Review Article

Methods of recording mandibular movements - A review

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ABSTRACT

The aim of this article is to review the current literature on various methods of assessing mandibular movements. As mandibular movements reflect the functional morphology of temporomandibular joint (TMJ), the occlusal morphology of each tooth may be functionally related to its antagonist, to the TMJ and to the other components of the stomatognathic system in reasonably precise ways. Articulator specifications thus can be based on common recognizable elements of jaw movements involved in chewing, swallowing, speech, regardless of various occlusal schemes. This would enable the dentist to prevent or minimize periodontal and temporomandibular disease and consequent tooth loss. The movement pattern of the mandible in function has long been the subject of considerable interest both from the physiologic and the clinical aspects. Mandibular movement is defined as "any movement of the lower jaw" and is determined by the simultaneous activities of the TMJ. The analysis of mandibular movements is specifically good at providing important parameters for evaluation of the TMJ function as well as for the determination of the state of muscles involved in mastication. With a precise knowledge of these, articulator specifications may be accurately made, which enable the dentist and the laboratory technician to build and test prosthetic appliances in an actual functional relationship as it occurs in the mouth. This article attempts to recapitulate the various methods of recording mandibular movements. Hence, this topic is chosen to provide the reader with a general picture about the innumerous recent methods available to assess mandibular movements.

KEY WORDS: Articulators, Mandibular, Movements, Pantograph, Temporomandibular joint

INTRODUCTION

We are blessed with a dynamic masticatory system which allows us to function and exist. The masticatory system is a complex unit that primarily consists of bones, muscles, ligaments, and teeth. It is a highly intricate unit and primarily related to chewing, speech, and swallowing. The ever so delicate balance between the various components of the system is monitored by the neuromuscular control. Maxillomandibular relationships establishment have got the attention of prosthodontists ever since the dynamic and static positions of the condyles in the glenoid fossa have been interpreted and understood.[1]

Mandibular movement is defined as "any movement of the lower jaw" and is determined by the simultaneous activities of the temporomandibular joint (TMJ). The form of the bilateral TMJs and their function facilitate the mandible in making a variety of movements mainly carried out in three different planes, namely, the sagittal, the frontal, and the horizontal planes. Mainly, these movements produce rotational (turning) and translational (sliding) motions.[2] The rotatory or the hinge-like movement occurs between the condyle and the articular disc. Basically, there are a couple of movements of the mandible:

- The functional movements which are characteristic naturally occurring movements such as those occurring during mastication, speaking, and yawning.
- The parafunctional movements which are non-characteristic movements such as clenching and tapping.

The maximum movement in a plane or direction is termed the border movement. There is a wide range of movement called intraborder movement that occurs within the confines of the border movements. Border movements are reproducible. Hence, they can be measured mechanically. Intraborder movements are not reproducible and hence cannot be measured with

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accuracy. A precise mandibular movement is required to move the teeth efficiently across each other.[3]

Unlike natural teeth, prosthesis is either ankylosed to the bone, rests on the supporting teeth or on the alveolar mucosa. Lateral forces produced during mandibular movements due to the prosthesis can traumatize these supporting structures. The analysis of mandibular movements provides important parameters for evaluation of the TMJ function as well as for the determination of the state of muscles involved in mastication.[4] A study of mandibular movements is thus essential for a clinician to simulate normal functioning of the masticating apparatus. Therefore, a thorough knowledge of mandibular movements is essential for the prosthodontist to understand various aspects of occlusion before fabricating the prosthesis. A good knowledge of various methods that have been employed to measure mandibular movements is of key importance in the clinical analysis of mastication.

HISTORY

Several methods have been employed to measure mandibular movements. Measurement techniques include simple measurement devices, such as a millimeter ruler, to sophisticated electronic devices to record movements of the mandible using magnets or photodiode sensors. Many of them are based on the use of recording instruments that usually employ sensors fixed on the mandible,[5] such as ultrasound,[6] accelerometers,[7] electromagnetic fields,[8] videofluoroscopy,[9] and optoelectronic devices.[10] Other methods include graphic tracings,[11] imaging (lateral radiographs),[12] or electromagnetic transducers cemented on anterior teeth.[13]

