ADT&T
Advanced Dental Technologies & Techniques

Sutter BA, Thumati P, Thumati RP, Radke J. Meniere's Disease Patients Treated with Disclusion Time Reduction (DTR): Masticatory Function Revealed from EMG and EGN (Part 2 of 4). *Adv Dent Tech*. Published online August 15, 2023.

Temporomandibular Disorders

Meniere's Disease Patients Treated with Disclusion Time Reduction (DTR): Masticatory Function Revealed from EMG and EGN (Part 2 of 4)

Ben A. Sutter, DMD[1a], Prafulla Thumati, MDS, PhD[2], Roshan P. Thumati, MDS[3], John Radke, BM, MBA[4] [b]

[1] Private Practice, [2] Director Oro-facial Pain Clinic, Rajarajeswari Dental College and Hospital, Bengaluru, India, , [3] Orthodontics and Dentofacial Orthopedics, RajaRajeshwari Dental College and Hospital, Bengaluru, India, , [4] Chairman of the board, BioResearch Associates, Inc.

Keywords: Menière's Disease, Endolymphatic Hydrops, Immediate Complete Anterior Guidance Development Coronoplasty, Vertigo, Tinnitus, Disclusion Time Reduction, Labyrinthectomy, Vestibular Neurectomy, Endolymphatic Sac Surgery, Intratympanic Steroid Injections

Advanced Dental Technologies & Techniques

Abstract

Objectives

The objectives of this research were: 1) to compare the changes in PHQ-15 scores to the changes in the EMG and EGN chewing data 2) to compare the progression of pain intensity, frequency of symptoms and functional restriction scores to the progression of EMG and EGN measurements pre and post DTR Therapy. The null hypothesis was stomatognathic dysfunction plays no role in Meniere's Disease symptoms. The alternative hypothesis is that the dysfunction of the masticatory system does contribute to the symptoms associated with Meniere's Disease (MD).

Methods

Two different TMD treatment centers recruited 86 patients previously diagnosed with Meniere's Disease and referred by otolaryngologists using MRI. Inclusion required patients to answer questions regarding their symptom intensity, duration and frequency prior to treatment, 3 weeks post treatment and 3 – 4 months post treatment. Muscular and movement dysfunction were recorded at each time point. All Subjects were selectively treated with DTR via Immediate Complete Anterior Guidance Development coronoplasty. Student's t test was applied to the measured data, Wilcoxon Signed Rank test to the survey data. ($a = 0.05$)

Results

As indicated in Part I, four months after treatment the group's symptom intensity, duration and frequency of painful symptoms declined from pre-treatment medians between 5 to 9 (0 to 10 scale) to post-treatment values that were all less than 1.2 ($p < 0.00001$). Significant improvements were revealed in this dysfunctional group's mean chewing motion parameters, including reduced mean jerkiness and the dysfunctional masticatory muscle activities ($p < 0.05$).

Conclusions

The pre-treatment symptom scores were significantly reduced after physical treatments and continued to significantly reduce at 3 – 4 months after the end of physical treatment. The concurrent significant improvements in the masticatory timing, motion and muscle function support a physical etiology for Stomatognathic Dysfunction tied to these subjects' Bite Force and Bite Timing.

Clinical Significance

A clinical diagnosis of Meniere's Disease should be considered as an indication to routinely evaluate a patient for the presence of temporomandibular disorders (TMDs).

a Principle investigator

b Statistician

Note: This data set will be used in four different articles. Part I evaluated the effect of DTR on symptom resolution. This one analyzed EMG and EGN Masticatory function, the third will analyze Temporomandibular Joint Vibration changes, and the fourth part TMD vs MD and Somatic Symptom Disorders with PHQ-15 scores and functional scores, all in attempt to shed new light on MD etiology.

