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The Diagnostic Value of Biometric Instruments

John Charles Radke &Gerardo Ruiz Velasco

Chapter 2: Jaw Tracking with Electrognathography

Table of contents

Clinical Applications of Magnetic Jaw Tracking

A brief history of the technology

The original idea for magnetic tracking of jaw motion was first published in October 1967 in the Journal of Prosthetic Dentistry, proposed as a possible method of measuring freeway space in edentulous patients, more than 50 years now in the past (Kydd, Harrold & Smith, 1967).

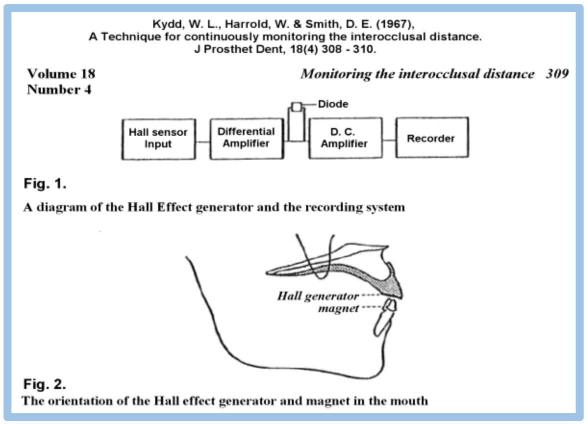


Figure 1. Redrawn from an illustration from the publication of the magnet-based jaw position monitoring system proposed by Kydd et al in the 1967 issue of the Journal of Prosthetic Dentistry.

Subsequently, Dr. Bernard Jankelson launched Myotronics Research, Inc. and in 1971 began an effort to produce the first magnetic jaw tracker for use in his own clinical research study. The second publication of record in English appeared in 1972, in the JPD's November issue, coming from Japan (Bando, Fukushima, Kawabata & Kono, 1972).

As soon as a first Kinesiograph was operational, an interest in obtaining one was expressed from Prof. H. Mitani at the Dental University of Osaka, Japan, Prof. Alan Hannam at the University of British Columbia and Prof. Malcom Boone, working in prosthodontics at Indiana University. These first three Kinesiographs were made to order by Myotronics Research, Inc. and were both large and expensive to produce. However, these devices provided that first opportunity to record jaw motion while a subject functioned in a natural and unobstructed way. Previous jaw tracking devices utilized clutches glued to the teeth and other obstructions to natural function. Two other advantages of the Kinesiograph were the speed and simplicity of application (Jankelson, Swain, Crane & Radke, 1975).

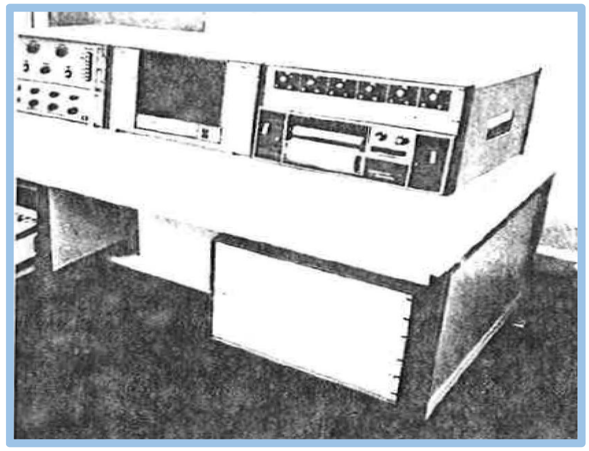


Figure 2. The Kinesiograph delivered to Indiana University in 1973 included an Instrumentation Tape Recorder and paper Strip Chart Recorder.

By 1975 Myotronics Research, Inc. had produced a more compact version of the Kinesiograph, the K-5R. It was manufactured inside an expensive Tektronix storage oscilloscope and included a polaroid camera for obtaining permanent records. It was more compact and user friendly.

Figure 3. The K5R Kinesiograph as it appeared in 1975, built into a Tektronix storage oscilloscope. It was very fast and easy to apply to a patient.

At the time that Myotronics Research, Inc. was developing the Kinesiograph, Dr. Arthur Lewin in South Africa was developing a very similar magnet-based jaw tracker together with Siemens Dental later called the Sirognathograph. While it used slightly different sensor technology, it was also tracking a very small permanent magnet (Lewin, van Rensburg, & Lemmer, 1974; Van Rensburg, Lemmer, & Lewin, 1974). The Sirognathogaph was commercialized by Siemens Dental in the latter half of the 1970s (Lemmer, Lewin & van Rensburg, 1976; Lewin, Lemmer & van Rensburg, 1976; Lewin & Nickel, 1978).

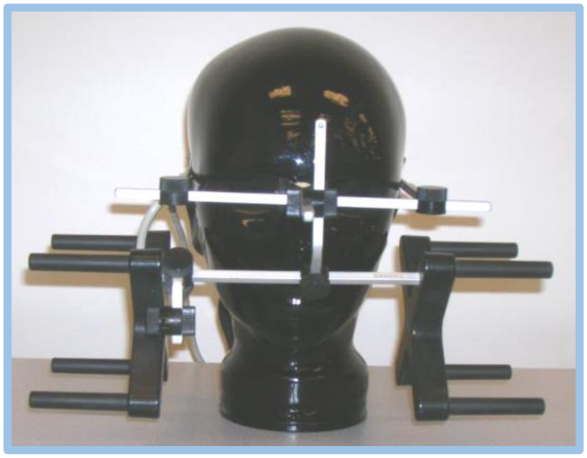


Figure 4. The Sirognathograph was produced in Germany for about 25 years until Siemens sold off their dental business to Sirona. BioResearch was the North American and later world-wide distributor of the Sirognathograph from 1984.

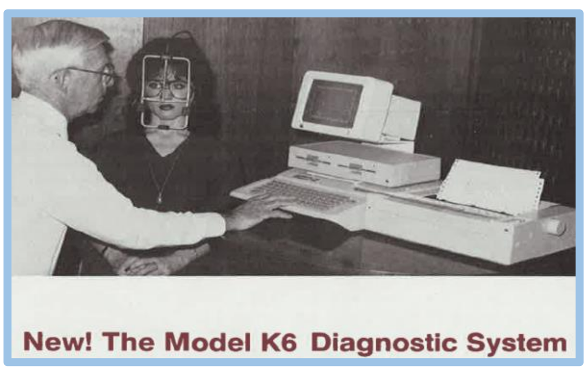
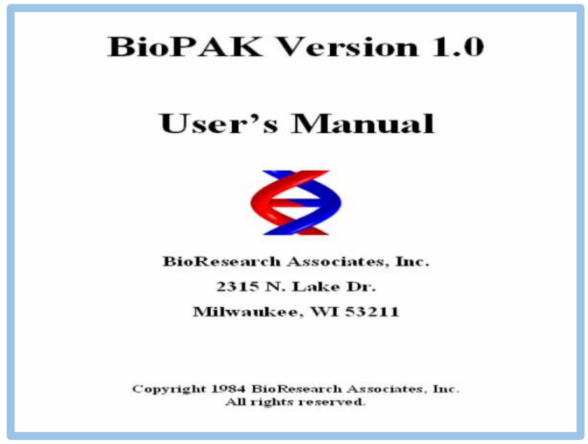


Figure 5. Myotronics K-6 Apple II system was introduced in 1985 using the old K-5R array.

By late 1984 the Sirognathograph was interfaced with the IMB® personal computer and used together with the BioPAK™ software program developed by BioResearch Associates, Inc. for the evaluation of masticatory function.



BioPAK Version 1.0

User's Manual

BioResearch Associates, Inc.
2315 N. Lake Dr.
Milwaukee, WI 53211

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Figure 6. BioPAK™ is the software developed by BioResearch Associates, Inc., specifically for the Sirognathograph in 1985. Version 1.0 was written for Microsoft DOS, but the program was upgraded in 1993 to run under Windows.

At the same time Myotronics was interfacing their K-6 to the Apple II computer using the K-5R sensor array from the 1973. See figure 5. By 1987 they had developed a new array that copied the geometry of the Sirognathograph array, which improved linearity and range and is still in use with the K7. See Figure 7.

In 1995 the Sirognathograph was discontinued as BioResearch replaced it with a new jaw tracker, the JT-3. It increased the number of sensors from 8 to 48 and the geometry of the array, which increased the wide-open range and linearity of its recordings compared to all previous jaw trackers. The JT-3 continued to operate with the BioPAK program, running under Windows 95 and later versions. In 1999 the interface of the JT-3 was upgraded to the PCMCIA card, which allowed it to use a notebook computer. Previous interfaces had required a desktop style P. C. This improved portability and reliability. See Figure 8.

Figure 7. The new K-6 array, which copied the geometry of the Sirognathograph, was introduced in 1987. It is still used with the K7 today.

