The Diagnostic Value of Biometric Instruments

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Chapter 4: History and applications of the T-Scan

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Abstract

The development of the T-Scan was initiated in the 1980s as an instrument to measure occlusion and it is still being refined and improved today. A variety of applications have evolved from its use with prosthetics, orthodontics, TMD, etc. Some of the criticisms that have been leveled at the T-Scan have been due to misunderstandings of its function, improper application or a desire for a device that can treat every painful condition. The importance of selecting an appropriate patient for T-Scan treatment is key to its good use.

Although PubMed currently lists 117 studies that include the T-Scan, dental academics, especially here in the U. S., still mostly ignore occlusion as a potential etiology of some TMD and too often favor a psychosocial etiology for TMD. Although it has been documented that TMD patients as a group are far more depressed than asymptomatic subjects, those depressions have been recently demonstrated to be secondary to painful, yet treatable physical malocclusions. Although it has not yet been tested, it is likely that other primary painful conditions also lead to secondary anxiety and depression. While correlations between TMD and psychosocial factors abound, it is long past time to test whether those psychosocial factors are the primary cause of TMD pains or whether they are secondary to those correlated physical conditions.

Clinical Applications of the T-Scan

History of T-Scan development

The original idea for the T-Scan was developed by a small group in Boston at Tufts University in the 1980s. (Maness & Podoloff, 1989). The idea of T-Scan was never considered to mark teeth or to replace existing occlusal marking products. It was conceived as a method to measure the force and timing of the contacts. It was also a method that was eventually developed to find the center of force with respect to the arches.

In the beginning there were technical problems with the thickness, flexibility, uniformity and the resolution of the T-Scan wafer. First generation wafers were too brittle and had a very short life-span (Patyk, Lotzmann, Scherer & Kobes, 1989). By the third generation the problems of thickness and flexibility had been solved, but the resolution was not acceptable (Patyk, Lotzmann, Paula & Kobes, 1989). Also, the dead space between traces was still greater than the active area of the wafer, causing some contacts to be missed and consequently, a lack of consistency (Tokumura & Yamashita, 1989; Setz & Geis-Gerstorfer (1990).

Another limitation of the original T-Scan was the lack of sensitivity of its wafer due to using only a 4-bit analog to digital converter (Maeda et al, 1989). The range of forces within the occlusion is such that 16 amplitude steps were not enough to give reasonable resolution to the forces. This limitation was solved quickly with the second-generation system that was developed to interface to the parallel ports of personal computers. The new T-Scan parallel handle incorporated an 8-bit A to D converter with 256 levels of force intensity preceded by an analog amplifier that greatly increased the force resolution and allowed one to adjust sensitivity to the individual patient's range of forces. This enabled static measurements in a Maximum Intercuspation Position (MIP) to be made very reliably along with a Center of Force (Nabeshima et al, 1990; Maness, 1991).

In the fourth generation of the T-Scan wafer the lines were widened and the dead spaces between them narrowed such than it became impossible for a tooth to only contact the dead space without contacting the active area. This greatly improved the T-Scan's reproducibility. The newest T-Scan Novus is shown in Figures 1 and 2.

From the beginning there have been different ideas as to how the T-Scan can best be used in a clinic. An early idea for the use of the T-Scan was to use it to trace the arches (Collesano, de Rysky, Bernasconi & Magenes, 1989).

Figure 1. The Latest T-Scan Novus handle samples from 175 to 500 samples/second and connects directly to a USB port for maximum security.

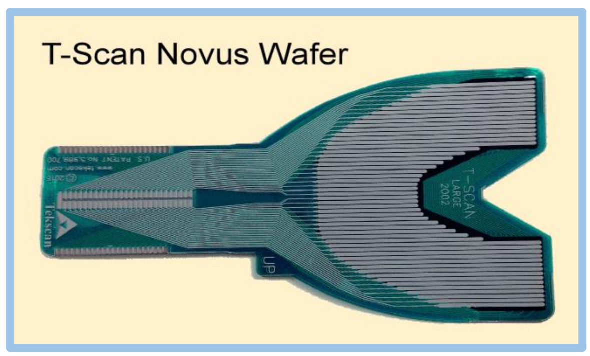

Figure 2. The T-Scan Novus wafer is 100 microns thick uncompressed and about 60 microns when fully compressed.

Another idea was to measure guided closure contacts (Kong, Yang & Maness, 1991). These represented adaptations of the T-Scan to the gnathological concepts of the current time. Some clinicians that were actively developing the osseointegrated implant systems advocated using the T-Scan as a very sensitive measure of the difference between the forces applied to the implant and to adjacent natural teeth (Chapman & Kirsch, 1990; Stevens, 2006). Other authors began to appreciate the additional capability of the T-Scan to measure the timing of the contacts as well as the relative forces that are applied to individual teeth (Reza Moini & Neff, 1990).

Another idea that developed out of the use of the T-Scan was measurement of posterior disclusion time (Kerstein & Wright, 1991). This concept has evolved into what is currently referred to as *Disclusion Time Reduction* (DTR). It has been shown repeatedly to provide relief for certain temporomandibular disorders with muscular pain symptoms. Since Disclusion Time Reduction, more descriptively termed ***Immediate Complete Anterior Guidance Development*** (ICAGD), only records the lateral excursions from centric, it eliminated the problem of missing a contact, even with the older generation wafers.

With the ever increasing interest in implants the T-Scan was recruited to evaluate the forces applied to the occlusion on the prostheses (Garg, 2007; Pellicer-Chover et al, 2014). It was also used to evaluate resorption of the residual ridges when mandibular implant supported overdentures are provided (Khuder et al, 2017). As the problem of late implant failures has become more recognized, it has been observed that the contact force on an implant can change over time and may need to be re-adjusted (Madani, Nakhaei, Alami, Haghi & Moazzami, 2017). T-Scan represents a very sensitive way to detect any increase in the contact force on an implant and to measure a force reduction.

Another concept that has been tested in vivo is the relative balance of occlusion (Mizui, Nabeshima, Tosa, Tanaka & Kawazoe, 1994). It has been shown that in normal asymptomatic subjects the occlusal forces tend to be balanced, both left and right and antero-posteriorly in centric occlusion. However, in the subjects with craniomandibular disorders, this full arch balance is often absent. This is an important concept, both for adjusting an occlusion and for the complete reconstruction of occlusion prosthetically.

It was discovered that reproducibility could be enhanced by first conditioning the T-Scan wafers with four bites into the intercuspal position (González Sequeros, Garrido García & García Cartagena, 1997). This action conditions the wafer to the unique morphology of a patient's occlusion and allows obtaining a more precise recording. This approach has been used to compare relative bite force distribution in the intercuspal position after corrective orthognathic surgery (Iwase, Sugimori, Kurachi & Nagumo, 1998).

Within the specialty of prosthodontics, the delivery of a prosthesis with a precise occlusion is a difficult task. The T-Scan has been shown to be helpful in achieving this type of result (Kerstein, 1999). It was also found that the delivery of complete dentures could be enhanced by adjusting the occlusion with the T-Scan at the time of delivery (Okuma, Hirano & Hayakawa, 2002).

The concept of a "balance of forces" within the arches led to the addition of a "Center of Force" function within the T-Scan II (Hirano, Okuma & Hayakawa, 2002). This function shows the center point of all forces applied between the arches and how that point shifts with time during excursions.

Another step in the development of the ICAGD procedure was the addition of simultaneous EMG recording of the masseter and temporalis muscles through a LINK between the T-Scan and BioPAK programs (Kerstein, 2004). This link provided a real-time indicator of the end-point of the process, which is the desired reduction in muscle activity.

A key factor in the development of successful diagnostic procedures is a clear understanding of what is normal and healthy. This factor had been missing in the study of occlusion until a study was produced from 123 subjects with normal intact dentitions (Hu, Cheng, Zheng, Zheng & Ma, 2006). This study used T-Scan II and found; a) no significant difference in bite force between sides, b) 98.4 % of subjects had a center of force centered between the posterior region of the molars.

A very definitive and exhaustive exercise to study the effects of precisely introduced individual tooth occlusal interferences was undertaken by authors at the Catholic University of Salta in Bueno Aires, Argentina (Learreta, Beas, Bono & Durst, 2007). On a group of subjects (50) with normative dentitions the T-Scan was used to precisely introduce occlusal interferences on individual teeth while the bilateral masseter, temporalis, trapezius and suprahyoid muscles were recorded electromyographically. While the temporalis showed the highest disruption due to the interferences, all muscles were significantly stimulated, even the trapezius.

A group of authors at Guanghua College of Stomatology in Guangzhou, China used the T-Scan II system to investigate the relationship of non-carious cervical lesions to the presence of occlusal interferences (Yang, Lin, Zou & Li, 2007). Comparing 157 teeth with lesions to 157 adjacent teeth without lesions, they found that a significantly higher proportion of the occlusal interferences were on teeth with cervical lesions.

Although the T-Scan measures only the relative forces around the arches, some believe it is more important to measure the absolute forces as a better indication of health. After modifying and calibrating the T-Scan III wafer, the absolute forces were correctly estimated (Throckmorton, Rasmussen & Caloss, 2009). However, in most clinical situations, measuring the relative forces provides enough information to allow correction of a malocclusion.

Along with all the high-quality research that has been conducted for decades using the several evolving T-Scan versions, there have been a few published studies that have lowered the bar of adding to knowledge. A good example would be the publications by Forrester et al in the 2009 Texas Dental Journal and republished in the Journal of Oral Rehabilitation in 2011 (Forrester, Pain, Presswood & Toy, 2009; Forrester, Presswood, Toy & Pain, 2011). In this one study the T-Scan wafer was cut in half and placed on one side of the arch at a time while the subject was instructed to bite on it. EMG was used to measure the activity of the anterior temporalis and the superficial masseter muscles, with and without anything between the teeth. Although the T-Scan wafer is only 100 microns uncompressed, about 60 microns compressed, that is a large unilateral change with the masticatory system's high degree of sensitivity. The T-Scan wafers are never cut in half during normal use and thus never applied unilaterally. In fact, when used whole, the T-Scan wafer thickness typically varies only about one micron between sides. The fact that the muscles adjusted to a 60-micron change is no surprise, but it is also no indication of any negative aspect of the normal T-Scan usage. The only aspect of this study that is difficult to comprehend is how the peer-reviewers failed to reject it for publication (twice).