INTRODUCTION

Much has been published on Menière's Disease (MD), which was first identified and characterized by Prosper Menière over 150 years ago.[1] Today diagnosing and treating MD among clinicians remains challenging[2-7] and as a result MD continues to be a catchall for vertigo of unknown origin. Endolymph Hydrops (EH) remains a histologic finding in most but not all MD cases, while the MD diagnosis remains purely a clinical diagnosis. There is no agreement on the etiology of MD as it relates to Endolymphatic Hydrops.[6, 8-12] Current considerations is that EH is a histological sign of the disease rather than a causative etiology.[6,9-16] Some research has attempted to induce MD by increasing the endolymph production or limiting its reabsorption through medications. Those models did produce EH but did not produce MD symptoms.[17-19] Even if EH does have some influence over vertigo, it does not adequately explain the persistence of tinnitus, ear fullness, or hearing loss progression.

In an attempt to bring clarity to the ENT community a few consensus statements and reviews have been published.[6-12] The American Academy of Otolaryngology – Head and Neck Surgery published a clinical practice guideline on MD[6] with the stated purpose: "To maximize treatment, it is important to clinically distinguish MD from other independent causes of vertigo that may mimic MD and present with hearing loss, tinnitus and aural fullness."[6] Even though TMD has been known to present with this same presentation of symptoms,[20-31] the AAO-HNS fails to make any mention of the similarities in inner ear symptom presentation between TMD and MD anywhere in its 55-page guideline. This is counter intuitive if the aim of their guideline is to distinguish MD from other causes that could mimic MD symptomology. See Appendix summary for TMD vs MD Symptomology Comparison.

It is well known that James Costen, an otolaryngologist, read his initial findings of inner ear and sinus symptoms related to disturbed function of the TMJs in 1934 before the Texas Ophthalmological and Otolaryngological Society and was later pubished.[32] More recent authors have subsequently labeled his work *Costen's Syndrome*, which eventually became known as TMJ Syndrome and currently is labelled as Temporomandibular Disorders (TMD) or Temporomandibular Joint Disorders (TMJD).

From the 1990s into the 2000s research spearheaded by Bjorne et al began establishing a link between TMD and MD.[22,33-35] Treating TMD patients that were also diagnosed with MD resulted in complete resolution of the MD (and TMD) symptoms or decreased to a level they no longer were life altering for the patient. The symptom resolution was long term as indicated by 3-year and 6-year follow up studies.[33,34] Treatments rendered were occlusal adjustments, TMD splint therapy, cervical spine therapy and physical therapy.[22,31-35] It is impossible to know if one therapy is responsible for the therapeutic outcome or if it was a result of a synergistic effect of all of the therapies being used in conjunction with each other.

A couple of case studies have shown occlusal adjustments to be highly effective in the treatment of patients that have a diagnosis of Meniere's Disease.[36,37] The present study only used bite revision therapy via DTR in an attempt to bring symptom relief in a cohort of 86 subjects with a diagnosis of MD. DTR has previously demonstrated effective and long-term symptom resolution in patients diagnosed with TMD and Orofacial pain.[38-47]

OBJECTIVES

The objectives of this cohort study were: 1) to perform DTR Therapy on patients with an otolaryngologist's diagnosis of MD who presented with long Disclusion Times and/or a bite force imbalance, including high excursive muscle activity levels, all of which could promote MD symptomology and 2) to reveal any significant changes in masticatory function as indicated by EMG and EGN data. The Null hypothesis: DTR does not affect MD symptomology.

METHODS

Eighty-six patients previously diagnosed with Meniere's Disease (MD) by otolaryngologists were evaluated in two different dental practices that offered specialized Disclusion Time Reduction (DTR) services for patients with temporomandibular disorders (TMD). All patients had prior magnetic resonance imaging (MRI), which ruled out auditory neuromas. All 86 patients had received various unsuccessful treatments from dietary restrictions such as avoidance of salt and caffeine to inner ear gentamycin and stem cell injections. None of these treatment options had brought about relief for an extended length of time. While patients were not selected at random, they were consecutive patients referred to each of the two dental offices. In one general dentistry office located in Eugene, Oregon, 32 consecutive patients diagnosed with MD were treated successively. All who walked in and met the inclusion criteria were evaluated and treated. The second dental office was located within the RajaRajeshwari Dental College, Dept of Orofacial Pain under Rajiv Gandhi University of Health Sciences in Bengaluru India. The Dept of Ear Nose and Throat at RajaRajeshwari Medical College was contacted to refer patients (52) that met the inclusion criteria to the second dental office to be evaluated and treated with DTR. An IRB approval was requested and obtained for a retrospective cohort study #BIRB/99Z/2022.