Figure 8. The JT-3 array introduced in 1995 included 48 sensors to increase its range and linearity. It was replaced in 2004.

As it happened the Hall sensors used in the JT-3 were discontinued in 2003, necessitating a re-design of that EGN. To avoid being dependent on any outside suppliers, BioResearch decided to design and built a new total array, including the sensors. This resulted in the JT-3D, which was introduced in 2004. The new array included new flux-gate magnetometers that are made more sensitive than Hall sensors and can therefore be place further away from the magnet. This again increased the range and linearity of the array. It was also decided to stop mounting the array on the patient's nose. This had always been a source of some complaints of discomfort. Mounting the array based on the relative positions of the nose and the ears made the set-up alignment a bit problematic because in humans these features of anatomy vary a lot. Thus, the JT-3D uses a very comfortable headband and has no contact with the patient's nose or ears. See Figure 9.

Figure 9. The JT-3D jaw tracker sensor array has increased the range of recording, linearity, patient comfort, and clinicians have a more open access into the patient's mouth. This image also shows the correct placement of the JVA sensors for simultaneous recordings.

An additional feature of the JT-3D array is the fact that a clinician can more easily look in and have access into the patient's mouth. There is nothing blocking the face below the level of the eyes. This is very important in certain clinical procedures. The alignment bar shown in figure 9 is removed after the array is aligned to the small magnet adhered to the gingival tissue in the labial vestibule with Stomahesive.

Jaw tracking has continued to develop with the addition of new software features. The BioPAK program is currently in its ninth revision and includes many features that were not imagined in the beginning. The ability to record natural masticatory motions as led to analysis software specifically designed to evaluate patient chewing capability (Radke, Kull & Sethi, 2014).

The Magnet-based JT-3D Electrognathograph

This magnet-based 3-dimensional jaw tracker has evolved from the original Kinesiograph, which was developed as a method to record jaw motions during natural functions without any interference from clutches (Jankelson, Swain, Crane & Radke, 1975). A single small magnet is adhered to the lower incisors and adjacent gingival tissue in the labial vestibule. The sensor array is placed on the patient with a head-band that is adjusted to a snug fit. The patient is instructed by the operator to complete a standard series of jaw motions. The traces are saved to the computer hard disk and the patient is dismissed. All of this occurs within a few minutes and is typically accomplished by an assistant. The jaw tracking records represent not only the present masticatory status, but also a permanent reference for the future. Every patient is unique as an individual, thus having a refence to the patient's healthy function can be very valuable at a later date after dysfunction occurs.

The JT-3D, compared to previous models, has the added clinical advantage of a quicker setup, easier operation and a Universal Serial Bus (USB) interface that communicates with virtually all modern computers, tablets, etc. that are Windows® compatible. The current *BioPAK*™ *Software for Windows*, which has been developed over the past 34 years, is also user friendly and quite intuitive to operate.

The main Objectives of EGN Recording

I. *Range of Motion* (ROM): Three planar views show any limitations, deviations or deflections in 3 dimensions (Agerberg & Carlsson, 1972), see figure 10.

II. Protrusive guidance: The significance of *Protrusive Guidance* (Lundeen, Shryock & Gibbs, 1978) Vs *Anterior Misguidance* (Yoshioka, Ogawa, Kuwahara, Takashima & Maruyama, 1993).

III. *Velocity*: Speed and smoothness of function in open-close movements and in masticatory function (Lewin, Lemmer & van Rensburg, 1976).

IV. The stability of the *Rest Position* and the analysis of *Freeway Space* (Thompson, 1946; Pleasure, 1951).

V. Significance of the location of the *Rest Position* in relation to the *Intercuspal Position* (ICP), the maxillo-mandibular relationship (Kawamura, 1971).

VI. *Segmentation* of masticatory function into individual cycles and *Quantitative Analysis* (Yoshioka, Ogawa, Kuwahara, Takashima & Maruyama, 1993).

VII. Normal / abnormal masticatory Average Chewing Patterns (ACP) and their significance in the analysis mastication (Kuwahara, Miyauchi & Maruyama, 1992).

Range of Motion (ROM)

It has been well documented in the past that the normal Range of Motion exceeds 40 millimeters and that it can exceed more than 70 millimeters. (Knap, Abler & Richardson, 1975). However, it is not fully understood by all that ROM includes the lateral and protrusive ranges as well. See Figure 10.

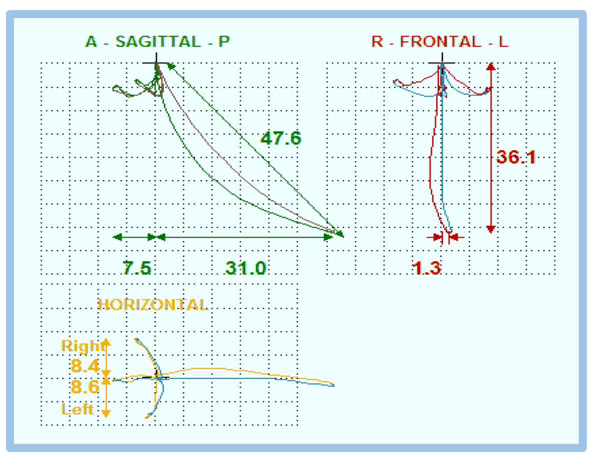

Figure 10. A ROM recording in 3 dimensions from a normal subject, which includes lateral excursions used for testing condylar translations. There is minimal deflection (1.3 mm left) and a good level of symmetry in the record.

The significance of recording lateral and protrusive is based on the relative translation of the two condyles. If condylar translation is equal or nearly so, the amount of lateral excursion will be similar for left and right movements (frontal and horizontal views) and the protrusive movement will not deflect to one side.

In the lateral dimension it is important to detect deviation and deflection (Steed, 1997). The former includes movements away from the midline that return to the midline at maximum opening. By contrast, a deflection is the farthest away from the frontal midline right at maximum opening.

The significance of a deflection

The most common reason for a deflection is an internal derangement with an anteriorly displaced disk limiting the translation of the ipsilateral condyle. See Figure 11.

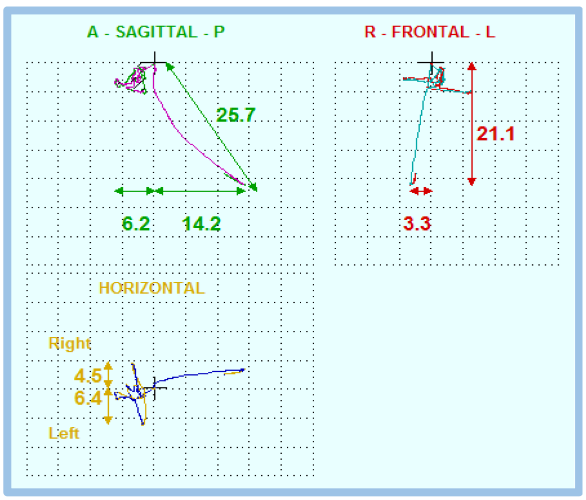

Figure 11. A ROM that is very limited, < 30 mm, and includes a deflection to the right. This is an indication of a relatively acute, non-reducing, displaced disk in the right TMJ. Note also the small lateral movements in both directions in the Horizontal graph.

If the deflection is large and the ROM is less than 40 millimeters, it will interfere with mastication on the contralateral side. If the deflection is less than 3 millimeters and the ROM is within normal limits (40 - 70+ mm), the deflection may be due to a mild asymmetry of the jaw or to some degree of hyper-translation of the contralateral condyle. The former case may benefit from any type of treatment that reduces the disk displacement and improves joint function, but the latter case can usually be ignored. A large deflection will cause the patient to favor chewing on the side of the displaced disk. A patient that chews exclusively on one side will usually develop an asymmetrical musculature due to the lesser effort required from the contralateral side muscles.

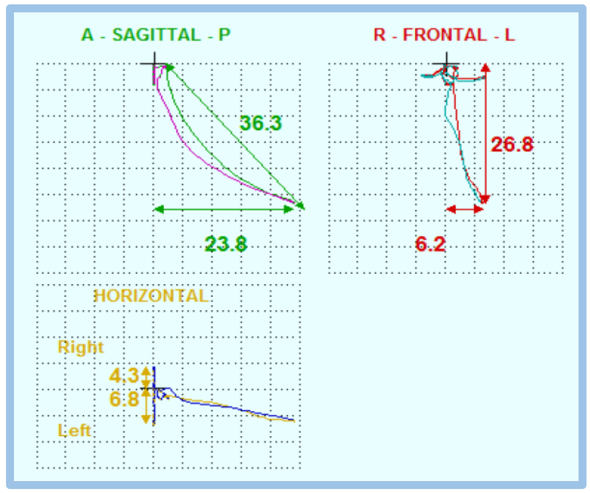

Figure 12. An example of a chronic Left-DD, which has achieved an adapted ROM

With a chronic DD the ROM increases, often to a nearly normal dimension. When unilateral the ROM includes a larger deflection as the affected joint is usually no longer painful. It is common that eventually the disks in both joints displace, which produces a symmetrical ROM, usually just short of 40 mm without any large deflection.

