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Jaw tracking devices - historical review of methods development. Part I

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SUMMARY

Chewing or mastication is one of the main functions of the stomatognathic system. The use of devices for quantitatively measuring mandibular motion has recently become more common in scientific and clinical use. Often, the goal has been to provide an objective basis for diagnosing musculoskeletal disorders of the jaws, to monitor the progress of active treatment methods or to evaluate prosthodontic treatment functional results. To better understand differences between various systems to record mandibular motion a review of recording methods presented over the years was made.

To give fundamental description for development of existing methods review was divided in three parts.

Part I includes analyses of methods using mechanical devices, photographic methods and roentgenographic methods, describing not only technologies by themselves, but also analyzing essential limitations, possible direction of the functional improvement and, specially, their scientific and clinical significance.

Key words: chewing movements, tracking devices, mandibular motion

INTRODUCTION

Chewing or mastication is one of the main functions of the stomatognathic system. An integrated neurologic controlling system, the central pattern generator (CPG), regulates and coordinates all structural components involved in the process.

The use of devices for quantitatively measuring mandibular motion has recently become more common in the clinic. Often, the goal has been to provide an objective basis for diagnosing musculoskeletal disorders of the jaws or to monitor the progress of active treatment methods. The extent to which jaw tracking provides a useful research tool, a diagnostic aid, or a therapeutic monitor clearly depends on what is being measured, how the process is carried out, and why the information is important (1).

To better understand differences between various systems to record mandibular motion a review of some recording methods presented over the years was made.

METHODS USING MECHANICAL DEVICES

Various graphical methods have been used to elucidate articular movements of study casts mounted in an articulator. However, the validity of these studies is questionable and will not be dealt with in this paper.

In 1896 were first published works using a graphic recording method presented by Ulrich and Walker (2). In both studies, an arrangement was used that consisted of a marking needle attached to a face bow, which was attached to the lower teeth, and a marking disc or cardboard attached to the upper jaw or the head. Hesse (1897) employed an intra-oral needle, placed in the gap after a lost first lower molar, making imprints on an ebonite disc in the upper jaw (3). However, all the methods had the disadvantage of causing interferences with natural jaw movements. All these researchers performed registrations in one or two planes (horizontal and vertical), but the methods allowed recording in one plane at the time only.

In 1952 Posselt used a graphical method to analyze the mandible's capacity for border movements in the horizontal and the median planes, and to determine the influence of various factors on the retruded and the habitual positions of the mandible in undergraduate students with complete "harmony" of occlusion.

To record the horizontal movements Posselt made an intra-oral apparatus that consisted of a maxillary vulcanite plate with an interchangeable glass slide, which was covered with different thicknesses of wax. A mandibular vulcanite plate held the stylus of the tracking device. No significant differences between the recordings of the retruded position were found.

To record the area of movement in the median plane, splints on upper and lower jaws with an extra-oral tracking device in the median plane were used. No part of the apparatus prevented the natural intercuspation of the teeth, but it must be considered probable that the graphical apparatus fitted in the mouth influenced at least extensive movements. Therefore, he did not attempt to carry out a further analysis of habitual movements, but examined whether they coincided with the border movements or not.

In 1957 Stuart introduced an apparatus for jaw tracking purposes, which was based on the principles of a pantograph. The instrument was made of a series of rods arranged like a parallellogram. There were six recording styli and recording plates arranged at right angles to each other around

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the skull. Thus, each recording plate had a stylus at right angles to it to record movements. They were supported by a series of rods and adjustable sidearm, all of which were firmly attached to the teeth by cemented clutches. When the mandible moved, each of the six recording styli recorded a line on its related recording plate. The clutches were rigid and made from metal or plastic. When the recording was completed, the upper and lower components of the pantograph were attached to each other. A face-bow transfer was used to orientate the pantograph to the hinge axis and the axis-orbital plane before removing it from the mouth. Thus it was possible to transfer recordings from a person to an articulator (5).