Graphic methods were used at an early date by Ulrich[14] and Walker,[15] the movements of the mandible being recorded with a stylus on a plate attached to the upper jaw or the head. Photographic methods also seem to have come into use in early years; Luce[16] photographed the sunlight reflection from beads placed opposite to the condyles. Walker (1896) stated that the absence of condylar inclination is the dictating factor and said that the dentures balanced using Bonwill's articulator did not balance in the mouth. He gave "facial clinometer" for the measurement of the condylar movements. Posselt[17] studied condyle movement by profile radiography. Cinematography was used for the first time by Thourén (1914),[18] and this technique was later improved by Hildebrand (1931),[19] who by utilizing mirrors succeeded in obtaining simultaneous recordings in two planes. Utilization of roentgenography in the study of mandibular movement appears to have been first introduced by Sicher (1929),[20] who reported that he had been able to examine positions of the jaw by ordinary roentgen recordings. A similar technique, which also included stereoscopic roentgenograms and photogrammetric analysis, was used later by Lindblom (1960).[21] Hildebrand used fluoroscopy together with roentgen kymography and recorded the movement pattern of the mandible as kymograms showing the condylar movements in different planes. The first studies of the mandibular movements with the aid of cineroentgenography were carried out by Klatsky (1939).[22] His apparatus was based on the principle of direct cinematographic recording of the fluoroscopic image. Zola and Rothchildlo followed mandibular movements with a condylar thesiograph.[23]

METHODS FOR RECORDING MANDIBULAR MOVEMENTS

Methods using Mechanical Devices

Various graphical methods have been used to elucidate articular movements of the study casts mounted in an articulator. In the absence of the patient, the articulator serves as a patient because it can be automated with patient records that allow the operator to construct a restoration that will be physiologically and psychologically successful. Some of these devices make no attempt to represent the TMJs (facebow transfer) or their paths of motion. Some instruments allow eccentric motion determined by inadequate registrations. Some utilize average or equivalent pathways.[24] Some attempt to reproduce the eccentric pathways of the patient from three-dimensional registrations. Hesse (1897) employed an intraoral needle, placed in the gap after a lost first lower molar, making imprints on an ebonite disc in the upper jaw. 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 parallelogram. It consisted of six recording styli and recording plates set at right angles to each other around the skull.It was the Only study done in 1986 which compared the jaw movements recorded by two different pantographs. Donaldson *et al.* determined that mandibular movements with a mean difference of <0.1 mm was noted by these pantographs. Messerman In 1969 presented the Case of Gnathic Replicator which was able to measure three-dimensional jaw movements in all six degrees of motion of the jaw.[25] Using the case gnathic replicator, Gibbs *et al.* provided a study of jaw motion and maxillomandibular relationships during chewing. The same equipment was also used to measure the angles of approach of the chewing cycle.

Photographic Methods

Luce first introduced a photographic method with a single camera and one stationary photographic plate. Ulrich, Walker, Munzesheimer[26] used photographic method as well. These researchers used self-luminous or intermittent light indicators with the form of polished metal balls placed on a facebow, 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. Munzesheimer used more than one camera to attain a three-dimensional recording. In 1914, Thouren introduced another method, which included photography using a member of successive photographic plates – cinematography. 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. Condylar movements were studied employing cinematography.[16] As a reference point, the authors used a pinplaced directly into the mandibular condyle. The movements of this pin were detected and equated with the movements of a pin fixed 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 last photographic methods to be mentioned is photoanthropometry that was developed de Rudd and introduced in 1969.[27] The technique depended on the use of an optical device - a prism beam splitter - that was attached to the lens of a motion picture camera. For reference, fluorescent indicator spheres were fixed to frameworks made for the upper and lower jaws. These spheres, coated with fluorescent paints, were 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.

Roentgenographic Methods

In 1939, Klatsky introduced cinefluorography (cineradiography) - the making of a motion picture record of the image seen on a fluoroscopic screen. 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] 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 800–1000×. In 1989, Tobey and Lincks introduced the videofluoroscopic method to study oral motor function in terms of chewing, swallowing, and speech in a group of patients with maxillary defects. Indicators fitted into the obturator prostheses were used. It was found that all prosthetic reconstructions were sufficiently stable during function.