The Inclusion criteria were:

- A MD diagnosis from an otolaryngologist with MRI that definitively ruled out an auditory neuroma.
- The existence of ongoing MD symptomatic episodes
- 28 teeth with symmetrically missing teeth (if one molar was missing on the left side, then one had to be missing on the right side)
- Near normal occlusal relations with molars and premolars in contact during the right and left excursions
- Angles Class I and Class III occlusal relations, with guiding anterior teeth that were either in contact, or near to contact.
- Patients that had been previously treated for MD but had not received symptom resolution.
- Patients 18 years of age or older

The Exclusion criteria were:

- Severe Class II malocclusions
- Anterior open bite where anterior guidance contact could not be achieved.
- A previous history of TMJ trauma
- The presence of unstable Temporomandibular Joint internal derangements verified by CBCT and/or Joint Vibration Analysis (JVA).
- Patients that had been previously treated with MD therapy and received symptom resolution.
- Patients who had undergone prior TMD therapy, including prior occlusal adjustment treatment.

Informed consent was obtained from each patient for undergoing the DTR coronoplasty, and for collecting MD symptom severity, frequency and duration data from questionnaires as well as masticatory evaluation. Oral health histories were also obtained where the whole participant group reported experiencing MD symptoms. All the group reported fullness in the ear, tinnitus, vertigo (including drop attacks) and hearing loss in at least one ear. The group also reported many TMD symptoms with moderate to severe frequencies and intensities. The TMD symptoms seemed to be randomly distributed and no correlation could be made with any one symptom to the MD symptoms. DTR therapy is discussed and reviewed in Part 1 of this series and will not be repeated here.

Every participant underwent a pre-DTR right and left excursive Disclusion Time/muscle hyperactivity evaluation with the synchronized T-Scan 10/BioEMG III technologies (Tekscan Inc., S. Boston, MA USA; Bioresearch Assoc., Inc. Milwaukee, WI, USA). **See Figure 1A**. This allowed accurate EMG and disclusion times to be recorded prior to the therapy. All subjects, at the same appointments, had masticatory function assessed with combined electrognathology (EGN) (Bioresearch Assoc., Inc. Milwaukee, WI, USA) and electromyography (EMG) recordings of gum chewing.[48-58] **See Figure 1B**. This was done to evaluate; 1) the function of the TMJ and 2) the quality of mastication of a soft bolus (gum) using BioPAK software (BioResearch Associates, Inc. Milwaukee, WI USA).[59-61] The recordings were repeated at each initial appointment and mastication was evaluated at pre-treatment and 3 to 4 months follow-up appointments.[62] The analysis of the masticatory function data is reported in this Part II.

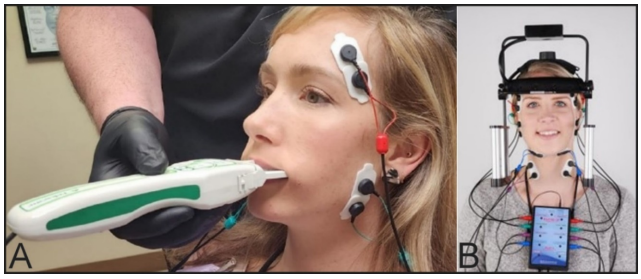

Figure 1. A) T-Scan 10 digital occlusal analyzer recording bite force and time synchronized with BioEMG III measuring the temporalis (red leads) and masseter muscles (blue-green leads) in real time. B) The BioEMG III records the muscle activity and JT-3D magnetic incisor-point tracker records the motions of masticatory function.

A total of 86 patients participated, 47 males and 39 females at a ratio of 1.2:1. The mean age was 50.8 (+/- 18.1) years with a range from 17 to 80 years and a median of 55. While the age distribution was not a normal one, it does represent a range of likely candidates. Patients were selected sequentially as they agreed to participate.