The significance of a deviation

During opening a deviation indicates a resistance to translation of the ipsilateral condyle (on the side that the deviation goes towards). However, a deviation that occurs during closing indicates a resistance to the translation of the contralateral condyle. See figure 13.

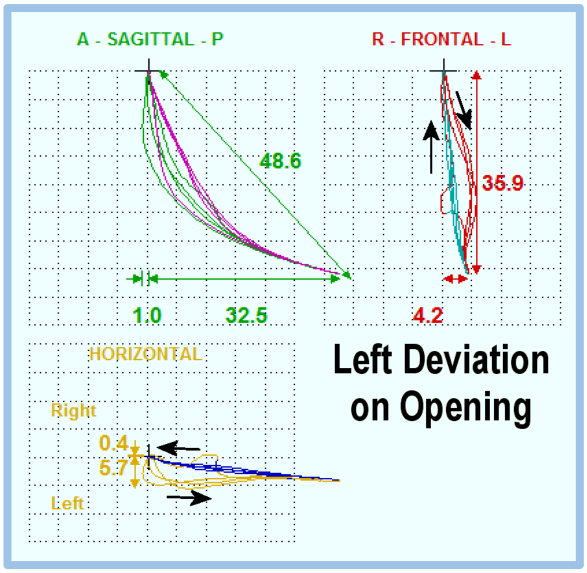

Figure 13. A deviation during opening is most often associated with a reducing displaced disk in the TMJ towards which the mandible moves. The disk is resisted by the condyle until it finally reduces, which allows the mandible to return to the frontal midline.

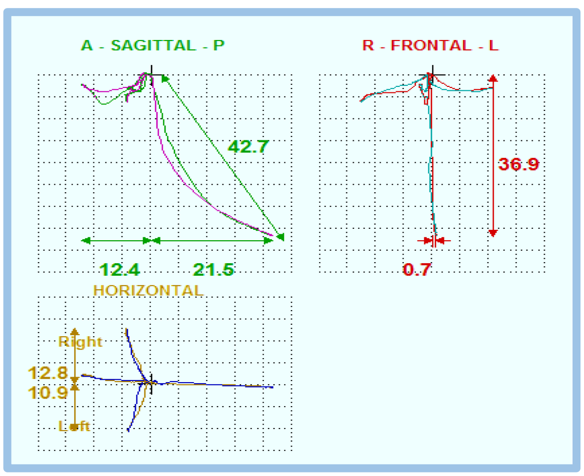

Figure 14. A normal control subject's ROM is symmetrical, straight in opening and closing and close to equidistant going left and right.

An opening deviation is most often associated with a reducing displaced disk (DDR). A strong resistance to reduction causes the mandible to deviate towards the affected side as the patient opens. As the disk reduces, the mandible can return to the midline or nearly so.

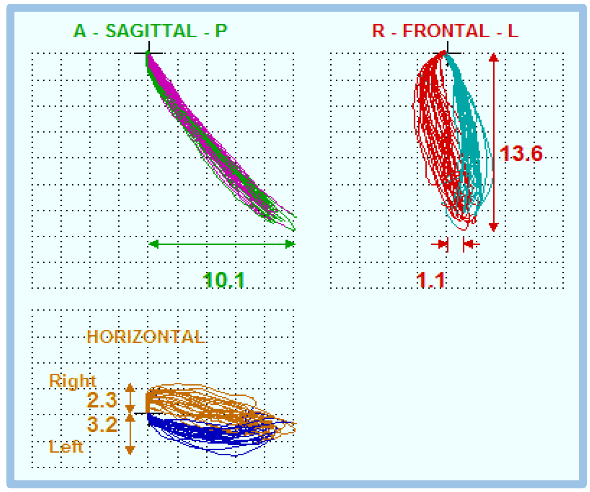

Figure 15. Normal chewing motions occur in the Frontal and Horizontal planes with little motion in the Sagittal plane.

In contrast, a normal (control) subject can open with minimal deviation or deflection and move laterally in both directions with equal distance and smoothness. See Figure 14. The example ROM in figure 14 is at the low end of the normal range, but the lateral excursions do not indicate any limitations. This is a small mouth with good joint mobility. A larger mouth with chronic bilateral DD limiting the ROM could have nearly the same range to wide open, but have far less lateral mobility.

Protrusive Guidance (during closure)

It is a misconception that the anterior teeth should somehow guide the closure during mastication (Lundeen, Shryock & Gibbs, 1978). The normal pattern of masticatory movement includes a lot of variation in vertical and lateral movement, but relatively little antero-posterior variation (see the section of this chapter describing masticatory patterns). See Figure 15. In contrast, the normal envelope of speech movement includes mainly vertical and more antero-posterior directions of movement with a smaller lateral component. Thus, the arrangement of the incisors is far more important for speech.

Certain phonetic sounds, mainly those related to consonants such as F, S and V are produced with the maxillary and the mandibular incisors in very close proximity …within just a few tenths of a millimeter. See figure 16.

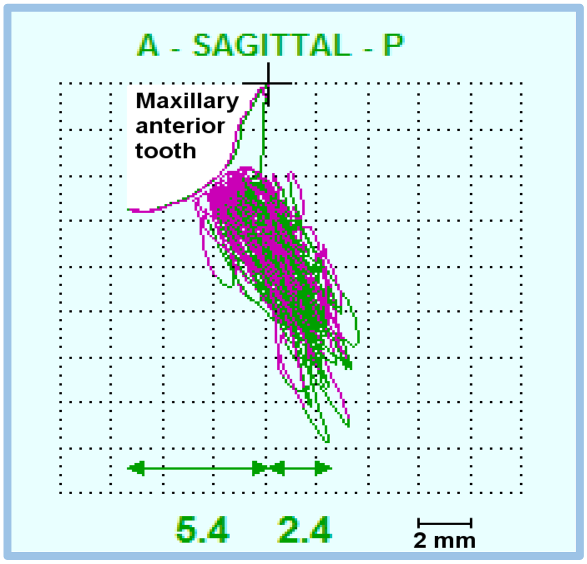

Figure 16. During Speech (My Grandfather) the incisors normally approach very close to the occlusion, but without any actual tooth contacts.

The loss of anterior teeth makes speech difficult, but can have little effect on a patient's ability to masticate food (Evans & Lewin, 1987). Mastication normally occurs completely within the premolar and molar regions of the dentition (Inoue, Yamaguchi, Mato, Ishigaki, Takashima & Maruyama, 1994), but speech cannot be formed properly without any anterior teeth.

Protrusive Non-Guidance / Mis-guidance

A complete lack of anterior guidance can occur with excessive over-jet or an anterior open bite. These conditions may not interfere with the patient's ability to chew, but will affect the patient's speech, See Figure 16. The relationship of the anterior teeth is only critical for these 2 functions; 1) the incision of food and 2) the accurate pronunciation of words. In contrast the presence of a very steep anterior protrusive guidance in a "deep bite" overbite dentition, such as with a Class II, division 2 malocclusion, can interfere with the patient's ability to chew (see Figure 17.). Osaka University Professor Takao Maruyama, who is the retired chairman of fixed prosthodontics for the School of Dentistry, coined a term for this condition which he called, "Anterior Misguidance."[5] This can also occur with an anterior crossbite, either a partial (one tooth) crossbite or a complete anterior crossbite (Class III malocclusion). Although anterior misguidance interferes with mastication it is usually not a problem with speech for the Class II division 2 occlusion. However, the class III malocclusion often interferes with precise pronunciation and can cause an obvious speech impediment.

The Significance of the Velocity

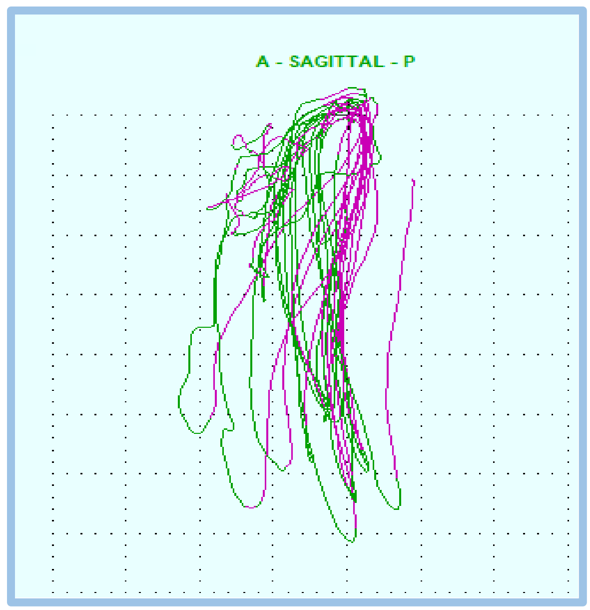

Figure 17. Sagittal view of chewing with anterior mis-guidance. The mandible is pulled back away from anterior contact during closure and comes forward during opening.