In 2010 the T-Scan III was tested again for errors (1 %), accuracy (2 %) and reliability (2.8 %) on a population of 42 subjects in a simulated clinical situation (Koos, Godt, Schille & Göz, 2010). No significant differences in the measurements were observed after changing wafers or with repeated measures.

In studying the occlusions and disclusion times of post-orthodontic cases it was found that even though the subjects achieved a "normal looking dentition" after orthodontic treatment, the post-ortho disclusion times were longer than those of healthy control subjects (An, Wang & Bai, 2011). These results suggest that an opportunity exists to further refine a post-ortho occlusion.

One curiously weird study was first performed in 2012 (Helms, Katona & Eckert, 2012):

"A matched pair of IPN Portrait 33° molar denture teeth was placed into occlusion with the mandibular tooth supported by a load sensor and the maxillary tooth mounted onto a vertically sliding assembly with a total weight of 15·1N. The three-dimensional force and moment components on the mandibular tooth were measured when the teeth were in direct crown-crown contact (control) and with the products in place. All six products, (Accufilm I, Accufilm II, Hanel Articulating Silk, Rudischhauser Thick and Thin, and

T-scan) showed significant (P<0·05) differences in forces and moments from control."

How is placing a T-Scan wafer between single opposing denture teeth set in a mechanical fixture testing occlusion? The authors did not even hazard a guess as to how these "differences" might affect the accuracy of the actual process of evaluating occlusion.

One of the important aspects of utilizing the T-Scan is understanding what constitutes a normal condition. This was repeated by using the T-Scan II system with a group of 30 healthy subjects (Cheng, Geng & Zhang, 2012):

"The results showed that there was no significant difference between the occlusal force of the two sides under the intercuspal position mode (P = 0.3242). The average percentage of intercuspal position occlusal force in Max force was 96.89%. The confidence interval (CI) was 90.88 % - 100 %. The average occlusion time was (0.2015 ± 0.0861s)."

Note: The occlusion time is defined as the time from the onset of tooth contact to a fully seated occlusion.

Using a combination of the MatScan to measure foot pressure and the T-Scan to measure occlusal pressure, it was determined that a difference in leg length can alter both posture and occlusion (Maeda et al, 2011). It required only a few millimeters of difference in leg length to alter the amount of foot pressure and a few millimeters more to alter the occlusal pressure between sides.

The question of whether occlusion plays a part in the symptoms associated with certain temporomandibular disorders, specifically ones including muscular pains, has been argued incessantly. In a study comparing 31 TMD subjects to 31 age and gender matched controls, it was found using the T-Scan that the TMD subjects had; 1) a higher incidence of premature contacts, 2) significantly greater bilateral asymmetry in the occlusal forces, and 3) prolonged occlusion and disclusion times (Wang & Yin, 2012). The authors concluded that "a significant association exists between occlusal stability and TMD in young adults."

The relationship between the lateral excursive muscle activity and lateral disclusion times was studied in 45 symptomatic subjects. After the excessive disclusion times were significantly reduced by the ICAGD procedures, the EMG activity of the masseter and temporalis muscles also decreased significantly (Kerstein & Radke, 2012). It was also noted that the masticatory Average Chewing Patterns (ACP) became more normal in appearance and that the number of silent periods triggered by occlusal interferences during chewing was reduced by half. A later re-analysis determined that the chewing motions were much smoother (less jerkiness) after the ICAGD procedures were completed.

Using the T-Scan III system, another test of "normal appearing occlusions" from a group of fifty-three volunteers found an average difference 7 % between sides clenching in MIP, while the average occlusion time was 0.34 sec. (Ma, Hu, Li & Lin, 2013). The center of force was located between the first premolar and the second molar. This is another important contribution to understanding what constitutes normal occlusion. It is understood that normal is different from perfect or ideal and includes "well adapted" too.

Historically, the coining of the term "Myofascial Pain Dysfunction Syndrome" (MPDS) originally meant a syndrome of painful muscles of the face without a known etiology, but was thought to be initiated by emotional stress. It was presumed that the stress induced by "gnashing of teeth" could produce the painful symptoms and that relieving the stress would be sufficient to reduce the pain (Laskin, 1969; Laskin, 1970). The MPDS theory was published twice, perhaps because of the excitement it generated, but no short or long-term convincing evidence has ever been produced to support it, only anecdotal. Today the acronym MPDS is used to loosely indicate a TMD patient with muscular painful symptoms. Actually, a more accurately descriptive term, occluso-muscle disorder (OMD), is more appropriate.

In 1992, with the publication of the Research Diagnostic Criteria, the old MPDS theory that psychological factors are responsible for the etiology of TMD was resurrected (Dworkin & LeResche, 1992). Currently, PubMed lists no less than 317 articles evaluating the RDC/TMD for its diagnostic use, but only one published study has ever tested whether its underlying hypothesis, that depression is one of the etiologic factors in TMD, is in fact true (Thumati, Sutter, Kerstein, Yiannios & Radke, 2018). As it was shown in this study, adjusting occlusion with the T-Scan did produce very significant statistical reductions in the levels of depression as indicated by the Beck Depression Inventory - II. Out of 83 TMD patients, 65 of which exhibited moderate to extreme depression before treatment, 81 changed to normal or a slight mood disturbance, while 2 reduced to borderline clinical depression after their DTR treatments. See Table 1 from the study. The authors acknowledged that treatment success was predicated upon the careful and accurate selection of appropriate patients in the study.

Total Score	Pre-treatment # of subjects	3 weeks post-Tx # of subjects	3 months post-Tx # of subjects	Levels of Depression*
1 - 10	1	53	76	Ups and downs considered normal
11 - 16	10	4	5	Mild mood disturbance
17 - 20	7	2	2	Borderline clinical depression
21 - 30	22	13	0	Moderate depression
31 - 40	22	9	0	Severe depression
over 40	21	2	0	Extreme depression
	83	83	83	total subjects
	5 - 55	0 - 42	0 - 19	Range of scores

Table 1. The reductions in depression after treatment with ICAGD of 83 OMD patients. Using the Beck Depression Inventory – II, which is a validated and popular assessment device, the results clearly indicate that depression is secondary to the painful conditions.

(Table 1 used with permission from the Journal of Advanced Dental Technologies & Techniques)

Occluso-muscle disorder patients are those TMD patients with various types of muscle pains, head-aches, but without serious temporomandibular joint dysfunction. When the patient has anterior coupling of the teeth, the ICAGD procedure can be an effective treatment. A group of fifty-one such patients were treated by T-Scan with disclusion time reduction and benefitted from a statistically significant and a solidly positive response. (Thumati, Manwani & Mahantshetty, 2014). The authors suggested that this procedure is one that is well suited for clinics.

Although PubMed lists 117 studies evaluating the T-Scan in the dental literature, a tiny few of them do not pass muster. The perfect example of such is an article purporting to determine the validity and reliability of the T-Scan III for measuring under laboratory conditions the total absolute bite force, published in two journals (Cerna Ferreira, Zaror, Navarro & Sandoval, 2015A; Cerna, Ferreira, Zaror, Navarro & Sandoval, 2015B). Never mind that T-Scan was designed for clinical purposes, not for use in measuring absolute forces in a laboratory. It had already been thoroughly tested in clinical settings. The main complaint from the Cerna group was that the sensors of different batches exhibited some differences in sensitivity, which is not in the least significant for the relative measurements that it was intended to accomplish. Within one batch the validity and reliability were shown, even by them, to be from good to excellent.

In another study of 149 healthy subjects, with or without previous orthodontic treatment, there was no significant asymmetry in the occlusal contacts of the young adults (Wieczorek & Loster, 2015). This was another affirmation that bilateral contact symmetry is a healthier condition. In a similar and concurring study (Qadeer, Yang, Sarinnaphakorn & Kerstein, 2016) the authors found that bilateral contact symmetry was present in both post-ortho and non-orthodontic subjects. However, when comparing the contact forces by quadrant, the post-ortho subjects had a significantly higher percentage of their contacts within the posterior portions of the quadrants.

Ultimately, the masticatory system must be able to masticate well to provide good nutrition. The kinesiometric indications of good masticatory function include; 1) the shape of the Average Chewing Pattern (ACP), 2) the size of the ACP, 3) the variability of the ACP, as well as 4) the smoothness of the ACP. Convex opening and closing, large size, low variability and a smooth pattern are associated with good masticatory function. In a study of twenty-nine occluso-muscle disorder patients that accepted treatment with ICAGD, all reduced their painful symptoms (Kerstein & Radke, 2017). After treatment, the kinesiometric parameters improved significantly in the direction of healthier masticatory function. In a periodontal study, eight-hundred seven teeth in thirty subjects with periodontal disease were compared to surrounding un-involved teeth. T-Scan was used to detect the presence of high occlusal forces on any of the teeth (Zhou, Mahmood, Cao & Jin, 2017). The teeth with high occlusal forces presented with deeper probing depth, a higher frequency of bleeding on probing and functional mobility particularly in the upper posterior teeth. The authors concluded that high occlusal forces, especially on posterior teeth with some periodontal involvement is an additional risk factor.

The T-Scan Novus is the latest hardware version of the product, along with the version 10.0 of the T-Scan software. Over the past thirty years of development vast improvements have been made in the product, both in the hardware and in the accompanying software. The two most difficult concepts to communicate with the profession have been; a) that the T-Scan is not a tooth marking system, and b) that the T-Scan doesn't replace existing tooth marking systems. The unique features of the T-Scan are its ability to determine the relative (%) force levels being applied to individual tooth contacts and show the timing of the contacts.