The Wilcoxon Signed Rank test was applied to the survey data of MD symptoms to detect significant improvements. Student's paired t test was applied to the measured intra-patient EGN and EMG data, making each subject his or her own control. Consequently, no separate control group was enlisted because the purpose was simply to correlate the masticatory function data with the MD symptom levels.

RESULTS

The previous report (Part I) revealed that the presence of ear fullness, vertigo and tinnitus were significantly reduced up to 3 – 4 months after DTR treatments ($p < 0.05$). This report (Part II) is focused on significant improvements in masticatory movement and muscle function towards the expected norms for these parameters.

Where the timing of the chewing motion was significantly changed post-treatment after DTR, the changes were towards mean normal values. For left-sided gum-chewing the mean Opening Time and mean Cycle Time were significantly shortened ($p < 0.05$) with a trend towards a shorter Occlusal Time as well ($p < 0.10$). For right-sided gum-chewing the mean Opening Time, mean Closing Time and Mean Cycle Time were significantly shortened ($p < 0.05$), while the Occlusal Time was significantly lengthened ($p < 0.05$). The pre-treatment cycle times were long, but the post treatment mean cycle times were within the expected normal range of 0.50 to 0.8 seconds. **See Table 1.**

The means of the left and right gum-chewing vertical Turning Points (TP) increased significantly towards the mean normal value (16 mm) after DTR treatment ($p < 0.05$). The mean of the left gum-chewing antero-posterior Turning Point increased significantly ($p < 0.05$), but the increase in the right-sided gum-chewing antero-posterior Turning Point did not reach significance ($p > 0.05$). For left-sided

Table 1. Changes in the mean timings of the left and right gum-chewing motion from before to immediately after DTR treatment.

Chewing Timing - Left	Opening Time (milli-seconds)	Closing Time (milli-seconds)	Occlusal Time (milli-seconds)	Cycle Time (milli-seconds)
Pre-treatment Mean	384	214	383	1062
Standard Deviation	236	77.4	819	1201
Student's t test p <	0.00000	0.2082 ns	0.0945 T	0.0054
Post-Treatment Mean	121	222	268	727
Standard Deviation	238	77.3	153	245
Notes: **T = trend towards significance,** ns = not significant				
Chewing Timing - Right	**Opening Time (msec)**	**Closing Time (msec)**	**Occlusal Time (msec)**	**Cycle Time (msec)**
Pre-treatment Mean	510	411	246	1294
Standard Deviation	728	895	103	1889
Student's t test p <	0.00023	0.0032	0.0143	0.00164
Post-Treatment Mean	247	182	287	713
Standard Deviation	147	67	141	258
Note: msec = milliseconds				

Table 2. Changes in the mean left and right Turning Points (TP) of gum-chewing after DTR treatment.

Left Maximum Opening Point	Turning Point Vertical (mm)	Turning Point Ant-Post (mm)	Turning Point Lateral (mm)
Pre-treatment Mean	11.5	2.9	0.6
Standard Deviation	4.7	7.0	2.9
Student's t test p <	0.00023	0.0081	0.0554 T
Post-Treatment Mean	13.3	5.1	1.1
Standard Deviation	4.4	7.1	2.8
Note: mm = millimeters			
Right Maximum Opening Point	**Turning Point Vertical (mm)**	**Turning Point Ant-Post (mm)**	**Turning Point Lateral (mm)**
Pre-treatment Mean	10.8	3.7	2.1
Standard Deviation	4.5	4.7	2.8
Student's t test p <	0.0041	0.1266 ns	0.0645 T
Post-Treatment Mean	12.3	4.5	2.7
Standard Deviation	4.3	4.9	2.8
Note: mm = millimeters, **T = Trend,** ns = not significant			

gum-chewing the mean lateral Turning Point significantly decreased ($p < 0.05$), but the right-sided gum chewing lateral Turning Point only trended toward a significant change ($p < 0.10$). **See Table 2.**

The mean Terminal Chewing Position (TCP) is the distance between the arches at the point of maximum bolus crush. The amount of crush is dependent on the nature of the bolus. Gum usually crushes to a very thin bolus. Although the bolus was crushed more in all three dimensions during left gum-chewing, only the left chewing Lateral TCP change was significant ($p < 0.05$) post-treatment with DTR. **See Table 3.**

Table 3. Changes in the left and right mean Terminal Chewing Positions (TCP) with gum-chewing from before to after DTR Treatment.