Only in 1986 was done study to compare jaw movements recorded by two different pantographs (6). Donaldson and coworkers concluded that these two pantographs recorded mandibular movements with a mean difference of less than 0.1 mm. A pantograph has to be attached to the teeth by clutches and its size and weight will no doubt cause interference with natural jaw movements. To analyze the recordings of the pantograph they must be reproduced in an articulator making movement recordings even more inaccurate.

In 1969 was presented the Case Gnathic Replicator by Messerman, which was able to measure three-dimensional jaw movements in all six degrees of motion of the jaw (7). It recorded information for playback to a jaw motion reproducer mechanism and for computer analysis. The system recorded jaw motion with six incremental, photo-optical transducers mounted between a maxillary reference bow and a mandibular-mounted face bow. The weight and frictional force from the transducers applied to the jaw were only 60g. The clutches, which attached the measuring instrumentation to the teeth, were cemented to the labial surfaces of the anterior teeth without interfering with the occlusal surfaces. The clutches were designed to minimize interference with lip sealing at closure. The head was unrestrained, and the patient sat upright during the recordings. With this system it was possible to measure angles of jaw opening and closing paths, instantaneous centers of rotation, jaw position, velocity, and accleration of movement.

Gibbs and coworkers, using the Case Gnatihic Replicator, provided a study of jaw motion and maxillomandibular relationships during chewing (8). Their report described jaw motion at the mandibular central incisors and at both condules. The maximum measuring error was reported to be 0.13 mm.

The same equipment was also used to measure the angles of approach of the chewing cycle (9). They concluded that the flatter the closing path when viewed frontally, the steeper it appeared when viewed sagitally. In their following study scientists used this method to compare the chewing patterns of children with primary dentitions with those of adults with a complete dentition. The authors concluded that by 12 to 14 years of age a person has a typical chewing pattern, which continues throughout adulthood (10).

Many other authors used the Case Gnathic Replicator too. Suit and coworkers studied the frequency and length of tooth gliding contacts of patients with normal occlusion and with malocclusion. It was not possible to distinguish good occlusion from poor on the basis of frequency and length of gliding contacts. Alexander used this system to compare border and chewing movements before and after orthodontic correction of five patients with a deep-bite malocclusion. No greater smoothness or regularity was evident following orthodontic treatment (12). Coffey and coworkers were examining the movement of the lateral pole of the working condyle during lateral mandibular motion. The authors were not able to confirm a correlation between lateral retrusive tooth contacts and temporomandibular disorders (13).

In 1991 Keeling used the Replicator to examine systematic and random errors associated with repeated measurements (14). The results supported finding that bias in repeated measurements of human chewing movements are due to the test subject's adaptation to the recording environment.

The Case Graphic Replicator demonstrated the chewing cycle in detail to accuracy not possible by previous techniques. It should allow normal chewing movements to take place, but since it is attached to the teeth, jaw movements can be influenced by the weight of the apparatus.

PHOTOGRAPHIC METHODS

Luce first introduced a photographic method with a single camera and one stationary photographic plate in 1889 (15). As reference he used bright silver beads that were fastened to a wooden pin inserted between the mandibular central incisors, and also placed extra-orally on a face-bow at the condyles. Strong sunlight was necessary so that a bright spot would be reflected from the beads. The sensitive photographic plate was exposed during opening of the mouth. The bright spot, which was reflected from the bead during jaw movement, was continuously photographed and its excursion recorded on the photographic plate as a line giving the actual movement. Recordings were performed in the sagittal and the frontal planes. Luce examined two persons only and described condylar movement during opening and closing of the mouth.

Ulrich (1896) (2), Walker (1896) (3), Munzesheimer (1926) (16) photographic method used a photographic method as well. These researchers used self-luminous or intermittent light indicators with the form of polished metal balls placed on a face-bow, at the anterior teeth, at the molars, and at the angle of the mandible. To record the movements the indicators were exposed to strong sunlight or magnesium light. As a rule, the photographing was performed with a single camera. Only Munzesheimer employed more than one camera to obtain a three-dimensional recording. None of the authors mentioned the position of the test person and no kind of head fixation was used. Also, the number of test persons was limited: Walker presented two cases, Ulrich twelve and Munzesheimer seven.

