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

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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 II includes analyses of electronic and telemetric methods, magnetometry and opto-electronic 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

ELECTRONIC AND TELEMETRIC METHODS

In 1953 it was introduced an electronic method to investigate the frequency of tooth contacts by Jankelson. Stainless steel orthodontic bands were fixed to crowned teeth and soldered to a plastic-covered copper wire, which was carried out of the mouth and connected to an EMG oscillograph. An electrical current was applied to the crowns through the wires. When opposing crowns made contact, the circuit was closed and the movement was recorded graphically. Thus, it was possible to establish the frequency of occlusal contacts during mastication (1). Yurkstas and Emerson used dentures in whose posterior teeth holes were made and wires placed and fixed with amalgam. The wires were connected to a battery and a graphical ammeter. Each contact was recorded as deflection of a pen line on a moving strip of paper. The amount of contact was evaluated as the percentage of strokes that contacted while the bolus was masticated. The authors found the all patients exhibited considerable contact between the teeth on the working side and almost 100% contact on the balancing side (2).

In 1961 Brewer and Hudson introduced a method using radio transmitters placed in complete dentures. The transmitting device consisted of an oscillator, a battery and a switch combined in one unit. The battery was connected so that any desired tooth contact closed the circuit, resulting in a signal picked up by the antenna tuned to same frequency as the transmitter. Signals were received and amplified to light a small neon bulb mounted to the subject's face outside his field of vision. The intercuspal position and the retruded contact position were studied and it was found that the frequency, the duration and the distribution of tooth contacts during mastication made up an individual pattern for each subject (3).

Graf and Zander miniaturized transmitters, making it possible to place a single transmitter in a removable bridge's pontic with the switch positioned to record contact from an opposing tooth in the intercuspal position and the retruded contact position. They found that tooth contacts in the retruded position occurred only during swallowing. The authors also found that strictly speaking teeth need not make contact more than 17.5 min/day, i.e. during eating and swallowing (4).

In 1967 Neill incorporated miniature radio transmitters in a mandibular denture. The open ends of the circuit were formed by isolated metal cusp of the first molar teeth. The transmitter was switched on when conduction between these cusps took place through the metal cusp of the opposing teeth. The number of recorded tooth contacts was higher on the non-chewing than on the chewing side. They occurred in a random fashion, and increased in frequency as the chewing sequence proceeded (5).

Glickman et al. (1968) achieved further miniaturization with the development of the multi- layer switch. This system enabled one transmitter to register three different occlusal positions by giving each contact a different frequency. Since these three points were situated within an area of 1.5 by 1.5 mm on the occlusal surface of the tooth, occlusal gliding movements could be recognized by three

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quickly following signals of different frequencies. Depending on the positioning of multiple switches it was possible to record the sagittal and the transversal gliding movements. The switch was closed only when a small gold inlay inserted in the opposing tooth cusp contacted it. Signals were picked up by an antenna and fed to a receiver, which was connected to an oscillograph. Most chewing contacts occurred in the habitual occlusion, only a few posterior to it. Also a few lateral gliding movements and retrusive glides took place. No repetitive patterns of tooth contacts were recorded during lateral excursions (6).

In 1969 Glickman coworkers introduced a new version of the switch with five contacts. The purpose of his new study was to distinguish between a single contact and gliding movements. The authors found 54% of tooth contacts during chewing to be single, and 46% were glides when switches were aligned in the anteroposterior direction, but there were 69% single contacts, and 31 % glides in the buccolingual direction (7).

In 1970 Pameijer and coworkers used the same method to study contacts of natural teeth during swallowing. Signals were emitted at one of several frequencies, depending on which part of the switch that was contacted. Tooth contacts during swallowing occurred more often in centric occlusion than in centric relation (8).

Glickman (1974) reported a study of one of subject with a completely reconstructed natural dentition, The findings indicated that the subject did not use the prostheses build with the occlusion in centric relation, but adopted the pre-existing centric occlusion (9).