In 1992, Palmer *et al.* 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.[29]

Electronic and Telemetric Methods

Neill (1967) 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. It showed that the number of recorded tooth contacts was more on the non-chewing side than on the chewing side. They occurred in a random fashion and increased in frequency as the chewing sequence proceeded.[30] Glickman *et al.* (1968) achieved further miniaturization with the development of the multilayer switch. This system permitted one transmitter to record three different occlusal positions by enabling each contact a different frequency. Gilling presented the photoelectric mandibulograph.[31] The apparatus comprised a mandibular rod, a light attached to the labial surfaces of the lower incisors, and photocells which were put on a frame. 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. By positional changes of the light source, this system sensed motion, discounting direct connection between the jaws and recording apparatus. Hence, the subject's jaw movements were not constrained and were recorded in three dimensions.

Magnetometry

In 1974, Lewin *et al.* introduced a recording method, using a small magnet attached labially between the central incisors of the mandible.[32] In this device, three pairs of transducers, making use of the "hall effect" discovered by 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.

In 1985, Maruyama *et al.* described the Sirognathograph Analyzing System (SGG/AS), which was developed by uniting the sirognathograph with a personal computer.[33,34] The SGG traced the position of the magnet attached to the labial surface of the mandibular incisor with eight magnetic sensors.

The Mandibular Kinesiograph (MKG)

In 1975, another system of magnetometry - The MKG was introduced by Jankelson. It is an instrument designed for research and diagnosis of mandibular function/dysfunction. It electronically records mandibular incisor-point movements in three dimensions. Measurement of vertical velocity is also provided by differentiating the vertical position signal.[35]

Opto-electronic Methods

In 1977, Karlsson described an optoelectronic motion recording system.[36] It consisted of light emitting diodes (LED), a position sensitive detector in a camera, and a computer with a camera interface. 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.

In 1985, another optoelectronic system (JAWS-3D) was designed for monitoring the functional movements of any mandibular point by Mesqui and Palla.[37] The system consisted of three 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 new optoelectronic system called “mac reflex” was described by Hamborg and Karlsson in 1996.[38] 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. The equipment proved to be easy to use in a clinical situation as it was accurate and interference with the oral tissues was minimal.

Motion tracking systems based on optoelectronic technology has become the preferred method to study jaw movements because of their operational and accuracy advantages over the other methods. Recent advancements include a wireless mandibular motion tracking device and optoelectronic data acquisition system capable of analyzing, by means of graphic computation, the real-time spatial behavior of the entire mandible during mouth opening and closing with no restriction of any movement.

Pantographs

It is a three-dimensional dynamic registration procedure utilized in Class IV B type of articulators. The tracings produced by pantographs are called pantograms.[39]

The pantograph is an apparatus consisting of two face bows; one fixed to the maxilla and other to the mandible and one holds the styli and the other recording tables. Six styli and recording tables are attached. Two are located adjacent to each condylar area in horizontal and vertical planes. Two additional tracing tables are placed in the incisal region of anterior teeth, in the horizontal plane. Mandibular movements then produce pantograms on the tracing tables. It was the Only study done in 1986 which compared the jaw movements recorded by two different pantographs.[40,41]

To eliminate the time-consuming procedure of transferring the tracing to the articulator, Denar developed pantronic in 1982. The pantronic is an electronic pantograph which provides a computer printout of numerical condylar measurements. There are three appliances available for tracings - one designed by Stuart, one by Granger, and the third by Guichet. The styli in the Guichet are on the upper bow and are pneumatically controlled by one bottom. Thus, the apparatus can be used easily and speedily by one man. On the other hand, Grangers and Stuart’s instruments have the condylar styli on the lower member and the arrow point tracing styli on the upper. In addition, Stuart and Grangers instrument record the center of rotation for each condyle because their horizontal styli are set to the terminal hinge axis.

It serves two principal functions: First, it acts as a facebow to transfer the maxillary cast to the articulator in an exact relationship to the condyles; second, it stores all the needed information for adjusting the articulator to the precise condylar movements of the patient.[42]

Stereographics

This system provides a more simplified means of accurately establishing articulator settings for precise technical work. Four studs embedded in the upper clutch allow intraoral molding of border movements in soft acrylic added to the lower clutch. These intraoral engravings provide a permanent three-dimensional record of guided jaw movements and are then employed to generate the equivalent condylar characteristics on the TMJ articulator guided by these intraoral engravings.[43,44] The intercondylar distance on the articulator is adjusted to equal that of the patient and the stereographic intraoral clutch records are fixed to TMJ articulator. The right and left articular fossae are molded in acrylic resin while allowing the articulator to track the engravings on the intraoral clutches. In this way, permanent condylar moldings are made that incorporate condylar inclination, progressive and immediate side shift at the correct intercondylar distance.[45]

Advantages of the stereographic system include, intraoral records are used to capture the patients border movement which are readily transferred to the laboratory articulator mounting. Intraoral records may be used to generate condylar fossa analogs and articulator movements. These analogs become specific articulator characteristics for each patient, incorporating details of condylar inclination and side shift that are determined by extraoral tracings.