The belief that one can interpret the marks on the teeth in terms of the amount of force applied has been shown to be hysterically false (Kerstein & Radke, 2014; Sutter, 2017). The marks are just marks and do not indicate anything about the level of force applied, only something about the morphology. A larger mark definitively indicates a larger area of contact, but not more force. The "quality" of a mark is a function of the marking material and the surface conditions of the teeth, but has nothing to do with the amount of force applied. The interpretation of the significance of paper marks on teeth is literally a guessing game. These facts have been difficult for the profession to accept probably because so many decades have passed while the interpretation of paper marks has been taught in the dental schools, in weekend courses and dental conferences. Although several "studies" have been done apparently to criticize and disparage the T-Scan, none of them used the T-Scan in the manner as it is used clinically and, in some cases, it was not even used at all. No study has applied the T-Scan to actual patients and found it to be without value.

The Characteristics of the T-Scan

Although the T Scan is considered by many as a treatment instrument, it has diagnostic capability as well. The simplest factor regarding occlusion after looking in the mouth and counting the teeth is noting which teeth contact in centric occlusion. This can be accomplished with marking paper to an extent, although some smudges on teeth may occur without a real contact. For this reason, a few dentists insist on using the thinnest material available. The equivalent indication of smudging with the T-Scan is due to bending of the wafer. This produces a dark blue color at the lowest level in the 3-D display. See Figure 3 below.

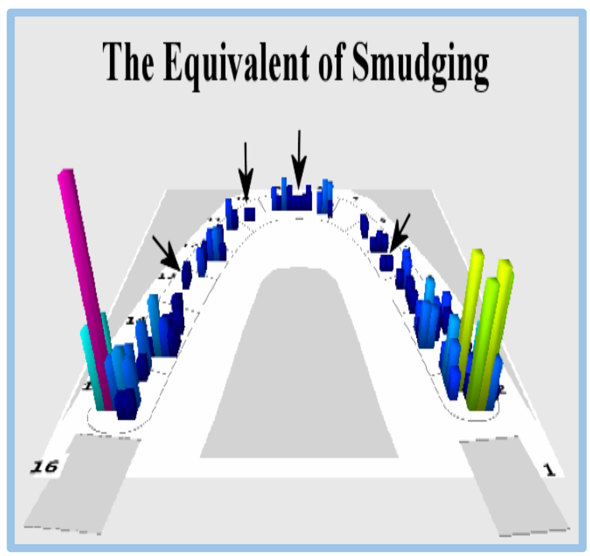

Figure 3. The bending of the T-Scan wafer can create a dark blue area that appears on the screen. It is usually ignored as the clinician is looking for the highest points, not the lowest.

Although the number of contacts around an arch can be 10 or more, there are usually fewer that are strong enough to be significant. When marking with paper, it is impossible to consistently choose which are the high-force contacts. Using the T-Scan it is very easy to see which contacts are high-force and which are not. See Figure 4.

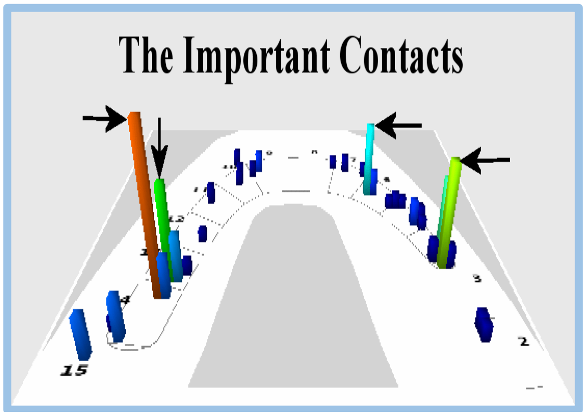

Figure 4. Although there may be 10 or even more points of contact between the arches, the important high-force contacts are often just a few.

Thus, the first unique capability of the T-Scan is identifying those few teeth in hyper-occlusion. It is usual to also mark the teeth with paper, but all the insignificant marks can be ignored. It is also possible to remove the bending indications from the graph displaying the contacts. See Figure 5.

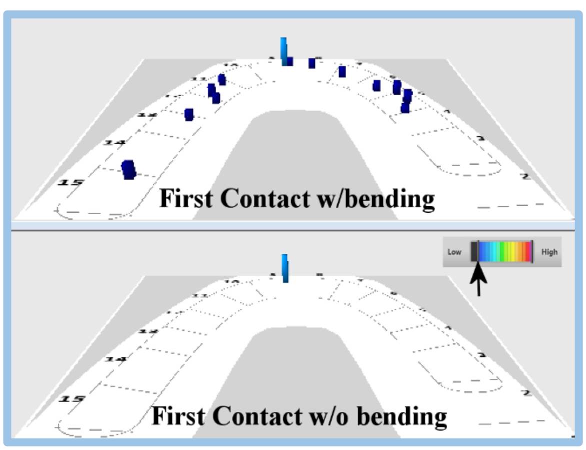

Figure 5. By raising the low end of the color bar slightly, it is possible to remove the indications that are caused by the bending of the wafer. This gives an unquestionably clear picture of the first contact.

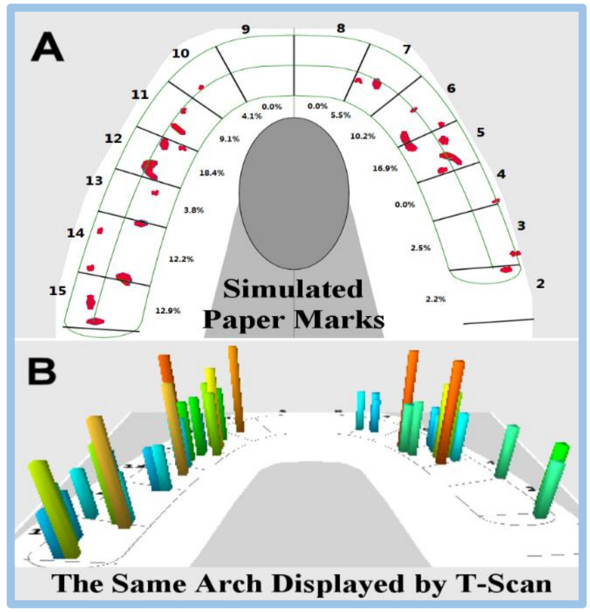

Figure 6. The same arch shown as simulated paper marks (A) and with the T-Scan display (B), which makes it possible to see the force levels.

Paper marks are useful to show where the teeth contact, but do not give any indication of which contacts have high or low forces (Carey, Craig, Kerstein & Radke, 2007). Not the size, nor the shape nor the appearance of a paper mark indicates the level of force. Thus, by viewing the contacts as paper marks, it is only possible to adjust the size of the area of contact, unless one is taken completely out of occlusion.

Looking at the simulated paper marks in Figure 7 one could suspect that there are more contacts on the left and that is correct. However, it is not possible from paper marks to discern which ones include high forces.

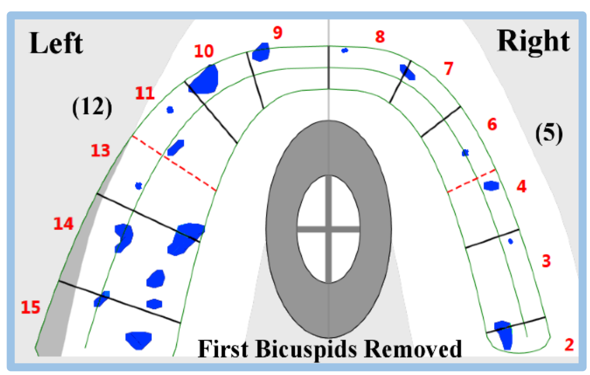

Figure 7. This simulation of paper marks shows where the contacts (and smudges) are, but does not give any clue which ones are high force.

Looking at the T-Scan's 3-D view in Figure 8 it becomes obvious where the high forces lie. Even though the T-Scan only measures relative forces, that is enough to determine where to adjust and the relative forces ignore the variations between subjects and focus on within-subject condition.

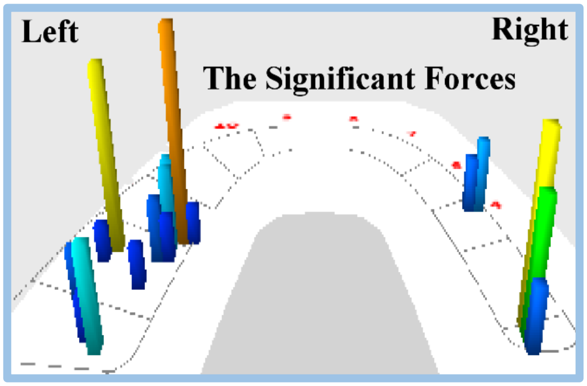

Figure 8. The same subject as in figure 5 with a T-Scan 3-D view. It is easy to identify the high forces within this image.

As the high-force contacts are plainly identified it is possible to determine if any are so relatively high that they need reduction. Then as the adjustments are made, the process is repeated to verify that the highest forces have been reduced. In Figure 9 the adjustments have been made and the left right balance is 49.8 % Left and 50.2 % Right.

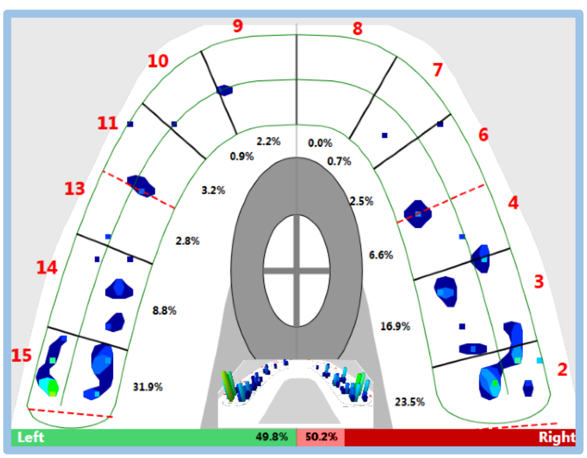

Figure 9. After reducing the high force contacts, it is clear that the left-right balance of forces has been equalized very well (49.8 % left to 50.2 % right).

