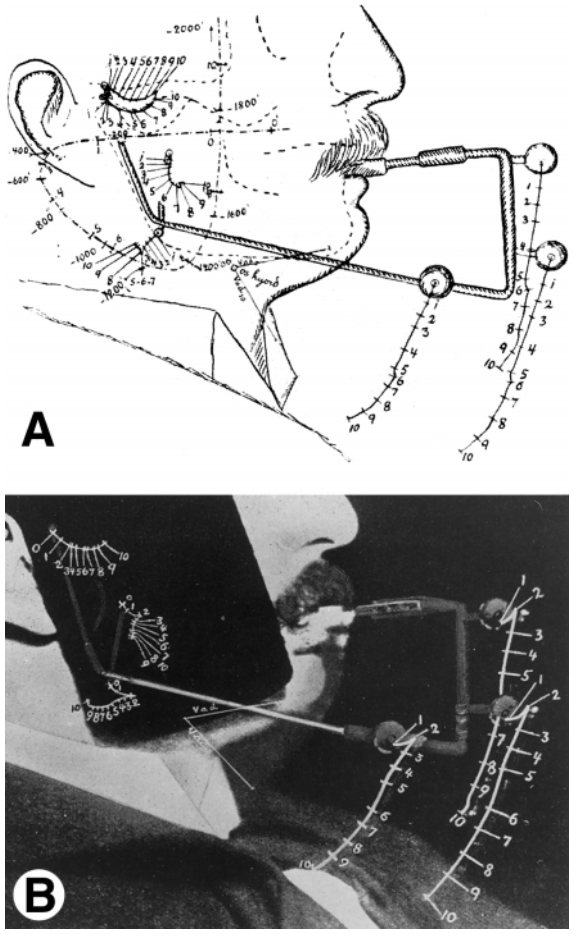

Figure 3. (*A*) A drawing of Ulrich's apparatus for measuring the movement of several points on the mandible. The apparatus is shown on a subject in Fig 1*B*. This illustrates the tracings of a habitual opening movement. The curve indicated with dots and dashes (-.-.-.-.-.) connects the instantaneous axes for the opening movements as calculated mathematically for this particular subject. (Reprinted from Ulrich, p 400.[12]) (*B*) A photographic plate exposure made during a protrusive movement with the teeth in contact and a subsequent wide opening movement. (Reprinted from Ulrich, p 402.[12])

dibular joint during opening, protrusion, and lateral movements, as well as of the ranges of functional movements during speech, singing, and mastication.

The movements of the mandible were recorded with a "photographic" method similar to those used by Luce[13] and Marey.[14] The apparatus was fixed to the mandibular teeth with a splint designed to avoid interference with occlusal contacts during mandibular excursions. The apparatus itself was an adjustable, U-shaped rod that extended anteriorly from the splint and then posteriorly, carrying a number of polished silver beads to either the right or left side of the subject (Fig 3*A* and *B*). Three of the beads were located in front of the incisors, a fourth at the mandibular angle, a fifth lateral to the mandibular foramen, and 1 or 2 at the condyle.[12] As with Luce's investigations, tracings of the moving mandible were obtained by exposing a photographic plate to the highly reflective silver beads during each movement sequence. Profile photographs were made during normal (habitual) opening (see Fig 3*A*) and attempted (unassisted) retrusion of the mandible (Fig 4). Similarly, exposures were made during mandibular protrusion with the teeth in contact followed by an opening movement (Fig 3*B*). In addition, exposures were made during lateral movements (Fig 5). To record these movements, the silver beads were placed on the device at the level of the occlusal plane, but lateral to the condyle. The photographs were made from above, so that the exposures representing the lateral condylar paths would appear on the horizontal plane.

The results of Ulrich's investigations are quite remarkable, but because his work was so obscure, some of his findings have been credited to other investigators.

Ulrich found that because the condyles begin a forward motion immediately upon jaw opening, a series of instantaneous axes were responsible for the opening movement. He described and demonstrated the "envelope of motion" of the mandible on the sagittal plane (Fig 6). He believed that there might be a terminal hinge axis that can rarely be

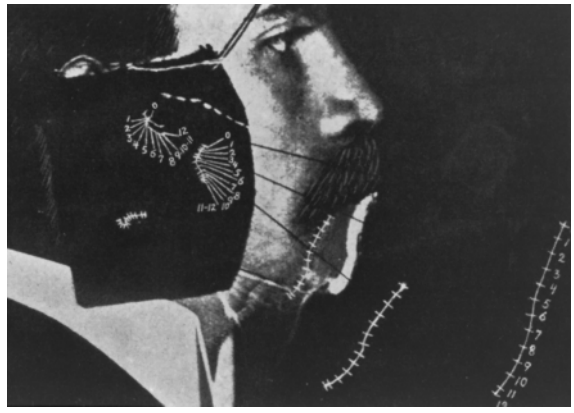

Figure 4. A photographic plate exposure of the same subject as in Fig 1*B* during an attempted (unassisted) hinge opening movement. (Reprinted from Ulrich, p 402.[12])

shown in habitual movements. Ulf Posselt, who described Ulrich's work in 1959,[15] pointed out that Ulrich did not investigate the influence of "training" or assisting the patient in the execution of the hinge movement, nor did he search for a terminal hinge axis with adjustable condylar pins or similar methods.