In 1967 was presented the Photoelectric Mandibulograph by Gillings (10). The apparatus consisted of a mandibular rod, a light attached to the labial surfaces of the lower incisors, and photocells which were held on a frame fixed to the without discomfort or restriction of head or muscle movements. All photocells were arranged in three sets with six cells in each: one set sensed the open-close, then the left-right, and a third the anterior-posterior movements. This system detected motion by positional changes of the light source, eliminating direct connection between jaws and recording apparatus. The subject's jaw movements were not restricted and were recorded in three dimensions. Authors also studied the nature of chewing movements during a simple chewing exercise in a group of young men. All subjects had substantially consisted and reproducible patterns of jaw movements, and they exhibited a pause in the centric occlusion at the end of the closing stroke. A constant velocity was observed for most chewing cycles (11).

MAGNETOMETRY

In 1974 Lewin and coworker introduced a recording method, using a small magnet attached labially between the central incisors of the mandible (12). In this device three pairs of transducers, making use of the "Hall effect" discovered by E. H. Hall in 1879, were mounted on a rectangular plastic frame located at a fixed distance from the magnet with the mandible in the rest position. The transducers produced signals of changing polarity and magnitude as the magnetic pole moved in union with the movement of the jaw.

Lemmer and coworkers analyzed the capabilities of this apparatus and concluded that displacements detected by the transducers represent a complex of translations and rotations through the magnet attached to the mandible, but these components of the displacements were not separable, and therefore, jaw movements could not be fully described from the data obtained (13).

In 1978 Lewin and Nickel overcame previous problems by introducing a new device- the electrognathograph- that was further developed into the Sirognathograph (Siemens GK). To measure the movements of the mandible in terms of rotation and translation a specially designed magnet was used, emanating a magnetic field. An antenna made from low-remanence metals was used to linearise the curves of the Hall generators. This device allowed measurements fully describing the movements of the mandible over a certain period of time (14).

In 1985 Maruyama and coworkers described the Sirognathograph Analyzing System (SGG/AS), which was developed by uniting the Sirognathograph with a personal computer (15,16). The SGG traced the position of the magnet attached to the labial surface of the mandibular incisor with eight magnetic sensors. A cross bar was supported on the root of the patient's nose, and side arms were supported on the upper parts of the earlobes and fixed with an elastic band to the occipital region. The position of the sensors of the antenna was adjusted to the mandibular incisors. The purpose of their first study was to investigate whether the chewing movement is reproducible or not, and they concluded that recording of the chewing movements can be used for clinical purposes, for example, the diagnosis of the stomatognathic function (15). In their second study the authors recorded chewing movements of patients with stomatognathic dysfunction, and concluded that patients with closed lock or bone changes in the temporomandibular joint had a high tendency for deviation of the chewing cycle to the symptomatic side(16).

Mongini studied the masticatory function under healthy conditions, and confirmed that habitual mastication is a rhythmic event with different envelopes of motion that alternate characteristically in each subject (17). In another studies of the jaw movements of dysfunction patients, he concluded that most parameters characterizing mandibular movements during mastication in normal persons are lost in dysfunction, and that jaw movements in TMJ-impaired patients markedly deviated towards the affected side (18).

Nishio and coworkers examined how occlusion influences the chewing movement and found that some subjects had a chopping chewing pattern, and recognized the chopping type as the basis of their chewing pattern. Others had a grinding type. This study suggested that the chewing pattern has some relationship to occlusion, especially to the distance of separation between the upper and the lower posterior teeth in the lateral mandibular position (19).

Kuwahara used this system to study the relationship between mastication and TMJ abnormalities and reported that the mobility of the abnormal condyle influenced the convexity of the opening path (20). Evaluating the chewing pattern of patients with TMD, authors were able to classify various patterns in relation to specific temporomandibular disorders (21).

The SGG was used until 1991, when Postic with coworkers attempted to determine the occlusal contact areas in which the movements of chewing hard and soft food take place and concluded that food consistency affects teeth gliding lengths as well as envelopes of chewing sequences (22). In their next paper authors compared the chewing cycles of dentate and denture-wearing subjects and found that the envelopes of habitual chewing movements of denture-wearing subjects were within approximately the same area as those of dentate subjects, but they showed greater mandibular excursions on the non-working side and the length of contact were larger (23).