A Misconception Regarding Jaw Motion

It has been assumed in the past that the first 10 to 20 mm of opening consists mainly of rotation in the sagittal plane, then translation of the condyle occurs. This suggests that in closing the same is true. However, the actual motions are quite the opposite, with the earliest part of opening being mostly a vertical translation of the mandible and a large percentage of sagittal rotation occurring as the mandible approaches maximum opening. The significance of this difference is that the thickness of the T-Scan wafer (100 microns uncompressed) does not alter the contact pattern. This is because of the extremely uniform thickness of the wafer at about (+/- 1 micron). That is, the thickness of the wafer only varies from about 99 to 101 microns. Consequently, when it appears that a 2nd molar is in hyper-occlusion, it is not due to the thickness of the wafer (e.g. a thick area in the wafer that is directly over the 2nd molar). It is also important to understand that the T-Scan wafer always covers the full arch. Placing a cut-in-half T-Scan wafer only on one side alters both the contact pattern and the muscular response to it. Of course, the T-Scan can't work with only half of a wafer and it would be irrational anyway to use it that way.

Consider the fact that there are some types of marking media that are twice as thick as the T-Scan wafer and still able to mark on every tooth within the arch. Looking at this normal control subject it is easy to see that contacts throughout the arch are recorded by the T-Scan. (Figure 10.)

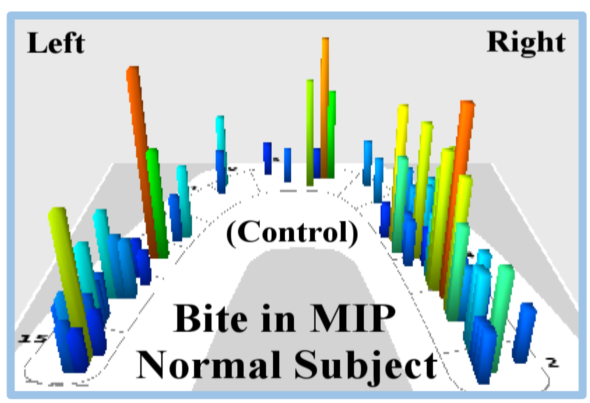

Figure 10. A normal control subject biting in MIP shows continuous contacts throughout the whole arch. Normally, the highest forces appear in the areas of the 2nd premolars and 1st molars.

It is not necessary or expected that the forces on every tooth be exactly equal. But when a situation such as that in Figure 11 appears, adjustment of occlusion is certainly warranted.

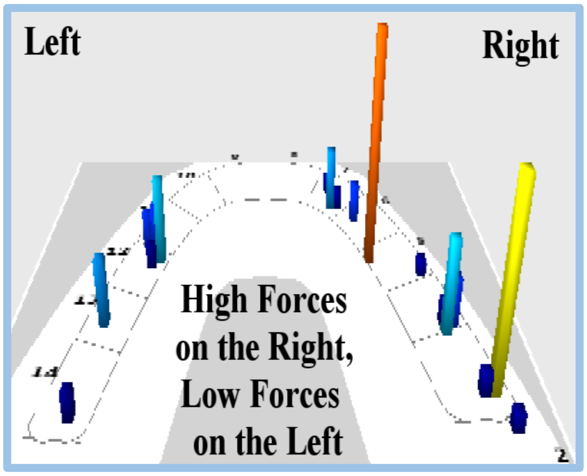

Figure 11. Two high force contacts on the right side and none on the left side while biting maximally in MIP. The lack of any strong contacts on the left can be for a variety of reasons. It is necessary to evaluate both the occlusion and the patient's function to decide what correction is needed.

The condition in Figure 11 could be due to a loss of some posterior teeth, along with some tipping of the remaining teeth on the left or it could be due to deterioration and collapse of the right TMJ. This requires a thorough examination/evaluation of the patient before arriving at a treatment plan. Just using logic, most will agree that having the contacts (more or less) evenly spaced about the arch is a good thing. Consequently, there are very few clinicians actively treating TMD today that truly believe occlusion never plays any part in etiology of symptoms.

Setting the Correct Sensitivity

One critical operator setting is the sensitivity. To get a usable recording, the sensitivity must be set correctly. Too much sensitivity causes the contact forces to limit (pink color), which makes it look like all high force contacts are equal. See Figure 12B.

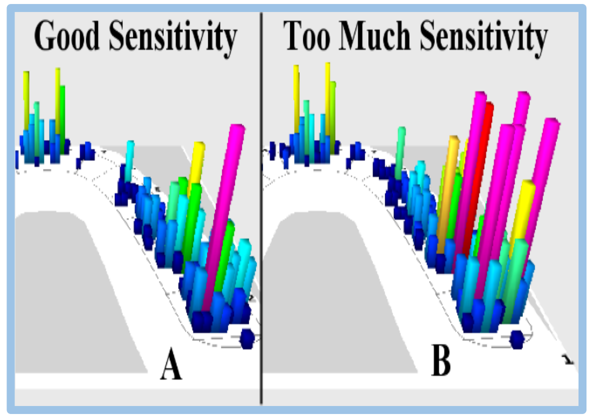

Figure 12. The display in (A) is correct, but the display in (B) is by the same subject and with too much sensitivity, it suggests that all 5 contacts are equally strong. When a bar is pink it cannot go any higher in the display and is limited.

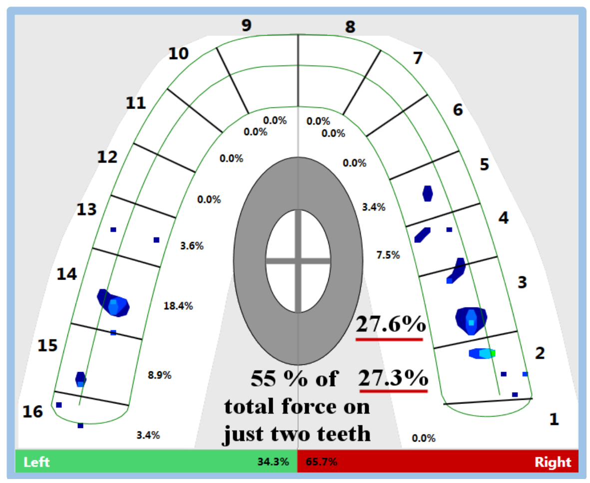

Figure 13. The 2-D view can provide the percentage of force on each tooth. This allows for precise adjustment of the force as well even on a single implant-supported prosthesis.

Note: When the sensitivity is set correctly there should be only one or a maximum of three pink bars seen in the 3D display.

Adjusting Implant-supported Prostheses

The T-Scan also shows the percentage of the total force that is applied to each individual tooth. See Figure 13.

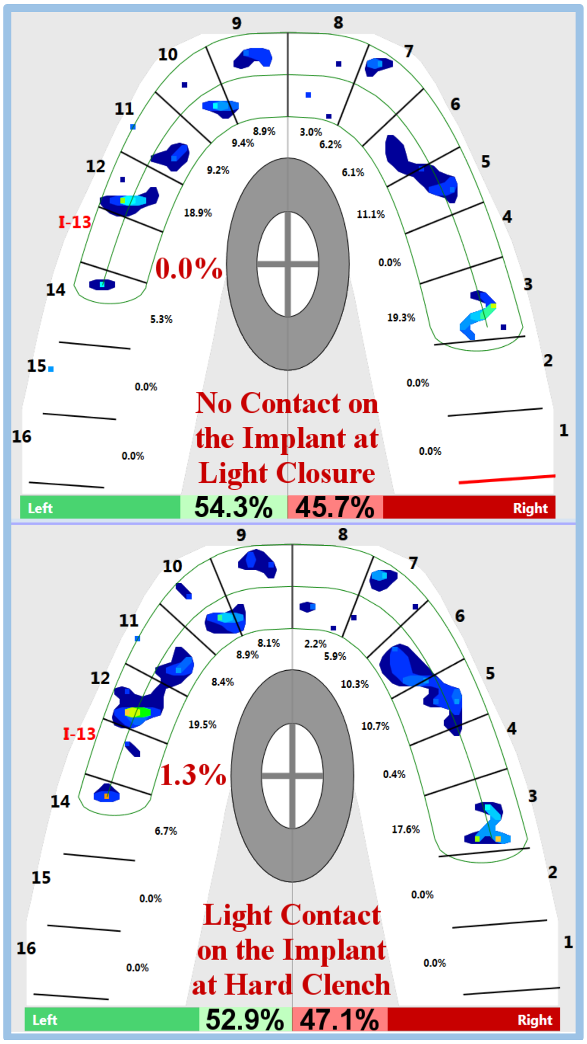

Figure 14. When checking the forces on implant-supported prostheses, a light closure should not indicate any force. A hard clench should induce only a light force on the prosthesis.

This can be especially useful when delivering an implant-supported prosthesis. The T-Scan user adjusts the occlusion to zero force with a light contact of the teeth and a minimum of force during a hard clench. See Figure 14.

The implant should also be checked within the DTR testing sequence, which will be described later in this chapter. Due to the possibility of natural tooth wear and movement within the occlusion, it is necessary to periodically re-check the forces on the implant. It can be done on a recall basis very quickly. Many a successfully integrated implant has gone awry over time as changes within the occlusal scheme have altered the forces applied to the implant-supported prosthesis. Today it is recognized that peri-implantitis, stimulated by excessive occlusal forces on the prosthesis, can gradually defeat an implant over time by destroying even well osseointegrated bone. Thus, in addition to good hygiene, an implant needs to be free of deflective occlusal forces to survive long term.

To retain an implant-supported prosthesis long-term, it is necessary to monitor it more carefully than the rest of the natural dentition. An implant's susceptibility to disease is much greater and its adaptability is less than a natural tooth. Figure 15 is an example of what can happen over time to a successfully integrated implant. After removing the excessive force on the implant, the lost bone support may be fully recovered (Stevens, 2006).