In general, the method can be characterized today as unsatisfactory. Large indicators on the teeth and heavy face-bows to attach the indicators were used. To some extent the method could be suitable to study empty movements, but not mastication since the indicators interfered with natural jaw movements.

In 1914 Thouren introduced another method, which included photography using a member of successive photographic plates-cinematography (17). The aim of his study was to describe the pattern of mandibular movements and to find the center of rotation of the mandible. As a reference point an indicator attached at the contact point between the mandibular central incisors- incision inferior- was used. At this point a visible needle was placed. Thouren used only one camera with a speed of 16 frames per second. The profile of the test person was photographed. In this study head fixation was mentioned. Thouren analyzed only empty movements in the horizontal and the sagittal planes to find the most protruded position of the mandible. He also found that there is no single axis of rotation of the mandible during various movements.

In 1931 Hildebrand postulated that to improve cinematography it was necessary to take into consideration the two following circumstances: an indicator must be small, light and as little obstructive as possible, and the placement of the indicator must be such as to render possible the most expeditious calculation of the actual curves of movement. This would provide a greater probability of correct results, and make possible the examination of a greater number of individuals. To obtain a recording in three dimensions with a single camera he employed a mirror attached to the headrest at an angle of 45 degrees to the sagittal plane. The indicator was placed infradentally, where the path of movement was identical with the path of incision inferior, and head fixation was secured. Hildebrand was able to measure the duration of the chewing cycle and the velocity (18).

Atkinson and Shepherd described an improved cinematographic method in 1955 (19). The aim of their investigation was to study the suitability of the cinematographic method for recording of jaw movements. They photographed indicator balls fixed to the upper and lower teeth, and the attachment system caused no interference with chewing. They also performed registrations with indicators attached to the tip of the chin and the tip of the nose, but these results were not reproducible. The camera speed was 64 frames per second. Experiments were repeated with different individuals and different foods of which apple and biscuit were later used as a standard. In next study authors applied this method to evaluate mandibular movements inpatients suffering from temporomandibular joint disturbances, and concluded that the regularity of the chewing cycle was disturbed for patients having pain or clicking in the temporomandibular joints (20).

Woelfel and coworkers performed a study whose objectives were to observe the chewing pattern of edentulous subjects to determine if alterations in the posterior tooth from affected the chewing pattern, to test the effect of posterior tooth form on denture stability, and to obtain information on tooth contacts during mastication (21). The test dentures had different posterior tooth sections that were possible to attach to gold inserts in the denture base with cold-curing acrylic resin. For reference, wire frames with three beads - at the lateral ends, aligned and cemented to upper and lower central incisors - were used. Head fixation was not employed. To obtain recordings in two dimensions a mirror was positioned at 45-degree angle to the midline. A camera was positioned in front of the patient, and had a speed of 24 frames per second. A test substance - unvulcanized rubber keeping the same consistency during chewing - was used, but this material could influence natural chewing because of its taste and stiff consistency.

Even condylar movements were studied employing cinematography (22). As a reference point authors used a pin placed directly into the mandibular condyle. The movements of this pin were observed and compared with the movements of a pin attached to the lower incisors. To obtain three-dimensional recordings, three synchronously running motion picture cameras were used. Head fixation was obtained with a special cap attached to the headrest. The condylar movements were described in detail. The authors assumed that the temporomandibular joint has adaptability to biomechanical changes.

Beyron did classical study on the mastication in 1964, observing Australian aborigines by means of cinematography (23). As aborigines mostly kept their lips apart during mastication, it was possible to see the incisal portion of the anterior teeth and follow directly the movement of the incisal angle of a lower incisor. Only some individuals had head fixation against the headrest by a broad ribbon tied round the forehead. As test food fresh roast beef was used. Photographs were taken by a single camera with a film speed of 32 frames per second. Recordings were made in the frontal plane only. It was found that chewing alternated regular between the right and left sides. The masticatory cycles were wider and more regular than what was found in subjects of European origin.