Left Terminal Chewing Position	Terminal Chewing Position Vert (mm)	Terminal Chewing Position A/P (mm)	Terminal Chewing Position Lat (mm)
Pre-treatment Mean	1.11	0.8	0.6
Standard Deviation	1.76	2.3	1.7
Student's t test p <	0.2571 ns	0.3105 ns	0.0034
Post-Treatment Mean	0.87	0.6	0.0
Standard Deviation	0.98	1.8	1.6
Note: mm = millimeters, , ns = not significant, Vert = Vertical			
Right Terminal Chewing Position	**Terminal Chewing Position Vert (mm)**	**Terminal Chewing Position A-P (mm)**	**Terminal Chewing Position Lat (mm)**
Pre-treatment Mean	1.15	0.47	0.40
Standard Deviation	1.60	1.52	1.57
Student's t test p <	0.4429 ns	0.4581 ns	0.1291 ns
Post-Treatment Mean	1.25	0.45	0.63
Standard Deviation	1.36	1.11	1.43
Note: A-P = antero-posterior, Lat. = Lateral			

Table 4. The Maximum Lateral Width of the frontal chewing pattern and the chewing velocities.

Maximum Width and Velocity - Left	Maximum Lateral Width (mm)	Maximum Opening Velocity (mm/sec.)	Maximum Closing Velocity (mm/sec.)
Pre-treatment Mean	4.5	90.1	95.1
Standard Deviation	1.9	48.9	38.9
Student's t test p <	0.0983 T	0.0000035	0.0061
Post-Treatment Mean	5.0	115.3	108.7
Standard Deviation	2.5	54.1	39.0
T = Trend, mm = millimeters, mm/sec. = millimeters/second			
Maximum Width and Velocity-Right	**Maximum Lateral Width (mm)**	**Maximum Opening Velocity (mm/sec.)**	**Maximum Closing Velocity (mm/sec.)**
Pre-treatment Mean	4.7	100.0	105.0
Standard Deviation	1.9	59.7	58.7
Student's t test p <	0.01722	0.00071	0.08785 T
Post-Treatment Mean	4.2	122.0	113.0
Standard Deviation	1.7	49.7	46.4
Note: mm = millimeters, mm/sec. = millimeters/second			

Maximum lateral width trended towards an increase for left-sided gum-chewing ($p < 0.10$) but decreased significantly for right-sided gum-chewing ($p < 0.05$). For Left-sided gum-chewing both the opening and the closing velocities increased significantly ($p < 0.05$). For right-sided gum-chewing the opening velocity increased significantly ($p < 0.05$) while the closing velocity only showed a trend towards increasing ($p < 0.10$). **See Table 4.**

Frontal opening angles did not change significantly for either left or right gum-chewing. However, frontal closing angles were reduced significantly to smaller angles for both left and right gum-chewing ($p < 0.05$). Jerkiness during opening was reduced significantly for both left and right gum-chewing ($p < 0.05$). Jerkiness was significantly reduced during closing for right gum-chewing ($p < 0.05$), but not for left gum-chewing. **See Table 5.**

The overall effort of chewing is indicated by the mean levels of EMG activity in the 4 superficial elevator muscles measured from each given subject. All four muscles significantly reduced their activity after DTR treatment, both for left-sided gum-chewing and for right-sided gum-chewing ($p < 0.05$). **See Table 6.**

Table 5. Significant reductions in the frontal plane closing angles and opening jerkiness during left-sided and right-sided gum-chewing. Lesser changes in the frontal opening angles and closing jerkiness.