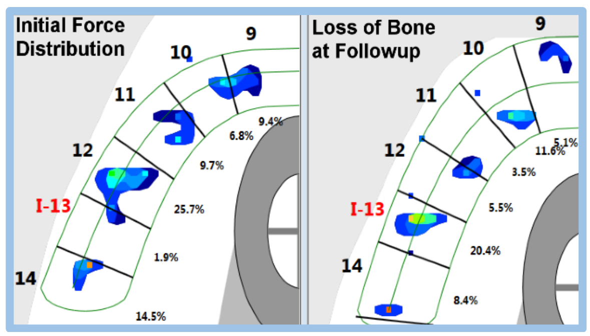

Figure 15. Even though the initial force level was set at only 1.9 %, upon recall it was discovered that bone loss had occurred and that the force level had increased substantially.

Logically, an implant does not need to regularly be in contact with an antagonist, the way a natural tooth does. just to avoid extrusion. Even with zero opposition, the implant is not going anywhere. It is therefore possible to have an implant prosthesis slightly out of occlusion at first contact and with little force being applied under hard clenching. However, that by itself is not enough protection against occlusal trauma. It is also necessary to make sure that no functional contacts traumatize the implant. This is best accomplished by the application of disclusion time reduction (DTR), as described later in this chapter. Of course, it is also necessary to prevent opposing natural teeth from extruding into contact with the implant.

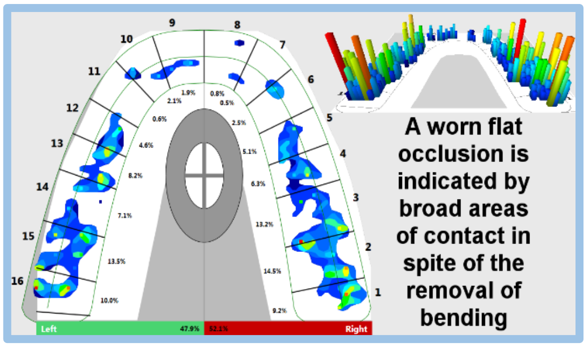

Figure 16. Broad areas of contact are coincident with a worn flat centric occlusion. A grinding pattern of mastication is required when the normal occlusal morphology has been destroyed.

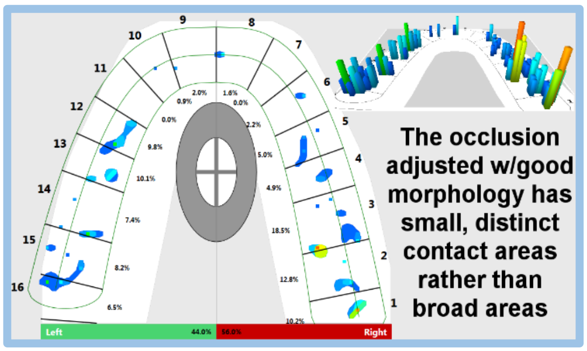

Figure 17. A well aligned occlusion that includes normal morphology shows small areas of contact. This occlusal relationship leads to a preference for a chopping type of masticatory function.

Considering the morphology of occlusion

One fundamental gnathological tenant of human occlusion is that the contacts should be relatively small, and that cusp tips meet in the fossae or on the marginal ridges. When an occlusion is badly worn, the amount of area of contact increases. This leads to a grinding pattern of mastication, which requires more muscular effort and usually perpetuates occlusal wear. This condition is easy to see in a T-Scan C. O. bite. See Figure 16.

There have been endless discussions of what constitutes the ideal occlusion, all the way from suggesting that “occlusion doesn’t matter” (Türp, Greene & Strub, 2008) to offering an extremely specific recommendation (Dawson, 1996). But others have been unable to find any “ideal occlusal contacts” within subjects that have an apparently good (Class I) occlusion (Ehrlich & Taicher, 1981). This diversity of opinions has just about rendered occlusion into the wastebasket in most scenarios of formal dental education today. The truth regarding occlusion, as expected, lies in between the extremes. While there isn’t a single prescription for “good occlusion,” there are some common tenants. The best indications of what constitutes a good occlusion come from studies of masticatory function, which is the most critical purpose of the system. While a pretty smile is wonderful, the ability to masticate is far more important to survival. This concept will be further developed in a later chapter.

Historically, the major arguments within the topic of occlusion have surrounded two areas; 1) the balancing Vs working side excursive contacts and 2) group function Vs cuspid protection. Many of the differences of opinion have been just that, as little data have been presented. The adaptability of the masticatory system allows a wide range of configurations to succeed, which has led some to the false conclusion that nothing at all regarding occlusion is important in relation to the etiology of TMD. (Pullinger, Seligman & Gornbein, 1993; McNamara, Jr., Seligman & Okeson, 1995; Clark, Tsukiyama, Baba & Simmons, 1997; Manfredini, Lombardo & Siciliani, 2017). The most common mistake made in evaluating the relationship of “occlusion” to TMD is seeking a strong correlation between single parameters of occlusion and TMD. **It is the total effects of all of the parameters of occlusion that determine whether TMD symptoms are initiated.**

It is a mistake for example to test whether Angle’s Class II is a cause of TMD by itself (Farronato, Rosso, Giannini, Galbiati & Maspero, 2016). It may be a contributor in some patients, but aside from overt trauma, no single factor has been found to be consistently pathognomonic of TMD. While it is true that an occlusion does not need to be “perfect,” that is not to say it can be totally ignored. The current data indicate that the best available evidence supports cuspid protection over group function and suggests that working side posterior contacts during lateral excursions are more harmful than most non-working side contacts. This may seem counterintuitive, but as the jaw moves laterally a roll of the mandible occurs naturally that increases the vertical on the non-working side. Thus, during the bolus crush in closing, the non-working side reaches occlusion slightly after the working side. Deviations during opening to avoid interferences on the non-working side tend to offer less problems than deviations in closing that are needed to avoid working interferences.

The Importance of Mechanoreceptors

Sensory motor integration is exceptionally fine within the masticatory system and the precision of mandibular movements is far greater than within any other limb. There are rapidly adapting mechanoreceptors within the dermal layers; the Meisner and the Pacinian corpuscles, (Bukowska, Essick & Trulsson, 2010) and there are slowly adapting mechanoreceptors, such as the Merkel disks and Ruffini corpuscle (nerve endings). Also, the periodontal mechanoreceptors, which are equally sensitive regardless of the state of the tooth vitality, are rapid adapting sensors and require a continuously changing input for them to respond (Loewenstein & Rathkamp, 1955; Linden, 1975). Intra-dental mechanoreceptors with rapidly acting response characteristics encode the mechanical vibrations from 10 Hz to > 300 Hz for the purpose of indicating texture (Dong, Chudler & Martin, 1985). The periodontal mechanoreceptors that are slower acting respond only to lower frequency events (Dong, Shiwaku, Kawakami & Chudler, 1993).

All of this makes the adjustment of occlusion a challenging task that many would rather forego. Marking contacts in the intercuspal position and attempting to decide where to begin adjusting is a no-win scenario, since the marks do not indicate either the amount of force or the timing (Kerstein, Lowe, Harty & Radke, 2006). Realistically, one can reduce the sizes of the marks, which is a common strategy, but equalizing the forces is literally guesswork.

Abfractions

Other areas of contentious thought are the various hypothesized etiologies of abfractions; GERD, occlusal trauma and tooth brushing wear. As the theories go, damage to the enamel of teeth is due to; 1) some people brush their teeth too vigorously, with a toothpaste that contains harsh particles and a brush with stiff bristles (Litonjua, Andreana, Bush, Tobias & Cohen, 2004; Pikdöken, Akca, Gürbüzer, Aydil & Taşdelen, 2011), 2) people that suffer from GERD and/or consuming many acidic soft drinks gradually dissolve the enamel and dentin from the teeth (Kwoni, Choi, Cheong, Park & Park, 2012), or 3) excessively high forces applied to specific teeth can lead to the presence of enamel abfractions (Miller, Penaud, Ambrosini, Bisson-Boutelliez & Briançon, 2003).

There has been a concerted effort to disassociate occlusion from NCCLs as the importance of occlusion has become rather *unfashionable* in recent years, especially with dental academia (Bartlett & Shah, 2006; Senna, Del Bel Cury & Rösing, 2012). However, a concept that NCCLs result from more than one etiology has gained traction recently (Pecie, Krejci, Garcia-Godoy & Bortolotto, 2011; Grippo, Simring & Coleman, 2012; Yang, et al, 2016). In terms of associated risk, age (increasing risk) and the tooth's location (premolars and cuspids), these are the higher risk factors, but frequency of tooth brushing and bruxism are lower factors (Bernhardt, Gesch, Schwahn, et al, 2006; Jiang, Du, Huang, Peng, Bian & Tai, 2011; Yoshizaki, Francisconi-Dos-Rios, Sobral, Aranha, Mendes & Scaramucci, 2017).

Surprisingly, one recent study concluded that soft toothbrush bristles are more damaging than stiff toothbrush bristles (Bizhang, Riemer, Arnold, Domin & Zimmer, S. (2016), which seems rather counterintuitive. Even with the clearly conflicted literature, it would seem that the enamel is more at risk from occlusal trauma in the form of abfractions, while exposed dentin may be more susceptible to damage from abrasive dentifrices and erosive acid attack. For the individual with

NCCLs, it is yet again likely that multiple factors have been influential.

Dentinal Hypersensitivity to hot/cold

Dentinal hypersensitivity has been considered as a result of exposed dentin. However, it is clear that the symptom of sensitivity to hot/cold is present also in the absence of exposed dentin. It has also been demonstrated that the symptom of sensitivity to hot/cold can be relieved by occlusal adjustment in the form of Immediate Complete Anterior Guidance Development (ICAGD). It can be applied to a number of symptoms including hypersensitivity to hot/cold. The objective of ICAGD is the elimination of all posterior contacts during lateral excursions (Yiannios, Kerstein & Radke, 2017), as the reduction of group function occlusion can also reduce hypersensitivity.

In cases where the dentin is exposed various chemicals (with or without cavitation) have been used to plug the tubules and reduce the sensitivity (Vyas, et al, 2017; Bakri, et al, 2017; Sauro, et al, 2016; Yu, et al, 2016; Xie, Wei, Li & Zhou, 2016). Thus, it is apparent that hypersensitivity may result from at least two different conditions that can trigger it and/or perpetuate it.