Ulrich also identified a "bodily shift" of the mandible during lateral movements (Fig 5), but just as with Balkwill's work, this finding remained unnoticed until about 12 years later when Norman G. Bennett described it for the third time.

According to Posselt, the methods used by Ulrich were sound and his findings were critically interpreted. Unfortunately, his pioneering work remained practically unknown outside the Danish dental profession, because his thesis was written in a language that was not internationally studied and only a few copies were circulated. Posselt used the word "published," but I am sure that he meant that only a few copies were bound and circulated.[15] Perhaps it would be appropriate to rename the lateral motion of the mandible the "Balkwill-Ulrich-Bennett" movement, and, of course, be prepared to include additional names as they are discovered.

Parfitt's "Graphic" Method

In 1902, John B. Parfitt, of Reading, England, presented a paper to the Odontological Society of Great Britain[16] introducing his "anatomical articulator." He suggested that it should be called a "Model Jaw" because "it may be made to reproduce to scale the motion of mastication of the jaws of any living subject" (Fig 7). Parfitt also introduced 2 mandibular facebows, 1 to transfer the casts to the articulator (Fig 8*A*) and 1 to produce a record of the contours of the condylar paths (Fig 8*B*).

Parfitt was the first investigator to imitate the anatomic curvatures of the condylar paths in an articulator. He showed that "the movements of the mandible are of three kinds: (1) rotation about a horizontal axis passing through the two condyles; (2) translation of the (mandible) forwards and downwards; (3) rotation about a vertical axis passing through one condyle."[16] Parfitt noted that these movements occur only in combinations.

The condylar paths were traced with his facebow "by attaching a small piece of crayon to the end of a stiff arm connected to a lower trial plate so that the crayon lies over the condyle." A paper card, held by a rod connected to the maxillary teeth or alveolar ridge, was placed under the crayon. After the tracings were made, pieces of thin metal were cut to the shape of the tracings and attached to the upper plate of the articulator. Parfitt may have been a little too optimistic when he remarked that "the instrument will be capable of imitating any movement possible to the lower jaw. . .and it is easy to use, as no nervousness or stupidity of the patient can cause an incorrect measurement to be taken."[16]

It is curious that with all the thought that Parfitt put into recreating the character of the condylar

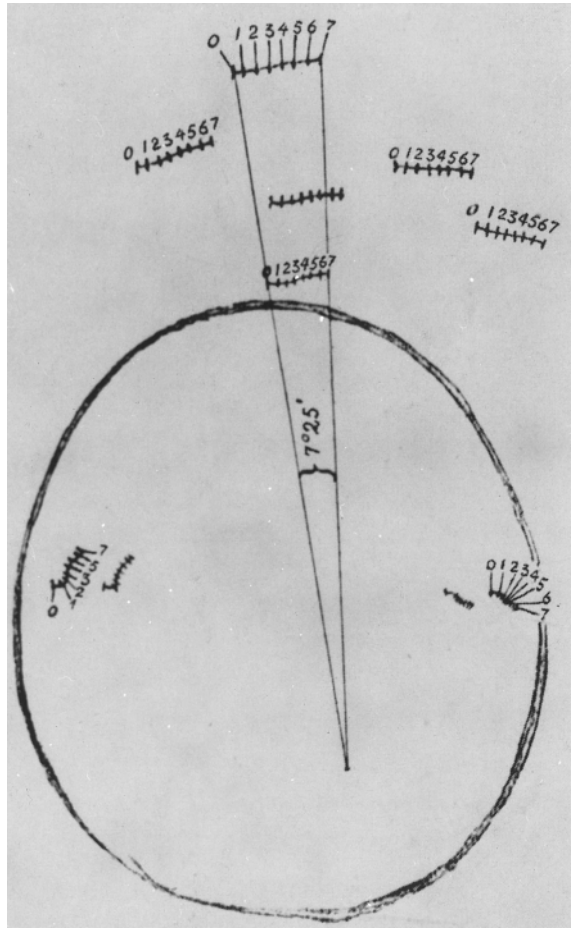

Figure 5. This drawing illustrates a lateral movement to the right as projected on the horizontal plane from above. The lateral movement when the subject attempted to protrude the mandible at the same time showed that the balancing condyle moved farther during this type of movement than during an uncomplicated protrusive movement. (Reprinted from Ulrich, p 404.[12])

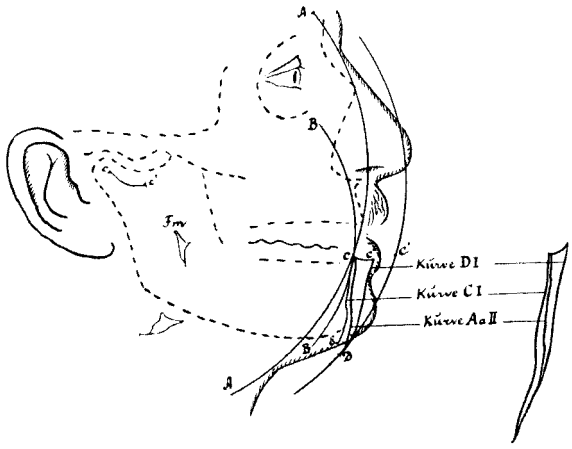

Figure 6. A composite drawing of the "movement area" on the sagittal plane for different fixed points on the mandible. (Reprinted from Ulrich, p 403.[12])

paths in his articulator, the concept of the incisal guide still eluded him—and the profession.