The velocity of specific mandibular movements can be very indicative of dysfunction or good function (Gernet, 1981; Lewin, Lemmer & van Rensburg, 1976). Every type of dysfunction, whether related to joint dysfunction or muscle dysfunction, tends to slow down movements and make them more variable. A simple open and close movement and all of the more complicated movements of chewing are equally affected by dysfunction and exhibit measurable reductions in their velocity. The smoothness of jaw movement is also reduced by dysfunction and the variability of the particular pattern increases as well. Good overall jaw function is indicated when a patient can open / close fully, rapidly, smoothly and consistently with peak open and close velocities exceeding 400 millimeters/second (see Figure 18).

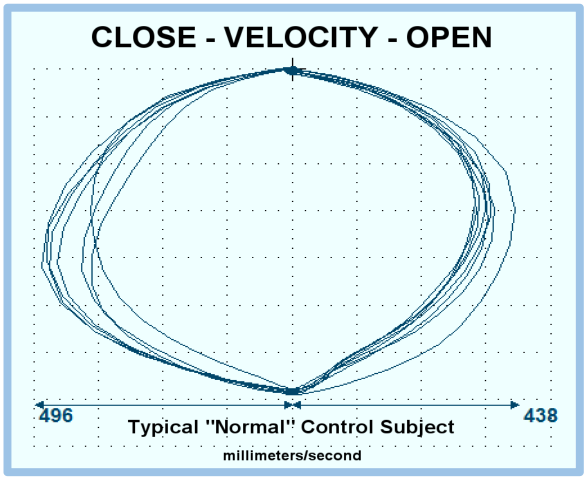

Figure 18. A normal opening and closing velocity pattern that is smooth and fast without any large interruptions in the pattern.

Anterior Misguidance Vs Reducing Displaced Disk

Anterior misguidance can reduce the closing velocity (Figure 19), but leave the opening velocity only partially aberrant. The avoidance of excessive anterior tooth contact is the reason for the closing reduction in velocity. An increase in variability during opening and a slowed closing occurs.

A reducing displaced disk is another factor that can alter the velocity both in opening and in closing (Farrar & McCarty, Jr, 1979). The opening velocity slows down right before the reduction occurs and speeds up immediately afterwards creating a dip in the velocity at the point of the reduction (see Figure 20). It is also true, but to a somewhat lesser extent, that at the point during closing where the disk displaces again a lesser slow-up occurs. The disk displacement is usually a less forceful event, which alters the velocity less when it occurs than the reduction. Thus, with a reducing disk displacement (DDR), the velocity is reduced and the pattern variability is increased.

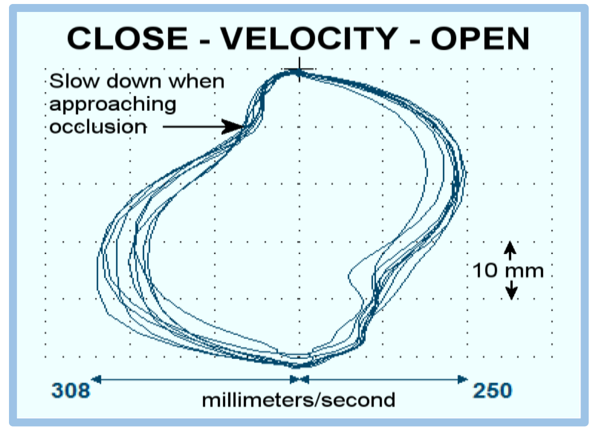

Figure 19. Anterior misguidance slows down the closure into centric occlusion during simple open and close movements, which then avoids any pre-mature contact.

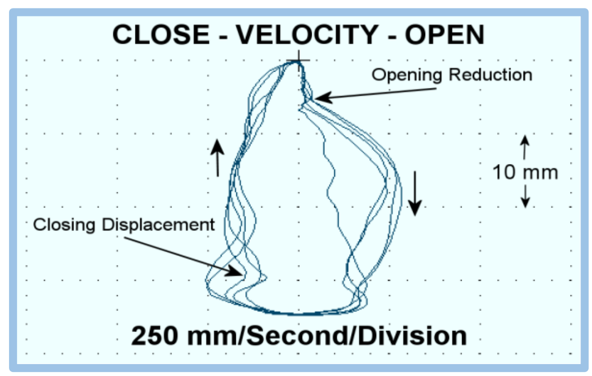

Figure 20. Velocity slows down in opening as the disk reduces and again in closing as the disk displaces.

ACP Chewing Velocity is Affected by Good Function Vs Dysfunction

An example of the ACP velocity during gum chewing from a subject without any dysfunction

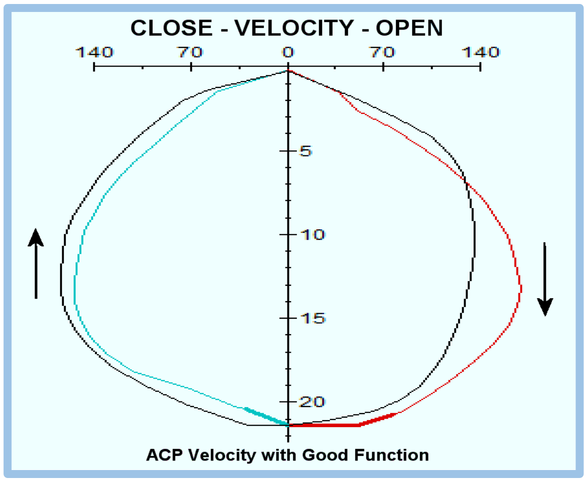

Figure 21. A velocity trace of open and close from a control subject with good function.

is exhibited in Figure 21. The closing peak velocity and opening peak velocity are usually very similar in amplitude and usually are above 100 mm/s. In this example the maximum peak opening velocity is 169 mm/s and the maximum peak closing velocity is 154 mm/s. The average peak opening velocity for this trace is 115.7 mm/s and the average peak closing velocity is 115.4 mm/s.

The general shape of the pattern is egg-shaped with a mean vertical maximum of 16 mm and a top that approaches to within 0.1 mm or 0.2 mm of the intercuspal position. This averaged pattern is convex both in opening and in closing throughout the complete cycle, which indicates smooth non-jerky movement (Radke, Kull & Sethi, 2014).

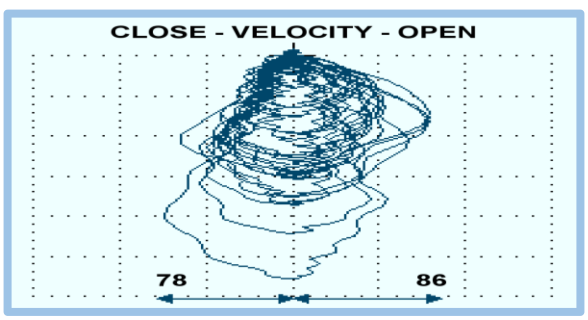

Figure 22. The ACP velocity pattern from a dysfunctional patient chewing gum is smaller than normal and does not closely approach centric occlusion.

An example of the ACP velocity of a very dysfunctional patient during gum chewing is presented in Figure 22. While the maximum peak opening and closing velocities appear similar in amplitude (92 mm/s and 86 mm/s respectively), they are much slower than shown for the normal example. The average peak velocities are 62 mm/s for opening and 57 mm/s for closing, far below the 100 mm/s expected from more normal subjects (Radke, Kull & Sethi, 2014).

In Figure 22 an example of a dysfunctional ACP velocity pattern shows a vertically squashed shape when compared to the normal egg-shaped pattern. The mean vertical maximum is only 9 mm. There is a slightly concave area approaching the intercuspal position (at the zero of the vertical axis) during the opening. In closing the concavity is more pronounced approaching occlusion. The top of the pattern, which represents the position of maximum bolus crush, is often about 2 mm from the intercuspal position. This indicates that the bolus (gum) is not being crushed fully.

Stability of the Rest Position

When the mandible is at rest the elevator muscles of the masticatory system (masseter, temporalis, etc.) are expected to be passive, not contracting (Kamyszek, Ketcham, Garcia Jr & Radke, 2001). If substantial muscle activity is present, the muscles are actively posturing the mandible instead of being at rest. Posturing is a compensatory activity indicating that a maxillo-mandibular mal-relation exists. However, the patient may be otherwise asymptomatic if the posturing requirements are within the patient's adaptive range. The posturing activity may be present in one or several muscles depending on the posturing requirements, but in either case the rest position will be varying over time. This can be seen with a jaw tracker monitoring the rest position continuously for a few minutes (Kydd, Harrold & Smith, 1967).