Adjusting TMD appliances (orthotics/splints)

Splint/orthotic adjustment is mainly done for the comfort of the patient and after complaints are lodged by the patient. It is not that common to consider the functionality of an appliance, even those that are intended to be worn 24/7 and while eating. Of course, there are a number of different appliances and each has its distinct purpose.

The anterior deprogrammer appliance

The anterior deprogrammer is primarily intended to reduce the activity of the temporalis muscles in clenchers and bruxers by only contacting with the central incisors. (Yustin, Neff, Rieger & Hurst, 1993; Landry, Rompré, Manzini, Guitard, de Grandmont & Lavigne, 2006). The reduced contacts have less of a suppression effect on the hyperactivity of other elevator muscles. It does establish a new more open vertical dimension but usually does not establish a new antero-posterior or lateral relationship between the mandible and the maxilla, as it usually permits the mandible to go anywhere horizontally.

It is usually a lower splint that snaps on to the lower incisors and there is very little adjustment needed. It is just large enough to maintain contact with at least one maxillary incisor during any lateral or anterior excursion.

The Sears Pivot splint

Sears (Kilpatrick, 1991) originally conceived of the pivot splint for the purpose of joint distraction for a patient with painful TMJ involvement. It is a lower full arch splint that contacts the maxillary arch in only two points bilaterally at about the first or second molars. It is used to disengage the occlusion from the intercuspal position and also to change the pattern of muscle activity. This is also referred to as muscle de-programming. The concept was first developed in the 1950s and its use has been variable over the intervening years as TMD treatment concepts have evolved. The main type of occlusal adjustment for a Sears Pivot would be to adjust the forces for bilateral equality in a clench. A modification of the Sears Pivot was designed to treat the patient with an anterior open bite (Garcia, 2001).

Anterior Repositioning Appliance (ARP)

Anterior repositioning appliances were designed to reposition the mandible forward just enough to recapture and retain a displaced disk between the condyle and the eminence (Owen III, 1989). It can be either a mandibular or a maxillary appliance, but the design of the mechanics is quite different. The appliance is often successful in recapturing a displaced disk when the condition is relatively acute but much less so with chronic disk displacement conditions. One predictable failure occurs when the patient is “weaned off” of the appliance, since the disk usually returns to the displaced condition thereafter. If the successful recapture position is maintained with orthodontic or prosthodontic treatment, then the chance of a permanent recapture is enhanced, but if the disk displacement includes a significant medio-lateral component, then the likelihood of a permanent recapture is reduced (Summer & Westesson, 1997). This is because any medio-lateral aspect of displacement usually indicates more damage to the lateral disk attachment.

An ARP is usually made with a relatively normal occlusal morphology, especially if one is making a mandibular appliance. In the case of a full arch functional appliance, the objectives of adjustment are the same as for a natural dentition (Davis, 1996). The forces are set to be equal left and right and heavier on the premolars and molars than on the anterior teeth. It does require extra effort to provide a functional occlusion on an appliance, but it does avoid the removal of the appliance to eat. ICAGD can be applied to the appliance to further refine it for good function (Kerstein, 1995; Kerstein & Radke, 2017).

The Mandibular Orthopedic Repositioning Appliance (MORA)

The MORA is a neuromuscular appliance that is designed to placate the masticatory musculature (Pertes, Attanosio, Cinotti & Balbo, 1989). It is a full coverage, usually mandibular appliance that realigns the mandible to the maxilla in a three-dimensional way (with 6 degrees of freedom) to a new position where the muscles are better able to provide normal function. The objective is to relax the musculature and to maintain relaxation. Since the appliance includes full occlusal contact the morphology is important and the adjustment of it analogous to that of a natural dentition. Although appliances do not usually duplicate a natural dentition precisely, the closer they match it, the more functional they can be. A rational of the appliance is to create a temporarily improved relationship that can be made permanent either orthodontically or with fine prosthetic treatment (Simmons III, 2002). The application of ICAGD is also appropriate for this appliance.

Michigan Splint (upper flat plane)

The maxillary flat plane Michigan Splint is one of the most utilized designs popularized by Ash & Ramfjord at the University of Michigan dental school (Carossa, Di Bari, Lombardi & Preti, 1990). Theoretically, the design disengages the existing occlusion and allows the patient's mandible to go anywhere within the horizontal plane of the appliance. The fact that it provides absolute horizontal freedom can be a step too far for many TMD patients.

In a natural dentition there is a "Home Plate," which is the intercuspal position. This Home Plate is a type of security blanket that is used to provide feedback from the occlusion to the CNS, telling it where to chew and the most stable position for swallowing. During normal chewing the mandible approaches the intercuspal position repeatedly to within a fraction of a millimeter without the teeth ever touching (See chapter 2: EGN). When Home Plate is entirely missing, the CNS is constantly searching for it. Of course, the patient can take the appliance out while chewing, but that defeats one of the primary objectives of disengaging the occlusion.

The Michigan Splint is not a repositioning splint even though the vertical is certainly changed. It is considered more of a palliative appliance for temporary relief of pain rather than a corrective appliance for a malocclusion. The assumption is that it will be removed as soon as (or if) the pain subsides. As such the adjustment of it is limited to evenly distributing the contact forces around the arch. ICAGD cannot be applied as there are no anterior cupids available to engage.

Specialty Appliances (Apnea, nighttime, etc.)

Night appliances are generally concerned with control of some aspect of a patient's physiology. A Sleep Apnea appliance, designed to enhance breathing at night, is not a functional appliance and does not need to allow the patient to chew. An anti-bruxing appliance is intended to prevent nocturnal bruxing, clenching and/or grinding of the teeth during sleep. An orthodontic retainer may be worn only at night or more often, but it is not a functional appliance and shouldn't interfere with mastication. The Myofunctional Therapy

Appliance is aimed at retraining the tongue and may or may not alter occlusion.

If an appliance is made to simulate a natural dental occlusion, it can be adjusted just as well. If the purpose of the appliance is not to simulate an occlusion, but for some other purpose, then any adjustment will be limited to the characteristics of that appliance and done more for patient comfort than for function.

Disclusion Time Reduction (DTR)

Disclusion time is the time it takes to make a lateral excursion and disclude the posterior teeth (assuming that is possible). The T-Scan is used to measure the disclusion time as a diagnostic procedure and then as a means to know which teeth need to be adjusted to reduce the disclusion time. This process is referred to as the Immediate Complete Anterior Guidance Development (ICAGD) and is a technique used to essentially create a cuspid protected occlusion (Kerstein, 1991). Note: The appendix includes a detailed discussion of the process of ICAGD.

Lateral excursions with light contact of the teeth are used to detect which teeth are in contact during the left & right excursions. The occlusion is most problematic when the molars and/or premolars rub during the lateral excursions. Historically, this is referred to as Group Function Occlusion. What has not been realized by most practitioners is that a lateral excursion is equivalent to chewing backwards. The pathway is normally the same one used for chewing, but it is the opposite direction to chewing. Consequently, any interferences to lateral excursions are also the same interferences to normal chewing function.

It has been demonstrated that by removing the interferences to lateral excursions, measurable improvements in function can be detected; 1) reductions in the overall amount of muscle activity, 2) reduced variability, 3) a more normal average chewing pattern shape, 4) a reduction in tooth contacts during chewing and 5) a smoother motion during chewing (Kerstein & Radke, 2017; Kerstein & Radke, 2012). Although there is apparently not a single universal occlusal arrangement that is best and/or that is required to allow function, the ability to close without any interference into occlusion is a very important factor in efficient and comfortable mastication.

Summary

For more than 30 years the T-Scan has been actively improved incrementally. However, the institutional bias against occlusion as a very important dental consideration started about the same time as the first version of T-Scan. While the early versions of T-Scan lacked consistency and durability, they introduced a totally new concept, that of measuring the timing and force of tooth contacts.

Early detractors were mainly those who were convinced that they could read the force of a contact from the paper marks (some still do) and therefore they did not need any new technology. Recently, the impossibility of that result has been clearly demonstrated (Kerstein & Radke, 2014; Sutter, 2018). When clinicians have been tested for their accuracy of recognizing the most forceful or least forceful contacts, their accuracy has been statistically no better than chance.

Differences have been shown between groups of TMD patients and control subjects in the center of force location, the relative distribution of forces around the arches and in the asymmetry of the contact forces, which have been correlated with depression and anxiety (Ferrato, Falisi, Ierardo, Polimeni & Di Paolo, 2017; Dzingutė, Pileičikienė, Baltrušaitytė & Skirbutis, 2017; Jivnani, Tripathi, Shanker, Singh, Agrawal & Singhal, 2017). However, each patient is an individual with a unique occlusal condition. The great value of the T-Scan is its ability to evaluate occlusion and precisely detect contacts that are interfering with masticatory function. The bottom line is: **It is no longer necessary to guess if and or where to adjust a mal-occlusion.**

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Key Words and Definitions

Center of force: The center of the total force as applied between the arches, which ideally falls on the frontal midline and between the 2nd bicuspid and first molar.

Disclusion Time: The amount of time required to move laterally from the maximum intercuspal position with the teeth in light contact until the posterior teeth are out of occlusion.

Disclusion Time Reduction (DTR): The process of adjusting the occlusion, also referred to by the terms of Immediate Complete Anterior Guidance Development, which is analogous to Cuspid Rise or Cuspid Protected Occlusion. The removal of any posterior (premolar or molar) contacts during lateral excursions.

GERD: Gastroesophageal Reflex Disease

Lateral Excursion: Starting from the intercuspal position the patient moves the jaw laterally (left or right) on command keeping the teeth in light contact. The purpose is to see if any of the posterior teeth remain in contact for more than a fraction of a second. The complete sequence should be completed within 0.5 seconds and the posterior teeth should disclude immediately.

Multibite: The patient produces 3 clenching bites in close succession to establish the consistency of the closures.

NCCL: Non-carious cervical lesions

Occlusion Time: The time from the onset of occlusal contact until the total tooth force reaches about 75 to 85 % of maximum (A to B in the force graph).