In 1994 Kazazoglu tested the technical and clinical limitations of the Sirognathograph and reported a slow sampling speed and sample artifacts that were possible to eliminate by using a customized pulse generator and software for controlled data acquisition. Clinically the effect of cranical movements during mastication could cause a baseline drift with consequent errors in the recording of the mandibular position. Also, the spatial relationship between the antenna, the cranial base and the magnet was found to be critical for repeatability of the recordings. To obtain greatest sensitivity the equipment had to be calibrated. Cranical stabilization was also necessary for accurate recordings, and satisfactory cranical stability could be achieved with a combination of a padded headband and voluntary limitation of cranical movement (24).

In 1975 was presented also another system of magnetometry - The Mandibular Kinesiograph by Jankelson (25). It recorded electronically mandibular incisor point movements in three dimensions by tracking a magnetic field emanating from a 2,8g magnet attached to a central mandibular incisor. The sensor system consisted of six magnetometers, and were constructed with rigid dimensional specifications, mounted on a structure of thin-walled aluminum tubing, and supported on the skull by a modified pair of eyeglass frames worm by the patient. The headset of the Kinesiograph was aligned to the Frankfort plane with a face-bow, and the magnet had to be located in the middle of the recording region of the sensors. The signals were tracked in the sagittal, frontal and horizontal planes.

Not until 1980 did Jankelson make a study to assess the validity of the data supplied by the Mandibular Kinesiograph (26). He tested the raw data and the corrected data, and concluded that in a test against a computer-controlled electronic measuring system, the validity of the Mandibular Kinesiograph recordings was confirmed as precise representations of mandibular movement at the incisor point.

Hannam examined the origin of error of measurements in an experimental environment. They pointed out some imperfections of the equipment, i.e., nonlinear response characteristics over the entire range of functional jaw movement, and fixed craniofacial landmarks. The authors concluded that these problems could be overcome permitting an acceptable error of measurement of linear incisor point movement. However, this study was carried out using a later version of the Kinesiograph (27).

Neill and coworker used this system to study the chewing activity of young adults. They found differences between men and women concerning cycle time, velocity of movement, dimensions of the chewing envelope, and the duration of the pause in the intercuspal position (28).

Kinesiograph was used until 1993, when Tsolka evaluated the effect of occlusal adjustment on the signs and symptoms of craniomandibular disorders and found that the mock and real adjustments had a similar effect on the opening and closing movements (29).

The Mandibular Kinesiograph and the Sirognathograph both enable jaw movements to be monitored without the head being restricted and without the need for any connection between the intramural marker and the transducing element. Both depend on a change in magnetic flux occurring when a small bar magnet moves relative to a sensor. These devices do not alter proprioceptive input either by interfering with the occlusal plane or by limiting the normal range of mandibular function. Neill and Howell investigated the relative merits of two instruments in 1984, and the Mandibular Kinesiograph proved to be the most versatile one (30). Michler tested both systems clinically and found a higher agreement between actual displacement and tracking using the Sirognathograph (31).

OPTO-ELECTRONIC METHODS

In 1977 Karlsson described an opto-electronic motion recording system (Selspot, Selcom AB, Gothenburg, Sweden) (32). It consisted of three basic units: light emitting diodes (LED), a position sensitive detector in a camera, and a computer with a camera interface. The LED emitted infrared light, which could penetrate soft tissues. These signals were focused on a photosensitive surface in cameras where they were transformed to digital impulses. The sensitive detector gave the information of any light spot that was focused on its surface. By using two cameras placed at right angles to each other, the three dimensional coordinates of a movement could be calculated. For recordings one diode was attached between the lower incisors. The reference diode was attached to the forehead. Thus, it was possible to exclude head movements by subtraction in data analysis. The author evaluated the system and concluded that the method had a satisfactory precision, good reproducibility, and a minimum of external influence on the test person. Karlson specified that perfect elimination of head movements could be obtained by using three reference diodes on the subject's head. To determine the suitability of the method for clinical application Jemt studied jaw movements in young adults. The study was performed with one camera and two diodes. A neck rest supported the head, and only small movements occurred during chewing. The following variables were analyzed: the duration of the chewing cycle and the total chewing period, the time in centric occlusion, the time for opening and for closing, the maximal vertical movement, its direction, and velocity. The mean cycle duration varied from 0.76 to 1.12s. The opening phase was shorter than the closing phase, the maximal vertical movement decreased throughout the chewing period. The authors concluded that the method was suitable for clinical situations (33).