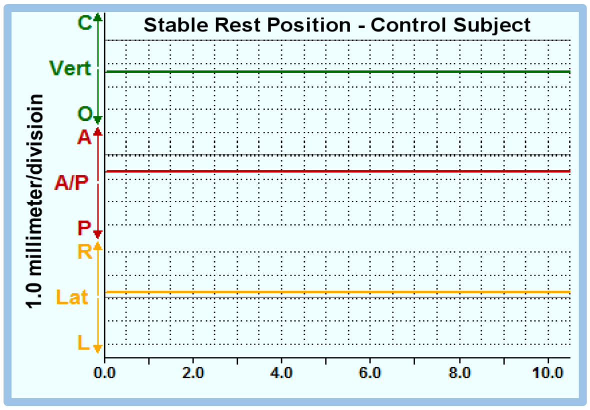

Figure 23. A very relaxed normal control subject at rest with no visible movement of the mandible.

Figure 23 shows an ideal resting position with almost no movement while Figure 24 shows a typical unrelaxed patient's moving rest position.

When a patient is identified with an unstable rest position it is appropriate to apply a type of relaxation therapy such as ULF-TENS. Once a stable rest position has been verified, an accurate measure of the freeway space is made with EGN.

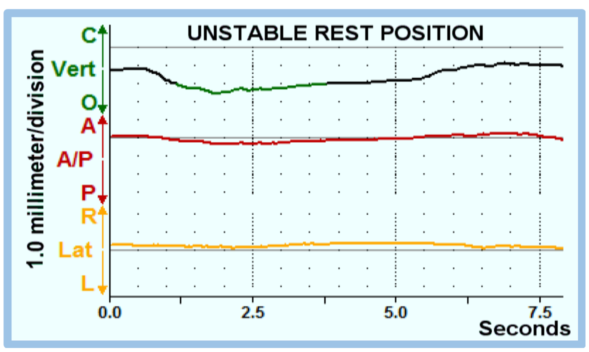

Figure 24. An unrelaxed and unstable rest position with movement of the mandible up and down, forward and back, left and right.

This is accomplished by recording the specific patient passively in the resting position, (in this example being pulsed with ULF-TENS) closing into the intercuspal position, tap-tap-tap into Centric Occlusion and then protruding with the teeth in light contact (see Figure 25). The rest-to-close distance in milli-meters is the freeway space (3.4 mm in figure 25). The tap-tapping establishes the habitual closing trajectory. The protrusion shows the protrusive guidance or, if it exists, the misguidance, in relation to the relaxed rest position. The other trajectory in figure 25 is calculated to pass through the relaxed position

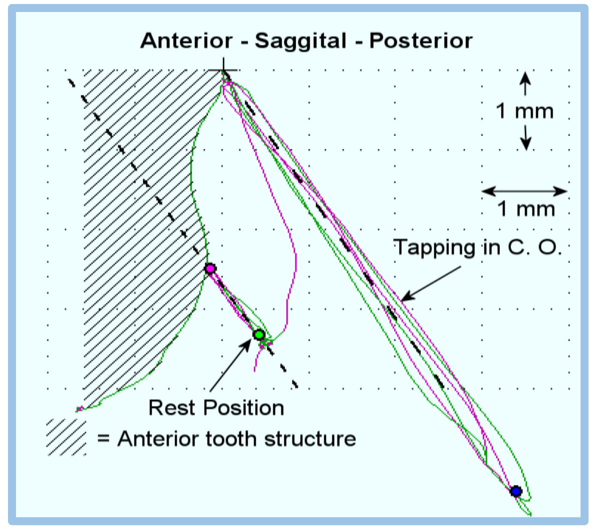

Figure 25. An X-Y View of the Rest, Pulse with TENS, Close, Tap and Protrude record showing freeway space (3.4 mm), the relaxed trajectory that passes through rest, the tapping trajectory and protrusive anterior contact.

and to be parallel to the tapping trajectory. This is the "neuromuscular trajectory" that is used by many TMD-treating dentists to provide a more muscle friendly occlusal position. A bite-point on this trajectory can be registered to orthopedically correct a maxillo-mandibular mal-relationship. Ideally, it would open the bite in figure 25 in the anterior by just 2.4 mm, which is a thickness that is durable for an orthotic. With this orthotic the overbite would also be reduced from 4.4 mm to 2.0 mm. What is not shown on the screen, but also occurs, is the elimination of any roll, pitch or yaw in the original maxillo-mandibular relationship. This hidden correction can sometimes be the most important one in symptomatic patients.

Significance of Rest Position

When a symptomatic patient exhibits an over-closed bite (more than 1 to 3 mm of freeway), as in Figure 25, the Jaw Tracker can be very helpful in deciding where to record a new bite position for an orthotic. The 3.4 mm freeway space in Figure 25. may be considered excessive if the patient is symptomatic, suggesting that treatment by appliance could be one option. The pink dot in contact with the protrusive border represents an ideal target on the screen to guide the bite taking procedure. As the bite record is taken, registration material is placed between the teeth and then the mandible is brought up to the Pink Dot while its position is viewed on the computer screen. To verify that the desired relationship has been properly captured, once the bite record has set, it can be checked to see that it matches the position of the target.

It is possible to check the orthotic position at the time of delivery by re-loading the trace, zeroing the patient while closed into the intercuspal position, and inserting the appliance to verify that the mandible goes back into the position of the Pink Dot. If made without losing the maxillo-mandibular relationship, the position of the appliance will overlap with the sagittal and frontal Pink Dots on the screen, which were previously saved with the trace (Salzman, 2018).

Analyzing Masticatory Average Chewing Patterns (ACPs)

There are 4 general patterns for the chewing of gum in the frontal plane including; 1) F1 = normal, 2) F2 – most often associated with disk displacement with reduction (DDR), 3) F3 – most often associated with acute disk displacement without reduction (DD) and 4) F4 – most often associated with chronic-adapted DD (Kuwahara, Miyauchi & Maruyama, 1992; Salzman, 2018). As shown in Figure 26, the left and right-sided Frontal Plane patterns are mirror images of each other. This is due to the fact that mastication is unilateral and an asymmetric activity.

While the general overall shapes in figure 26 are indicative of joint function or dysfunction, they relate to the non-working side joint. Thus, right sided chewing reveals left joint dysfunction and left sided chewing reveals right joint dysfunction.

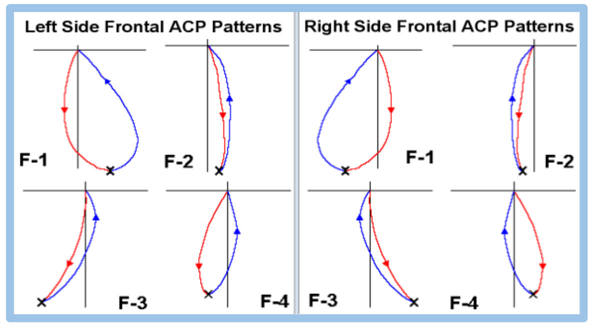

Figure 26. Right and left sided Frontal Average Chewing Patterns (ACPs). F1 is most normal, F2 is associated with DDR, F3 is associated with acute DD and F4 with chronic-adapted DD.

Note that the F-1 (normal) and F4 (the very well adapted DD) patterns are fully convex throughout the complete cycle. This is another characteristic associated with good function, especially in the areas of the pattern when approaching or when departing from occlusion. Any concavity there indicates an avoidance of a premature occlusal contact.

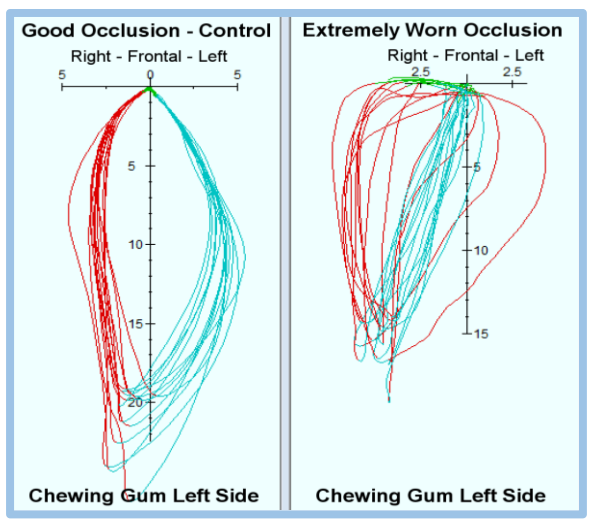

Figure 27. An approach to occlusion that is ideal (left) and one that suggests occlusal wear (right). A very adaptable patient may not show any other signs or symptoms of dysfunction.