Relative Force: The percentage of the total force applied to each tooth. This is also applied to the anterior Vs posterior segments and can also be by quadrant.

Sensels: The sensitive points on the T-Scan wafer that are equivalent to the pixels on a digital image screen.

End Notes

1. The history of the T-Scan development is only based upon the remembered events since the 1980s of Mr. John C. Radke. It is possible that some memories have faded enough to be slightly less than perfectly accurate. However, the general sequence of events is probably reliable.

2. All of the graphic data illustrations are taken from the T-Scan program, version 9.1 or version 10.0 with the exception of Table 1, which was used with the express permission of the Journal of Advanced Dental Technologies & Techniques.

3. Mr. Radke is the current chairman of the board of BioResearch Associates, Inc., a distributor of the T-Scan. He has been involved in the invention and in the research and development of many biometric instruments since the January 1972. He has never received any form of compensation of any kind from Tekscan, Inc. The information presented in this chapter are the facts and the opinions of Mr. Radke and not necessarily those of Tekscan, Inc.

Appendix to chapter 4 (Some tips on T-Scan Operation)

The 2-D, 3D and Force graphs

The 2 -D graph shows where the contacts are on the teeth, but only if you have registered the arch properly. That is done by adjusting the central incisor width. It defaults to 8.5 mm. Larger or smaller teeth will affect the positions of all of the teeth around the arch in relation to the contacts. Teeth 8 & 9 are always going to be O. K., but make sure 2 ad 15 appear in the correct locations. If not correctly registered, adjust the incisor width until they are. Also, be sure to indicate any teeth missing or implants. This can be done before or after a recording is made but should definitely be done before analysis and treatment is rendered.

Center of Force

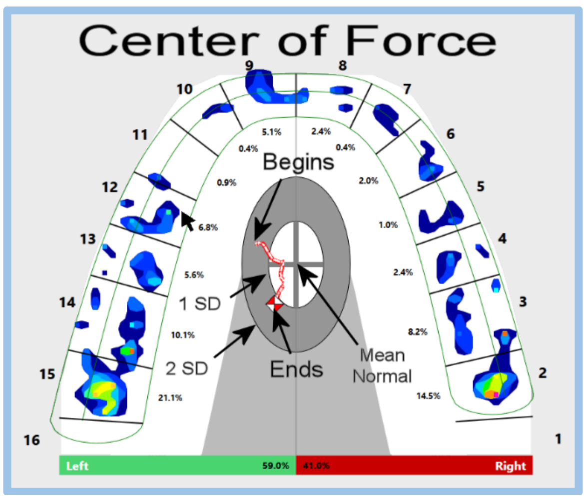

Figure 1. A 2-D graph showing the center of force (in red) from the onset of contact to the maximum force applied. SD = standard deviation. 2 SD = 95% of normal (asymptomatic) population.

If there are no visible bright colors (yellow, red, magenta) the sensitivity is probably set too low. If there are a lot of magenta colors visible, then the sensitivity is set too high. The sensitivity setting is easier to see on the 3-D graph.

There is a percentage indicated next to each tooth. Assuming you have registered the arch correctly, the percentages indicate the relative force on each tooth. If there is only one contact on a tooth, the force percentage also indicates that one contact.

The 3D Graph

The 3 D graph is easier to see the various levels of force at a glance, especially when setting the sensitivity. One to a maximum of 3 Magenta pillars is an ideal setting at maximum force.

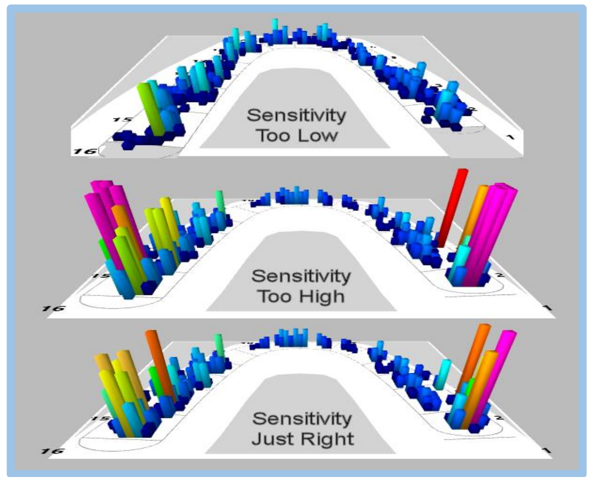

Figure 2. An accurate setting of the sensitivity is important to maximize the resolution. In the 3-D view it is easy to see the level and adjust it.

The Force and Timing Graph

To see the timing of the forces the Force Graph is handy. It shows the left, right and total forces.

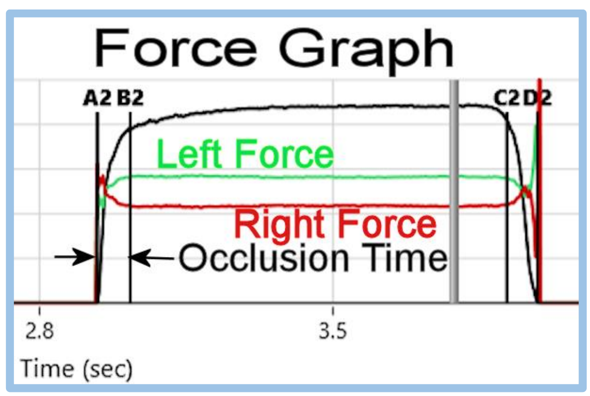

Figure 3. A is the onset of contact, B is the time of maximum intercuspation at 75 to 85 % of the maximum force and A to B is considered the "Occlusion Time." C is the onset of the release of force and D is the end of force. (A2 refers to the second clench in a Multibite sequence.

Implementing ICAGD

When adjusting the occlusion to reduce the long disclusion time, the Force Graph is used. C is set manually at the point where the left (green) and right (red) lines begin to diverge. For a left excursion the end point (D) is set where the (red) Right force has reduced to zero. See Figure 4.

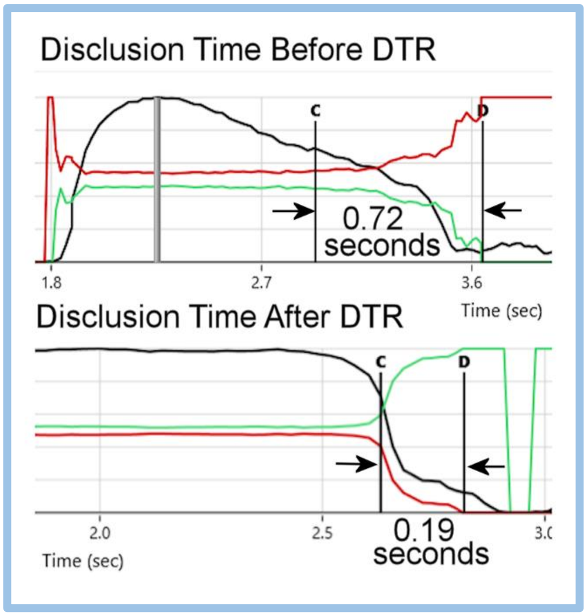

Figure 4. For disclusion time reduction it is very important that the C and D lines are correct. It is advisable to set them manually to avoid any error from the automatic placements by the program.

The process of applying the ICAGD treatment technique involves recording the disclusion time of the patient. This requires the patient to bite into the T-Scan Wafer fully and then slide into lateral excursion. The "Center of Force" in Figure 5 indicates that the initial contact was anterior and then moved into the molar regions bilaterally. The distribution of force was 46.9 % left and 53.1 % right (not too bad), but the forces are heaviest on the 2nd molars and the right central incisor.

In Figure 6 a similar pattern is seen post treatment but with a more even distribution of forces around the arches. The Center of Force has not changed significantly, but the forces are spread around with less on any one tooth. The left side shows 52.6 % and the right side 47.4 % of the total of the forces. Using the same sensitivity, the heights of the 3D bars were lower after this treatment.

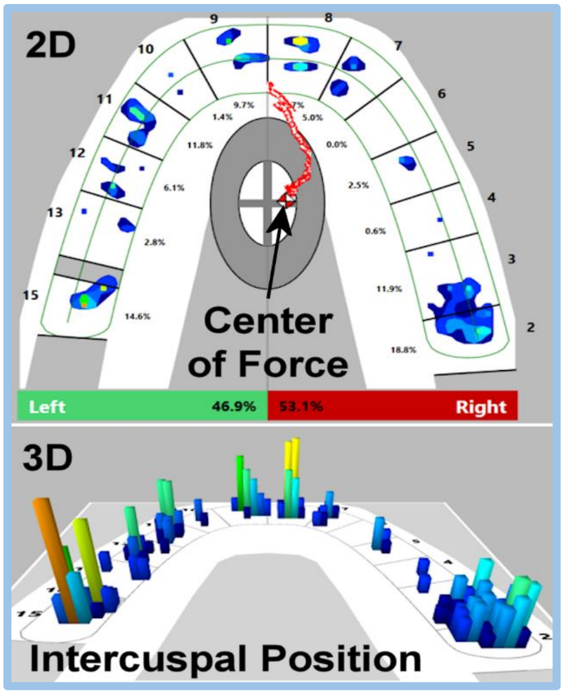

Figure 5. Prior to treatment the patient bites into the wafer at the intercuspal position. In this image the initial contact was anterior, but quickly moved to the most distal molars. (folding removed)

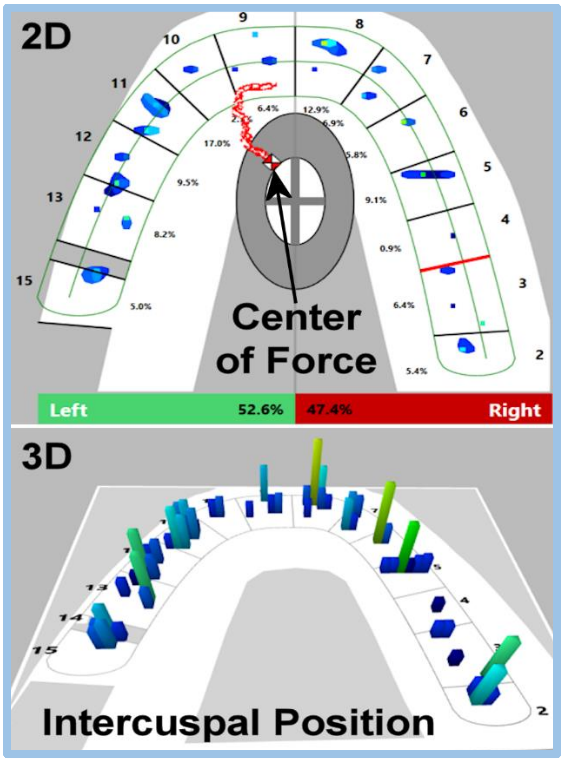

Figure 6. After DTR the patient bites again into the intercuspal position, this time with a more even distribution of forces. (folding removed)

The Lateral Excursion for ICAGD

When the lateral excursion is performed it is ideal if the Center of Force moves to the ipsilateral cuspid and the posterior teeth are disengaged.