Disadvantages of this include operator error, errors when molding TMJ analogs in the laboratory and inability of the operator to observe the cutting rods, as they are obscured by the clutches while they are guided by the gothic arch molding in the opposite clutch.

Axiography

By locating the condylar axis and then precisely tracing the movements of that axis three-dimensionally, the movement pattern of each condyle can be analyzed. With axiography, the mandibular function can be analyzed in relation to both condylar hinge axis and occlusal relationships and even the compressibility of the disc can be measured.

Axiographic recording procedure includes the following:[46,47]

Clutch fixation: The clutch is filled with impression plaster and seated on occlusal/incisal surfaces and firmly pressed over the lower teeth.

Analyzer bow preparation and placement: The side arms of the bow are adjusted over the ears. The first reference point is fixed at the level of the infraorbital margin.

Placement of recording arm bow: The vertical screws are adjusted so that the arms are parallel to the cradles and horizontal adjustment is calibrated to zero.

Hinge axis location: One hand of the operator is cupped under the patients chin, and the other hand is on top of patients head. The mandible is moved up and down in terminal hinge position. The recording arms are adjusted until the point of the stylus do not arc but remain stationary on the graph paper. The axis point is marked.

Recording of movements: The non-recording stylus is replaced with a recording stylus. To record the opening movement, the patient is asked to open toward maximum and this is repeated three times. Following this, the protrusive movement is recorded in the same manner starting from the hinge axis point.

Cadiax Compact

The Cadiax compact axiographic device was designed to produce a fast joint analysis for articulator programming and also to aid in diagnosing the functional mandibular disorders. It allows computerized recording of the opening, protrusion, and mediotrusion tracings, and it calculates the sagittal and transversal condylar inclination angles for the adjustment of articulators.

Computerized Analysis of Mandibular Movements

This digital system has been devised to analyze and duplicate jaw motion in an accurate manner. The hardware consists of these components: A sensor that senses the movements in all the directions, an analog tape recorder that stores the processed incremental data from the electronic module, duplicator that receives impulses from the electronic module, sigma 2 computer used to count and store the incremental pulses from the electronic module, and digital plotter used for the graphics display of the mandibular motion.[3]

Electromagnetic Articulography (EMA)

This device measures displacements of the structure in real time as well as the acoustics and mechanics of speech using a microphone connected to the measurement system. It has transmitter coils that determine magnetic fields to collect information about movements from sensors located on various structures (tongue, palate, mouth, incisors, skin, etc.). After measurement, the information is passed on to a computer and read to visualize the recording of the mandibular movements registered by the EMA.[48]

Computer-monitored Radionuclide Tracking

A new technique for the three-dimensional recording of a person's mandibular movement is described. A small and harmless radioactive source is fixed on the patient's skin at the point of interest or sealed in a tooth cavity. Using the proper collimation, the motion of the point source is recorded through a gamma camera and minicomputer. Long-term storage on a magnetic device offers playback, slow-motion facilities, and data analysis through the use of sophisticated computer languages. Simultaneous recordings using two cameras, or post-synchronization of two different views of an experiment, enable the three-dimensional restitution of mandibular movements. Superimposition of a grid of radioactive spots spaced at measured intervals during the recording permits a straightforward calibration of the patient's motion. This method offers a powerful tool of general interest for the tracking of dynamic events in many fields such as TMJ dysfunction and prosthetic restorative techniques.[49]

CONCLUSION

For replacement of teeth and restoring function, it is important to have a knowledge of the mandibular movements as it aids in selection and programming of articulators, understanding occlusion, fabricating dental restorations, and arranging artificial teeth. Therefore, this article gives a detailed history, understanding, and recent methods developed to assess mandibular movements.

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