Figure 27 shows a contrast between an ideal F1 pattern in the left image and something far less than ideal. The left image is an ideal masticatory pattern, but the right image shows a grinding pattern with some reversals during opening. This far less than ideal pattern may or may not indicate a significant problem, at least when no other signs/symptoms are present. However, the rather steep closing angle and the flat (lateral) opening motions, together with some reversed sequences, suggest the presence of a badly worn dentition (Kerstein & Radke, 2012). To determine whether a successful adaptation or dysfunction is present, it is propitious to record EMG activity from the masseter and anterior temporalis muscles (next chapter) simultaneously along with the chewing movements (Radke, Kull & Sethi, 2014). The complete absence of any silent periods indicates successful adaptation. This EMG subject will be elaborated further in the next chapter.

Calculating an Average Chewing Pattern

Every chewing cycle is unique and is a function of the manipulation of the bolus and the crushing stroke. Classification of each individual chewing stroke is a useless task since there is not any hard limit to the many categories and subcategories (Proschel, 1987). Consequently, it is necessary to calculate the Average Chewing Pattern (ACP) of chewing sequences before any definitive analysis can be done (Kuwahara, Miyauchi & Maruyama, 1992). Although no two chewing strokes are the same, when the ACP is calculated, the random variations are canceled and the underlying pattern of movement is revealed. While the individual strokes are never repetitive, the ACP is consistent when a standardized bolus (e.g. gum) is chewed.

The first step in the process of calculating the ACP is to segment a complete chewing sequence into individual cycles. It is necessary to establish three phases of each cycle; 1) opening time, 2) closing time and 3) the occlusal or pause time. A small increment (e.g. 0.3 mm) is used as the threshold for the beginning of opening and the end of closure. See Figure 28.

Next, a mean chewing pattern is calculated from all cycles. Each cycle is then tested for variation and eliminated if more than 2 standard deviations from the mean. This is done to remove outliers that are caused by swallows or other hesitations. The remaining cycles are then used to calculate the Average Chewing Pattern.

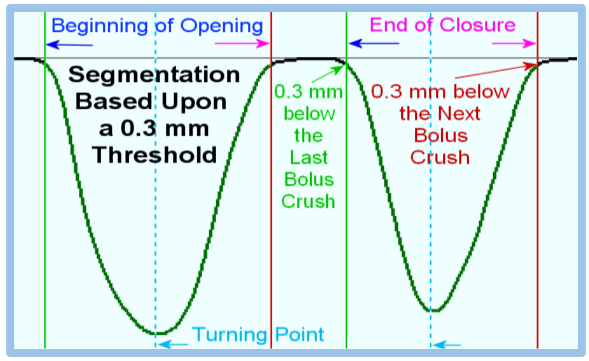

Figure 28. The process of segmentation using the threshold of 0.3 mm to establish the beginning of opening and the end of closure for each cycle.

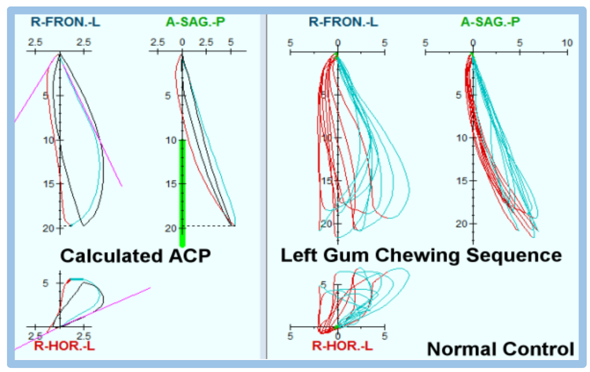

Figure 29. Comparing the calculated ACP to the total movement of a left gum-chewing sequence. Although there are a lot of variations within the sequence, a distinctly normal ACP is seen.

The gum-chewing sequence in figure 29 shows a lot of variation from cycle to cycle, but much of it is due to the random manipulations of the bolus. It is evident by the fact that the largest variations occur at or near wide opening, not approaching the occlusion. The black lines within the ACP are the ACP of a normal control population. This asymptomatic subject's patterns are very similar in shape to the population means.

The vertical population mean amplitude is 16 mm (+/- 3) for one stick of chewing gum. The population mean shapes are normalized to each subject's vertical amplitude (nearly 20 mm in figure 29). Although the shape is most important, the size of the pattern decreases with masticatory dysfunction too. Masticatory dysfunction causes four very measurable changes in the process of chewing; 1) a slowing down, 2) a reduction in the size of the pattern, 3) an increase in the variability and 4) a reduction in the smoothness of the movements (Radke, Kull & Sethi, 2014; Radke & Kerstein, 2017).

Significance of the rate of chewing

The rate of chewing is the easiest parameter to measure as you can simply count the number of cycles within a time-period. Two cycles/second is a fast chewing sequence, one cycle/second is a slow chewing rate. The mean normal rate is 1.4 cycles/second or 11 cycles in 8 seconds. Less than 9 cycles in 8 seconds is the onset or beginning of a dysfunctional rate. See figure 30. If there are also occlusal opening interferences, the opening can also be slowed. Normal control subjects close a little faster than they open while chewing. This can be reversed in dysfunctional patients, especially when it is difficult for the patient to find centric occlusion.

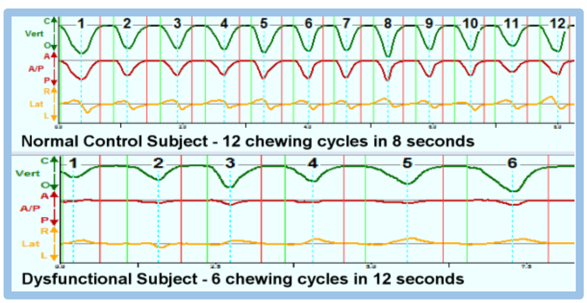

Figure 30. This typical control subject was chewing at 12 cycles in 8 seconds, but the dysfunctional subject chewed at a rate of only 6 cycles within the same time-period.

Significance of the ACP Vertical Size

Measuring the vertical size of the ACP requires recording jaw motion, segmenting the sequence, then averaging the size of the pattern. This cannot be done visually and requires some type of jaw movement recorder. When a patient's chewing becomes dysfunctional, the movements become more tentative and careful. This requires a slower approach to occlusion and tends to decrease the size of the ACP. See Figure 32.

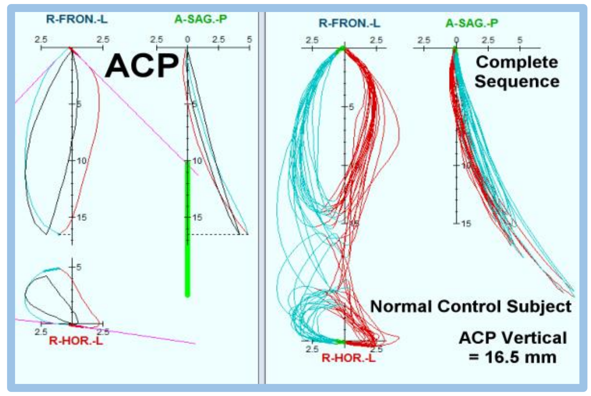

Figure 31. The mean normal population vertical component of the ACP is 16 mm, ranging from 10 to 22 mm, dependent on jaw size and mobility.

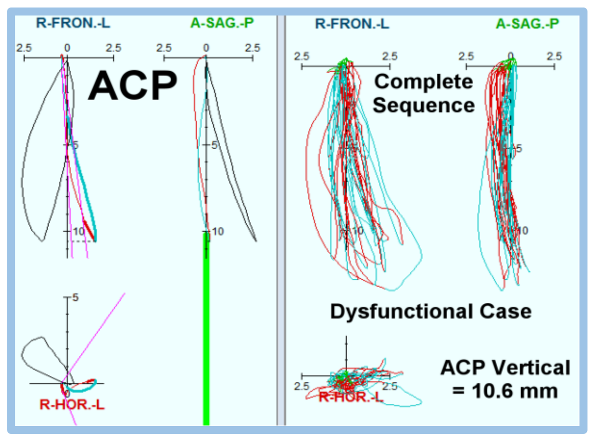

Figure 32. The ACP of dysfunctional subjects is usually a smaller pattern with a reduced vertical dimension. At 10.6 mm this one is at the low end of the normal range

It is important to carefully record these chewing sequences with a fresh **single stick** of gum (not a chicklet) that has been softened for about half a minute. At least 20 cycles should be recorded to guarantee that 15 good cycles will be available to analyze. Gum can be viewed as the kindergarten test of mastication, as it represents a very easy bolus to chew. If any patient can't chew gum, that patient is in a severe dysfunction. It is a good practice to also record left and right sequences chewing a tough bolus. It is intended to challenge the system and can sometimes expose a level of dysfunction that is not apparent during gum-chewing. The tough bolus can be any real food that is readily available in a size and texture that is very consistent, uniform, available and that preferably requires about 20 cycles to masticate.