(More on the History of Articulators: From Facebows to the Gnathograph in the next issue of the *Journal of Prosthodontics*.)

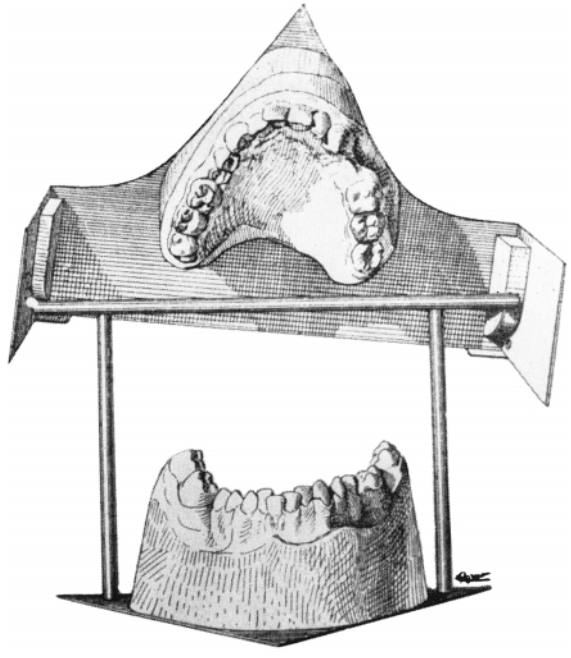

Figure 7. J.B. Parfitt's "Anatomical" Articulator, 1903. The metal condylar analogs produced from the tracings made by the graphic facebow (see Fig 8*B*) are attached to the upper member. The casts are mounted in the articulator with a mandibular transfer facebow (see Fig 8*A*). Parfitt believed that the articulator should be customized for each individual. (Reprinted from Ishihara et al.[17])

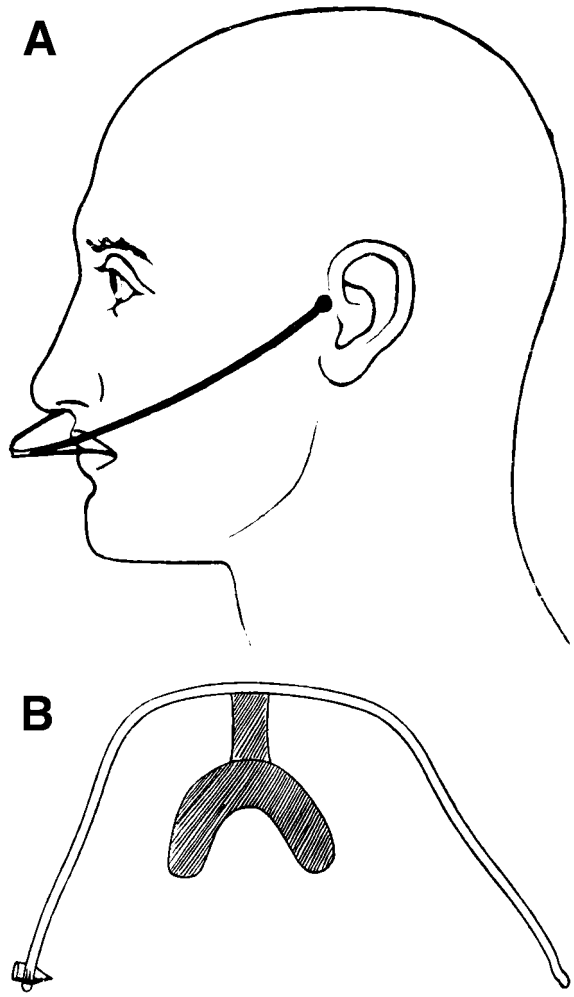

Figure 8. (*A*) Parfitt's mandibular transfer facebow, described as a trial plate with soft metal rods bent so that their ends lie over the condyles. After the mandibular cast was located in the articulator "so that the extremities of the transverse rod represent accurately the relative positions of the natural condyles," the maxillary cast was mounted with a "resting bite" record. The positions of the condyles were located by palpation. (Reprinted from Parfitt, p 119.[16]) (*B*) Parfitt's mandibular graphic facebow. One condyle path was traced at a time. The bow was described as a stiff arm carrying a crayon placed over the most prominent part of the condyle as it showed under the skin. (Reprinted from Parfitt, p 118.[16])

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