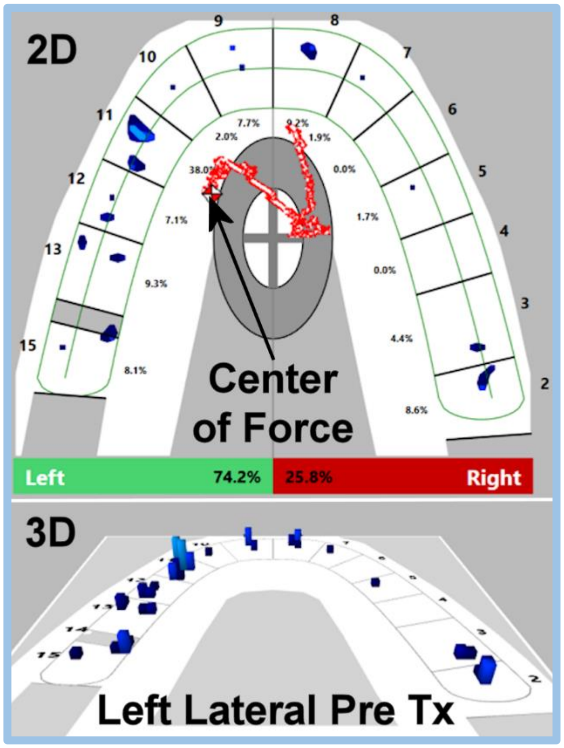

Figure 7. In the pre-treatment record the Center of Force never makes it to the cuspid as there are numerous working posterior contacts, some anterior contacts, and a couple of non-working posterior contacts too.

Figure 7 shows the non-cuspid contacting areas on the teeth that need to be adjusted to remove the interfering contacts. Compared to the pre-treatment record the post treatment pattern in Figure 8 appears much improved with much of the excursive resistance removed.

To see how the posterior occlusal interferences are affecting the muscles it is possible to record the EMG activity simultaneously. A software LINK is available that synchronizes the data. In Figure 9 the T-Scan time graph is shown with the bilateral muscle activity from the masseter and temporalis muscles. The ipsilateral temporalis is actively producing the lateral excursion and is therefore expected to be contracting somewhat.

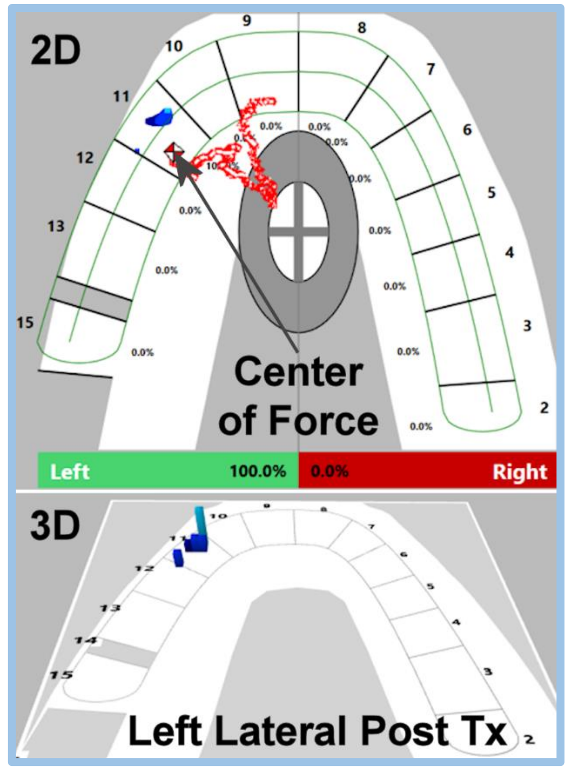

Figure 8. After DTR the picture is much improved although not perfect. The squiggly appearance of the Center of Force indicator as it moves towards the lateral reveals that some, probably light contacts still exist in the pathway of the excursion.

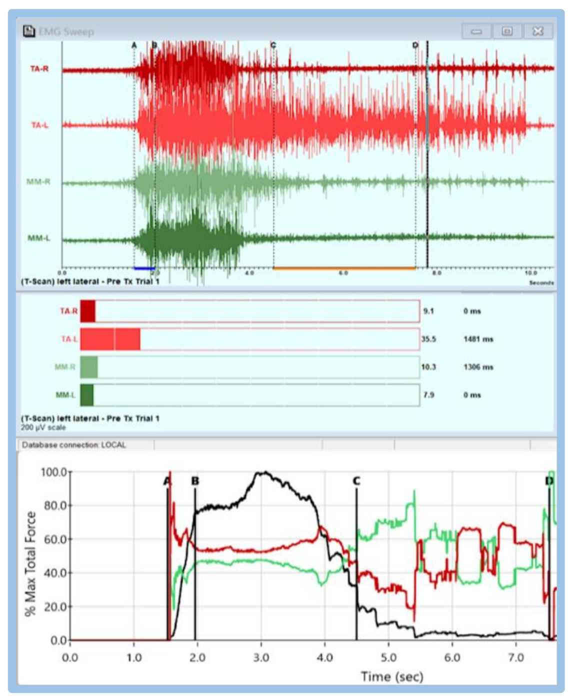

Figure 9. EMG activity and Timeline pre-treatment

However, it takes very little activity to move the mandible without any resistance. In Figure 9 the time from C to D is about 3 seconds. That is 2.5 seconds longer than normal, indicating the patient is struggling to produce the lateral excursion. Note the erratic appearance of the left (green) and right (red) force levels during the excursion. It appears that the patient is moving from contact to contact. In Figure 10 below that pattern is vastly different.

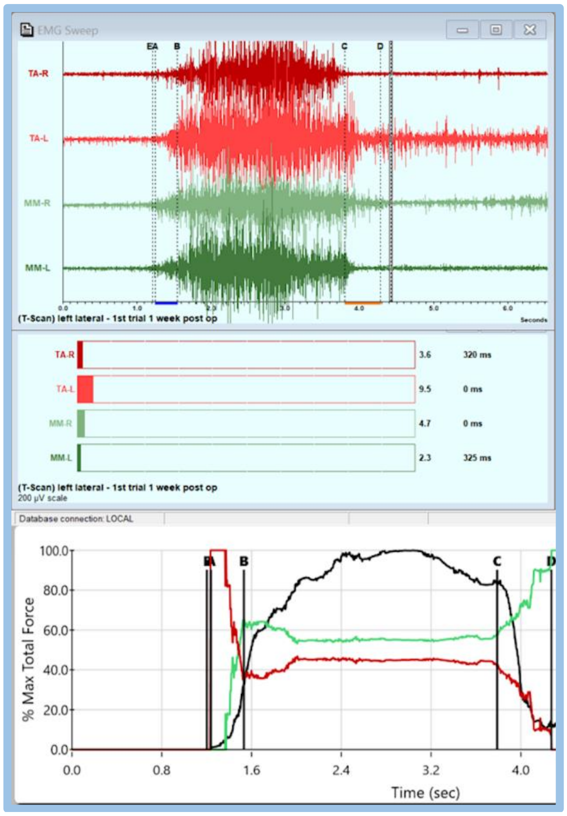

Figure 10. Post treatment the pattern changes rather dramatically, both for the time line and for the EMG activity. The time from C to D is now only 0.5 seconds and the EMG levels are much reduced.

Looking at the timeline in Figure 10, notice how much smoother the graph appears, how quickly the mandible moves from C to D. Compared to Figure 9 the EMG activity is greatly reduced as well, especially the activity of the ipsilateral temporalis. Since the posterior teeth are not rubbing as much during the excursion there is less resistance to the movement and less effort is required to complete the movement.

Can T-Scan be used to treat all TMD?

For some strange reason dentists have for decades sought the *"The One Treatment"* that can be applied to all TMD patients. Inasmuch as TMD encompasses at least 40 distinct conditions, and since many patients exhibit more than one, it is simply not realistic to imagine that one treatment for all TMD patients is possible.

When screening patients for possible ICAGD it is necessary to consider the status of the TMJs, any possible odontogenic conditions, the presence of myopathy, neuropathy, possible orthopedic mal-relationships and the arthritides. Only a portion, but a significant portion, of the total prevalence of TMD is related to just occlusal interferences. In general, patients with primary, un-adapted or poorly adapted TMJ internal derangements will not be resolved only by occlusal adjustment, but even a TMD patient burdened with substantial non-occlusal disorders and/or diseases can still benefit from an improved ability to masticate. The application of DTR has been shown to improve masticatory function, which makes the downside of applying DTR rather minimal.

Summary

Malocclusion is rather commonly associated with painful muscular symptoms of TMD that are referred to as an occluso-muscle disorder (OMD). However, TMD is also very often a combination of unoptimized conditions within the patient. It is not usually necessary to optimize everything that is less than ideal, only to reduce the malfunctions back to within the individual's adaptive capacity. The application of DTR is often sufficient just to accomplish that, thereby reducing the symptoms to an acceptable level for the patient. However, no treatment is ever absolutely permanent or final with respect to the masticatory system.