Ahlgren compared mastication in children with normal occlusion with mastication in children with different types of malocclusion (24). A single camera with a film speed of 24 frames per second was used. Indicators were placed on one upper and one lower incisor. The test foods were carrots and chewing gum. A head holder was utilized to orientate the subject's head with the occlusal plane parallel to Camper's plane. A mirror system was used to obtain recordings in the sagittal and the frontal planes. In general, children with malocclusion had a more complicated chewing pattern with frequent crossing of the path of motion than children with normal occlusion. Based on this findigs the author devised a classification system for patterns of masticatory movements.

The last photographic methods to be mentioned is photoanthropometry that was developed de Rudd and introduced in 1969 (25). The technique depended upon the use of an optical device - a prism beam splitter - that was attached to the lens of a motion picture camera. For reference fluorescentindicator spheres were fixed to frameworks made for upper and lower jaws. These spheres, coated with fluorescent paints, were located in the midline, laterally to the right first molar and on the right high axis. Photographing was carried out in a dark room with the use of ultraviolet radiation to produce fluorescence. The use of head fixation was not mentioned. Envelopes of motion were recorded in one plane at the time. Analysis of chewing of different test foods was performed for the right side only. The method has not been used in further studies.

ROENTGENOGRAPHIC METHODS

In 1939 Klatsky introduced cinefluorography (or cineradiography) - the making of a motion picture record of the image seen on a fluoroscopic screen (26). For the recordings an x-ray machine, an output screen and a 16-mm cine camera was used. The subject was seated in a chair with an adjustable headrest between the roentgen tube and fluorescent screen. Pictures were taken in posteroanterior and lateral projections. Klatsky used five seconds of exposure, which by then was considered to be within the limits of safety. In next study author evaluated the masticatory function of three individuals with different dental conditions (27). After using test foods with different consistency he hypothesized that hard bread, fibrous vegetables and steak should be considered as ideal masticatory stimulants, and should be used in the prevention of orthodontic problems.

In 1953 Jankelson improved the cinefluorographic technique by synchronizing the excitation of the roentgen tube with the camera shutter so that the roentgen rays stroke the patient only during those instants when the camera shutter was open, and thus they obtained the greatest length of film exposure without exceeding a certain radiation limit (28). The authors investigated the act of incision and of mastication, using different test foods, and concluded that the incision was not a simple cutting through the food, but the tearing off at the thinned portion, before cutting entirely through.

An impropriety of this method was the dim image on the screen, which could be improved only by increasing the dose of radiation, which was not considered acceptable.

In 1956 Berry and Hofmann started to use an image intensifying apparatus, which replaced the ordinary fluorescent screen, and was able to convert the brightness of the image 800-1000x (29). This gave a better picture, a longer recording period, and less radiation to the patient. The exposure was comparable to the dose received during exposure for a dental x-ray. Authors presented also their recordings of the temporomandibular joint (30). To determine the degrees of roentgenologic enlargement and to calculate the actual anatomic excursions a metal ball, 4.8 mm in diameter, was attached to the patient's skin covering the joint to be examined. This ball became magnified to the same extent as the joint structures. The author concluded that the most superior and posterior position of the condyle in the fosse occurred only at the end of the first bite, and upon final closure, before swallowing.