Significance of variability in chewing

Comparing figures 31 and 32 one can visually see a large difference in the variability of the chewing cycle pattern from cycle to cycle. This difference can be measured by calculating the mean times and standard deviations (SD) for each of the three segments in a cycle (opening time, closing time and occlusion time). For normal function the SD values should all be less than 50 milliseconds.

	Mean (milliseconds)	Standard Deviation (milliseconds)
Opening Time	302	35.3
Closing Time	295	33.2
Occlusion Time	192	37.7
Cycle time	788	55.8

Figure 33. For the normal subject in figure 31, the times of the three segments are similar, but with the occlusion time as the shortest. Their Standard Deviations are all less than 50 milliseconds.

	Mean (milliseconds)	Standard Deviation (milliseconds)
Opening Time	508	205
Closing Time	408	152
Occlusion Time	349	57
Cycle time	1265	303

Figure 34. For a dysfunctional subject, all four of the times tend to be lengthened, but the variability is also increased as evidenced by larger standard deviations.

The very large standard deviations indicate that the durations of the segments are changing a lot between cycles, one indication that a patient is struggling to chew the bolus. Some patients will exhibit less variation because they are being very careful, but then produce a small, slow ACP.

Thus, by recording 2 simple 30 second chewing sequences, a software program can reveal all four of these mean times and their variabilities.

Significance of smoothness

The smoothness of the chewing motions can be measured by calculating (using calculus) the third derivative of the motions (d^3x/dt^3, Leibniz 1679), which is called “Jerk” or the rate of change in acceleration. (Vikne, Bakke, Liestøl, Sandbæk & Vøllestad, 1993; Yashiro, Yamauchi, Fujii & Takada., 1999). Jerkiness can be very easily understood by anyone who has ridden with a new driver of a car with a manual transmission. The amplitude of Jerk varies with the amplitude of acceleration, so any fast-chewing subject will produce a high amplitude of jerk too, even if the motion is relatively smooth. However, true jerkiness produces rapid changes in the sign of jerk with many transitions between the increasing and decreasing acceleration values, which are called inflection points. Counting the number of inflection points can indicate jerkiness even when the movements are relatively slow.

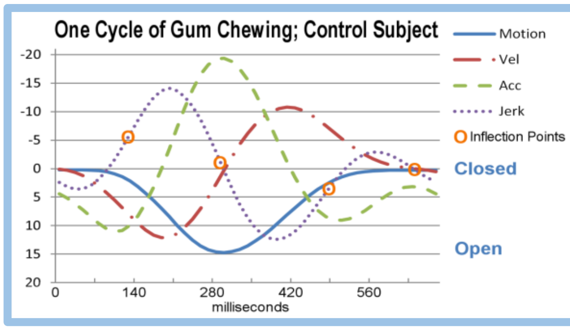

Figure 35. One chewing cycle from a normal control subject with ideally smooth function. The cycle includes two inflection points in the jerk function during opening and two during closing. A fast sampling rate, e.g. 1000 samples/second, is needed to accurately detect these transitions.

The jerkiness of one cycle is not very important, but counting the inflection points in an entire sequence and calculating the average per cycle is a way to measure real jerkiness of function. The minimum possible number of inflection points in one cycle is four. Opening requires accelerating at least once and one deceleration, producing two inflection points. The same minimums are also required in closing. By counting the opening and closing inflection points separately it is possible to measure the jerkiness within each component.

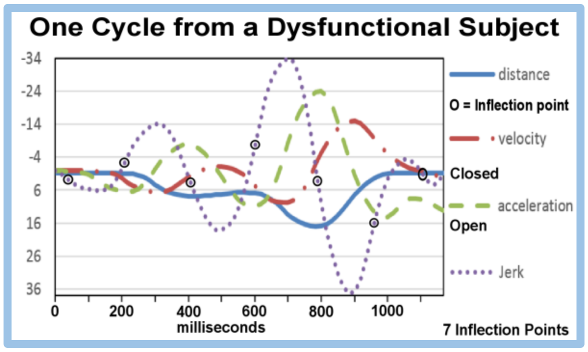

Figure 36. One jerky cycle from a patient that has chewing dysfunction. There are four inflection points in opening and three in closing.

Jerk can significantly increase after a successful adaptation to a TMJ dysfunction if the patient becomes less "careful" with respect to chewing. Thus, the concept that minimum-jerk may be a general principle of the central nervous system is questionable (Stein, Cody & Capaday, 1988; Yashiro & Takada, 2005). Jerk can be high when the subject is uncertain of where the centric occlusion is and continues to hunt for it or is actively avoiding occlusal interferences. See figure 36. Removal of occlusal interferences to function can reduce the jerk-cost of masticatory function (Yashiro, Fukuda & Takada, 2010).

Using EGN together with JVA

The previous chapter has illustrated the process of recording and analyzing TMJ vibrations. This process requires some means of estimating the position of the mandible when a vibration occurs. A metronome can provide a reasonable estimate only if the patient is able to follow it. When a patient has an internally deranged TMJ or severe muscle dysfunction, it can be very hard or impossible to follow the metronome precisely. By recording from the JVA sensors, together with the EGN, an enhanced capability is achieved. The combined process is referred to as JVA/JT. The records of JVA/JT pinpoint the onset of vibration precisely, which is helpful in the analysis.

The BioPAK software includes some additional features that are dependent on the presence of a measured position of the mandible.

Automatic "find the vibration" (F11)

When a vibration is marked for analysis in cycle one, pressing F11 tells the program to find the same vibration in the next 5 cycles.

Automatic noise reduction (under Options)

When activated, this feature uses the program's ability to recognize those areas within the record where no movement is occurring and samples the background noise (at all frequencies). When a vibration is marked for analysis, the background noise level, which is usually quite constant, is subtracted from all of the vibration parameters.

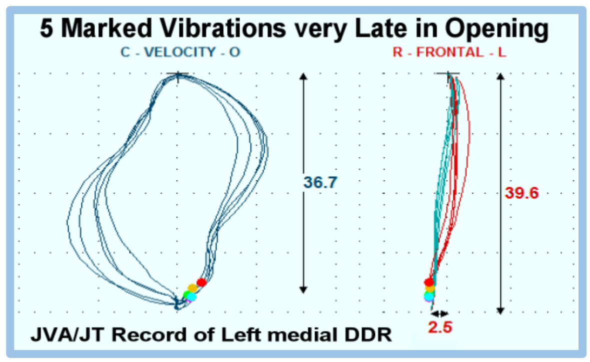

Figure 37. The colored dots in this image show the locations of the late opening vibrations that were caused by disk reductions. These precisely located late disk reductions are an indication of a chronic adapted condition with the patient functioning off of the disk.

The X – Y View of the JVA/JT trace in figure 37 shows with colored dots the precise locations of the vibrations occurring late in opening. This reveals both the locations and the consistency of the locations. A consistent late opening reduction is associated with a chronic-adapted condition where the patient is functioning off the disk, but in a well-adapted manner. By contrast, figure 38 shows an early opening reduction with an acute left anterior disk displacement. In this recording the measured velocity also reveals the greater resistance to each of the reductions as a sudden acceleration, which occurs at the onset of each vibration when the disk reduces. Without the jaw tracker the metronome velocity would only be displayed as an estimate of the disk reduction

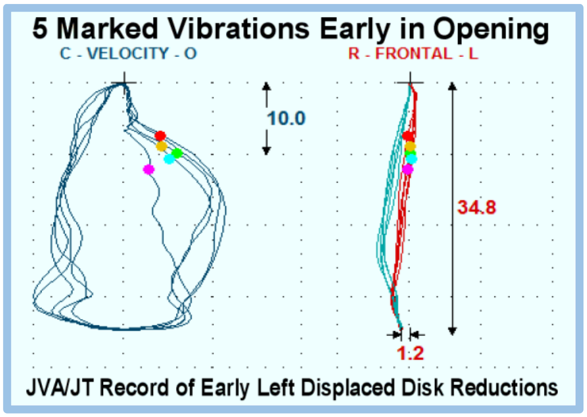

Figure 38. The colored dots in this image show the locations of the early opening vibrations that were caused by disk reductions. These precisely located early disk reductions are usually associated with a more acute condition.