Left Chewing Frontal Angles and Jerkiness	Frontal Opening Angle (degrees)	Frontal Closing Angle (degrees)	Opening Jerk (mm/sec^3)	Closing Jerk (mm/sec^3)
Pre-treatment Mean	87.8	73.7	6.0	3.2
Standard Deviation	23.6	20.8	3.7	1.1
Student's t test p <	**0.0983 T**	**0.0102**	**0.00000001**	0.2876 ns
Post-Treatment Mean	91.8	68.0	3.6	3.2
Standard Deviation	26.3	21.3	1.8	1.2
T = Trend, mm/sec^3 = Jerk (rate of change of acceleration), ns = not significant				
Frontal Angles and Jerkiness	**Frontal Opening Angle (degrees)**	**Frontal Closing Angle (degrees)**	**Opening Jerk (mm/sec^3)**	**Closing Jerk (mm/sec^3)**
Pre-treatment Mean	99.0	73.0	7.4	7.4
Standard Deviation	30.5	25.9	10.8	16.3
Student's t test p <	0.1243 ns	**0.0089**	**0.0008**	**0.0049**
Post-Treatment Mean	95.0	65.0	3.7	2.7
Standard Deviation	21.7	18.0	2.3	1.0
Note: ns = not significant				

The coefficient of variation (the standard deviation divided by the mean) is an indication of the relative variability. Among this group of subjects, significant reductions were seen in the right-sided gum-chewing relative variability after their DTR treatments ($p < 0.05$). For the left-sided gum-chewing only the non-working temporalis varied significantly less ($p < 0.05$), although a trend was present in the reductions in the CV for non-working masseter and working temporalis muscles activities ($p < 0.10$). **See Table 7.**

The Peak Amplitude in microvolts is the highest level of contraction during the chewing cycle. Three of eight mean values revealed significant reductions in peak amplitude ($p < 0.050$, three reductions showed trends towards significant reductions ($p < 0.10$) and two showed non-significant reductions. **See Table 8.**

The significant decreases in mean cycle times were repeated for all four muscles in both left and right gum-chewing with shortened mean times from the onset of opening to the peak amplitude of each muscle's contraction ($p < 0.05$). **See Table 9.**

Significantly shorter times from peak EMG amplitude to the end of closure (onset of occlusion time) was recorded in all four muscles during right-sided gum-chewing ($p < 0.05$). However, only the working temporalis' reduction in time achieved significance during left-sided gum-chewing ($p < 0.05$). **See Table 10.**

DISCUSSION

The results of this study corroborate the prior case report's that observed MD symptom reductions following a measured occlusal adjustment therapy (DTR).[36,37] EGN (jaw motion) and EMG (temporalis and masseter muscles) were recorded bilaterally and simultaneously and analyzed together. **Figure 2.** Shows an example of the pre-treatment Average Chewing Pattern (ACP) along with the timings, Turning Point, Terminal Chewing Position, velocities, angles and Jerkiness. The ACP was very small, slow and highly variable, all indications of masticatory dysfunction. In **Figure 3** the right and left temporalis muscle bursts (in red) and R and L masseter muscle bursts (in green) during gum chewing pretreatment. The right temporalis was providing a disproportionate amount of effort compared to a normal muscle balance. Notice there was a delay in all the peaks of muscle contraction (red numbers) until after the end of closure. This indicates hesitancy, in retrospect, most likely due to muscles that were firing carefully to avoid occlusal interferences.

In **Figure 4** the size of the ACP was increased dramatically (see Turning Point) and the velocities were increased towards normal values. The other numerical values were only changed slightly. In **Figure 5**, the same ACC data immediately following DTR therapy, the balance between the muscles was improved and only the masseter muscles peaked slightly delayed after the end of closure (red numbers in Figure 4). Synergy of muscle contraction was improved, and the ACC curve composite appears closer to a "normal" non-MD sufferer's muscle pattern.

In **Figure 6**, one month post DTR, the closing time, occlusal time and cycle time were reduced and most importantly, the ACP shapes (red and cyan) were matching the mean normal shapes (black) very closely. Note: The overall shapes of the APCs are more indicative of normality than any single parameter. There was some opening interruption in the velocity, probably a left TMJ issue, which retained a retarded opening time and contributed to a longer than ideal cycle time. **Figure 7** reveals the same ACC values one month post treatment. Only the right (working) masseter