Jemt and Karlsson used the system to study mandibular movements in wearers of maxillary and mandibular complete dentures before and after treatment. For recordings in three planes two cameras were used. In this study the movable LED was attached to the chin. New dentures influenced the mean chewing velocity very little. No difference between two test foods and no difference before and after rehabilitation was found (34). In 1982 Jemt and Hedegard investigated the suitability of the soft tissues over the chin as a reference point (35). For comparison one LED was attached to the chin, and another to a lower front tooth. Simultaneous recordings were made. Head movements were compensated for by three LED s attached to the spectacle frame of the test subject. A chin reference marker was found to be suitable for analyzing chewing rhythm. Vertical displacement and velocity were less marked using the chin marker.The method was used to study the chewing patterns before and after treatment with complete maxillary and bilateral distal-extension mandibular incisor. Prosthodontic treatment did not change the general the general masticatory pattern. The velocity of the mandible increased, but the number of chewing cycles decreased (36).

Still in 90th many scientifists were using this equipment. Karlsson and Carlsson compared masticatory movements of young and elderly subjects having a natural dention. For analyses, the single masticatory cycle was divided into three separate phases: mandibular opening, mandibular closing and occlusal level phases. No difference was found in the duration of the total chewing cycle. Mandibular velocity and mean vertical displacement were lower in the elderly group (37). Tzakis studied the effects of intense chewing on masticatory function and concluded that functional stimulation of the stomatognathic system with 30min of intense chewing created only a short-term effect on masticatory function. The occlusal level phase and the duration of the masticatory cycle were reduced (38). Kjellberg evaluated oral motor function in individuals with juvenile chronic arthritis. The moving LED was attached to the subject's chin. These children were compared to subjects that had a normal occlusion, and one that had a Class II malocclusion. The results showed that children with arthritis and condylar lesions had a reduced lateral mandibular masticatory movement, a longer occlusal time, a shorter amplitude, and reduced velocity (39).

In 1985 was designed developed the other one opto-electronic system (JAWS-3D) for monitoring the functional movements of any mandibular point by Mesqui and Palla (40). The system consisted of three CCD (Charge Coupled Device) cameras that recorded the position of six LEDs mounted on two triangular target frames attached to the upper and lower dental arches by means of custom-made metal splints. The upper target frame compensated for head movements.

The system was used to study the relationship between condylar rotation and translation (41). The results showed a highly linear relationship between condylar rotation and anterior translation during opening and closing in subjects with healthy temporomandibular joints. In clicking joints the movement started mostly by rotation, and ended with a pronounced rotatory component.

In 1994 Airoldi measured, under laboratory conditions, the accuracy of JAWS-3D. The reported error of the path of the point recorded varied between 0.11 and 1.33% (42).

The new opto-electronic system called "Mac Reflex" (Qualisys AB, Partlle; Sweden) was described by Hamborg &Karlsson in 1996 (43). This equipment consists of three basic units: two video cameras with a detecting lens sensitive to infrared light, a video processor, and a software package in a Macintosh computer. An infrared flashlight placed around the lens, synchronized with the electronic shutter, illuminated the field of view. Reflectors attached to the person reflected infrared light back to the cameras. To exclude the influence of head movements three reflecting markers, aligned in L-form and attached to a frame, were used. The authors tested the equipment in vitro and in a clinical study. They stated that estimated linearity of the equipment was 0.2mm (0.002%). The equipment proved to be easy to use in a clinical situation, the method was accurate, and interference with the oral tissues was minimal.

So far techniques based on opto-electronic devices appear to be least disturbing to individual chewing patterns.

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