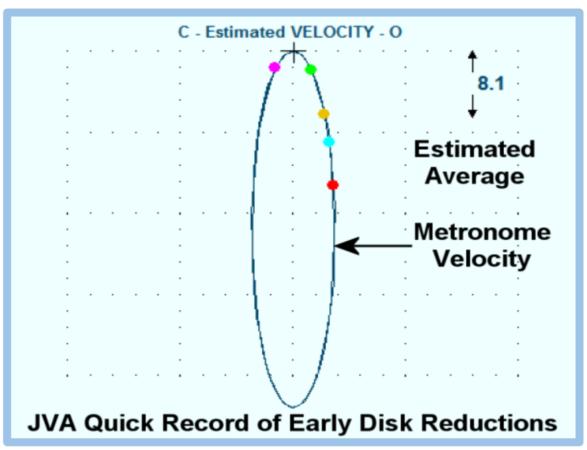

Figure 39. This JVA/Quick X – Y View shows the metronome velocity, estimates of the locations of the vibrations and an estimated average distance from occlusion.

positions and without any precise record of the consistency. See Figure 39.

Using the Jaw Tracker with EMG

Electromyography (EMG) is a popular tool used to evaluate muscle function. There are many measurements that can be made very well with EMG by itself. However, at times circumstances can mandate the combined recording of motions and muscle activity. One of these situations is the recoding of mastication.

When only EMG is used there is a requirement of establishing one channel as the reference channel. If this is done, the variations in the reference channel are transferred to all of the other channels that are recorded. Also, all of the variations between the muscles' activities and the motions

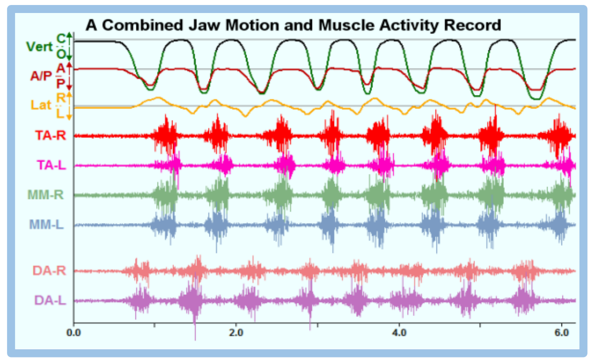

Figure 40. The combined recording of EMG and jaw motion solves the problems of recording the precise relationships between the motions and the muscle activities.

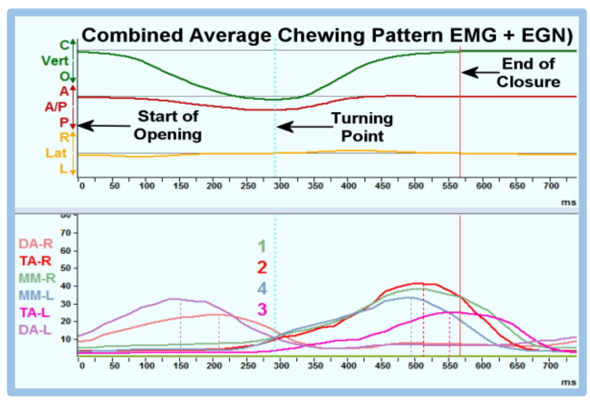

Figure 41. EGN + EMG records can be analyzed as together as one measurement. This illustrates the relationship between the motion and several muscles during mastication.

are lost. A good solution to this conundrum is to record the motions along with the EMG. See Figure 40. A later chapter will elaborate on the advantages of specific combined recordings.

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Key Words and Definitions

Electrognathograph (EGN): An electronic and magnetic device for incisor-point tracking of the mandible. It records motion at the incisor-point in three translations (Vertical, Antero-posterior and Lateral). Although it does not track other areas of the mandible, due to the well-known limitations of mandibular motion, an observer can conceive of how much of the rest of the mandible is moving from the recordings. The unit of measure it the millimeter.

Electromyograph (EMG): A device used for the recording of electrical output of muscle activity. It measures the activity in the range from a few microvolts to more than one thousand microvolts.

Joint Vibration Analysis (JVA): This device records any vibration emanating from the TMJ. It is very sensitive and aides in the diagnosis of TMJ internal derangements and degenerative joint disease. The unit of measure is the Pascal, which represents the pressure of 101.97 grams of force applied over the area of one square meter.

End Notes:

1. All the graphic data illustrations, except figures 33 through 36, are taken from the BioPAK program, © 2018 BioResearch, Associates, Inc. Milwaukee, WI 53223.

2. Individuals depicted in the illustrations are all professional models and have all signed consent forms for their use.

3. The description of the development of magnetic jaw tracking is based upon the recollections of Mr. John Radke, who became involved in it in January of 1972.

4. Other magnetic jaw trackers, besides the JT-3D, exist today. Their capabilities are limited by the software that is available and compatible with each device.

5. There are other jaw tracking devices that track the mandible with “6 degrees of freedom,” such that they measure three translations and three rotations, but all of them attach clutches to the subject. This allows the tracking other points not in the incisor area. In most published studies with 6-degree trackers, the area of the incisors is most often analyzed, probably because the motion at the incisors is the largest and more easily understood.

Appendix to chapter 2

The importance of proper alignment

To optimize the quality of jaw tracking records it is important to properly align the array to the magnet in the patient's mouth. See Figure 1.

Figure 1. A magnet positioner is used to precisely align the array to the magnet in the patient's mouth before starting to record. It points to the magnet.

For alignment there is a Magnet Positioner Tool that when placed on the jaw tracker, points to where the magnet should be. See figure 1. This tool makes the alignment very fast and easy to accomplish accurately.

The Set-up

Step one: The magnet is placed in the labial vestibule, adhered to the incisors and/or gingival tissue by Stomahesive, and with the Gold surface (north pole) facing up. All JT-3D trackers are calibrated to a reference magnet with a standard strength, but different magnets of different sizes and can be used just by entering their calibration values into the BioPAK program. The program reads the calibration value from each jaw tracker and automatically adjusts for any difference in the strength of the magnet currently being used.

Step Two: Once the magnet is in place the array is placed on the patient and adjusted to a snug comfortable fit. The operator views the vertical tubes and adjusts the array so that they are true vertical, both frontally and sagittally. The Magnet Positioner is placed on the array and the array is adjusted until the pointer is pointing at the center of the magnet, but 5 to 10 mm away from it.

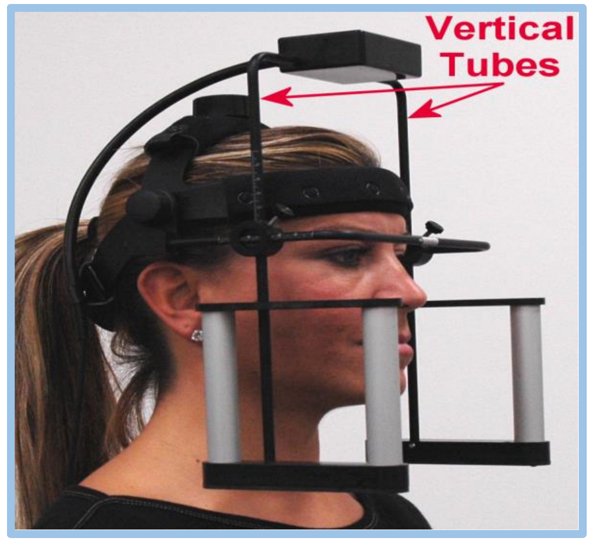

Figure 2. The array must be adjusted with the patient in an upright posture so that the vertical tubes, both frontally and sagittally, appear to be perpendicular to the floor while the patient is looking straight ahead.

Step Three: It is important to check the quality of the alignment. This can be done by recording the patient's range of motion (ROM) first. See Fig. 3.

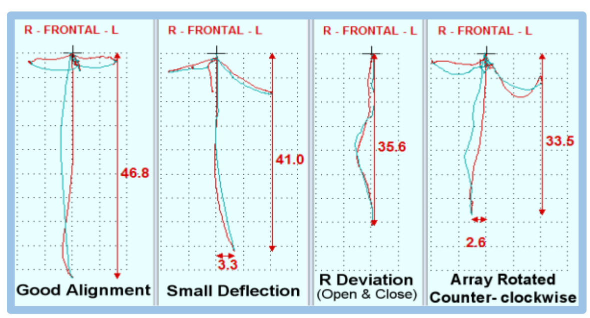

Figure 3. Check the alignment by recording one ROM trace and verifying that it appears the same as direct observation of the patient. In the sample on the right the array is rotated counterclockwise.

ROM is a large movement and it is possible to visualize if the patient is opening straight or not. If there is no deflection or only a slight visible deflection at maximum opening (less than 3 mm), then the jaw tracker should show the same result. If the entire trace appears rotated (see figure 3 above) the array may be rotated in the opposite direction on the patient. It is especially important that the frontal plane is correct because chewing is an asymmetrical frontal plane movement.

In contrast there is no universal sagittal angle that can be heralded as being the most normal. However, as a matter for future reference and consistency, it is important to align the array in the sagittal with the vertical tubes perpendicular to the floor too.