At this time period many investigators used cinefluorodraphy. Ardran and coworkers used this method to investigate the mobility of mandibular complete dentures, placing 0.5-1 ml of fluid barium suspension under the tongue immediately before each exposure to outline the sublingual space. They concluded that stability was mainly dependent upon the freedom of the tongue to move within the arch of the denture (31). Sheppard and Markus tried to establish the presence or the absence of tooth contacts during mastication. They found that during the major part of mastication teeth were out of occlusal contact (32). Sheppard investigated complete denture base movements during mastication. The opposing teeth were apart during most of this function, and more denture base movements occurred with the teeth apart than during contact. Thus, the direct effect of occlusion on stability and retention during mastication seems less significant than that of the musculature (32). The same author studied the direction of mandibular movements during mastication in subjects with a deep vertical overlap in the anterior region. For reference lead markers attached anteriorly at the midline of the maxilla and the mandible were used. Most masticatory strokes contained a lateral component, but only 8% of chewing cycles appeared to contain closing strokes in a vertical direction. Thus, the author concluded that vertical chewing did not seem to be a causative factor in the development of extreme vertical overlap of anterior teeth nor in the prevention of periodontal disease in these subjects (34). Hedegard and coworkers studied the position of the bolus in subjects with complete maxillary and partial mandibular dentures. The results showed that the patients used the molar and premolar segments to a greater extent than the incisor region, which was used mostly during the first few chewing cycles (35). Lundberg used the same technique to evaluate the position in complete denture wearers, and it was concluded that the position of the bolus depended on the properties of the food, since toffee was chewed mostly in the premolar region, but bread was distributed uniformly over the arches (36). Wictorin and coworkers studied the position of the bolus in individuals with a full complement of natural teeth. These subjects mostly used the premolar and molar segments to chew the same type of test food (37). Hedeg?rd compared the duration of the masticatory cycle in different groups of patients having complete dentures, partial dentures and a natural dentition. No significant differences could be found, but individual variations were considerable (38).

In 1979 Karlson tested the qualities of cineradiography and its clinical application (39). The author reported an absorbed dose for the head of the subject of about 5rad/s which is comparable to what is received at a full mouth radiographic survey, but with cineradiography theirradiated area is larger. The denture mobility, bolus position, mandibular movement pattern and chewing velocity were investigated in five groups of patients. Karlson concluded that cineradiography is well suited for the analysis of bolus position, registration of denture mobility and chewing velocity. However, other methods should be preferred to study the detailed mandibular movement pattern or tracking in three dimensions since the described method reproduced only frontal and lateral dimensions. In a further work, Karlson and Swartz did a cineradiography investigation to test two different types of denture adhesive used for complete maxillary dentures. No significant difference was found for denture mobility, and the authors concluded that denture adhesives have a limited effect for denture wearers with moderate resumption of the alveolar ridges. In this study the reported radiation dose absorbed by the skin was 0.1 ad/s (40). The same method was used to test denture mobility and bolus position during mastication in patients wearing conventional and pelotte-retained complete upper dentures. Gold pellets 2 to 4 mm in size were fitted in the dentures as indicators. With pellote dentures the bolus was positioned more distally, and the author assumed this was to reduce discomfort in the front region. Patients with conventional dentures distributed the bolus to all regions (41). In 1989 Karlsson and coworkers reported a longitudinal cineradiographic study of subjects with a complete maxillary denture and fixed partial mandibular denture with cantilever extension and pontiffs or sadles. They did three recordings - before prosthetic treatment, one month after treatment and approximately 12 years later. At the final registration a more developed version of cineradiography – the videofluoroscopic device – was used, which contained an image intensifier interfaced to a videotape recorder. The authors summarized that the position of the bolus was normalized after prosthetic treatment of severely reduced dentitions receiving extensive fixed cantilever bridges (42).

In 1989 Tobey and Lincks introduced the video-fluoroscopic method to study oral motor function in terms of chewing, swallowing and speech in a group of patients with maxillary defects (43). Indicators fitted into the obturator prostheses were used. It was found that all prosthetic reconstructions were sufficiently stable during function.

In 1992 Palmer and coworkers used video-fluoroscopy simultaneously with EMG to study the coordination of mastication, the oral transport and the swallowing during intake of test foods having different consistency and liquids (44). The authors described mastication and swallowing in detail and divided all these processes into three cycles- chewing, transport and swallow.

It can be concluded that by means of roentgenologic methods it is possible to analyze intraoral behavior under relatively interference-free conditions. The methods can be helpful to study the function and the mobility of dentures and the bolus position in two dimensions. Since in most cases it is necessary to use a test food with a contrast medium, this may influence the nature of movements because of the unnatural taste. The decision to carry out such studies has to be taken after weighing other factors relating to the radiation to which the patient is exposed, but the probability that the absorbed dose of radiation will cause injuries, is considered low (39). Still it is doubtful that a research ethic committee would allow the use of x-rays for such experimental purposes today.

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