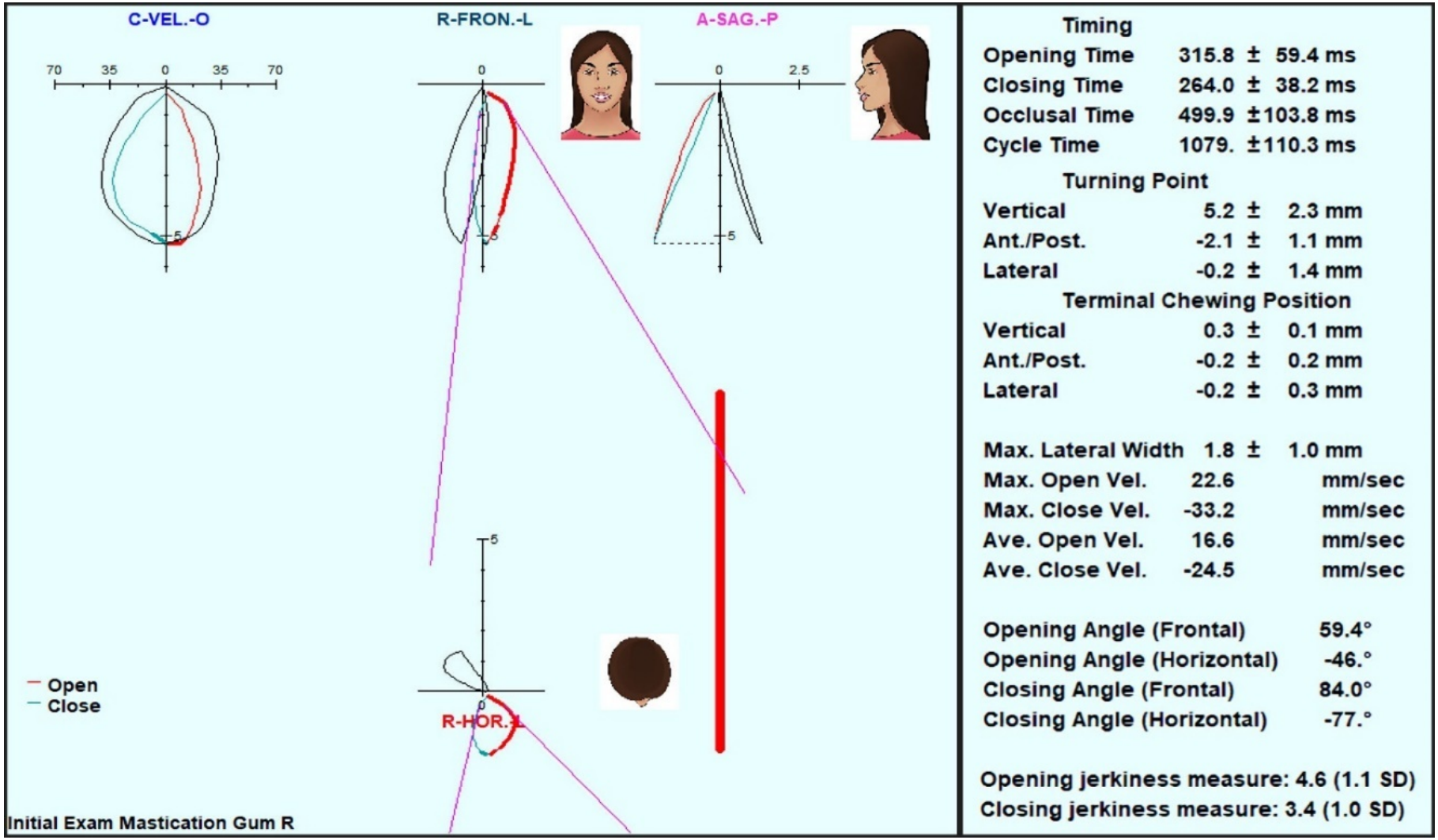

Figure 2. One sample patient's Average Chewing Pattern (ACP) pre-treatment with numerical values. Vertical Turning Point is very small, (should be 10 – 22 mm), lateral Turning Point is on the wrong side, the terminal chewing position is too far from MIP (limited crushing of the bolus), opening and closing velocities are very slow and jerkiness is too high for opening and marginally adapted for closing. Black lines are the mean normal patterns scaled to the patient's vertical dimension, red lines = opening, cyan lines = closing.

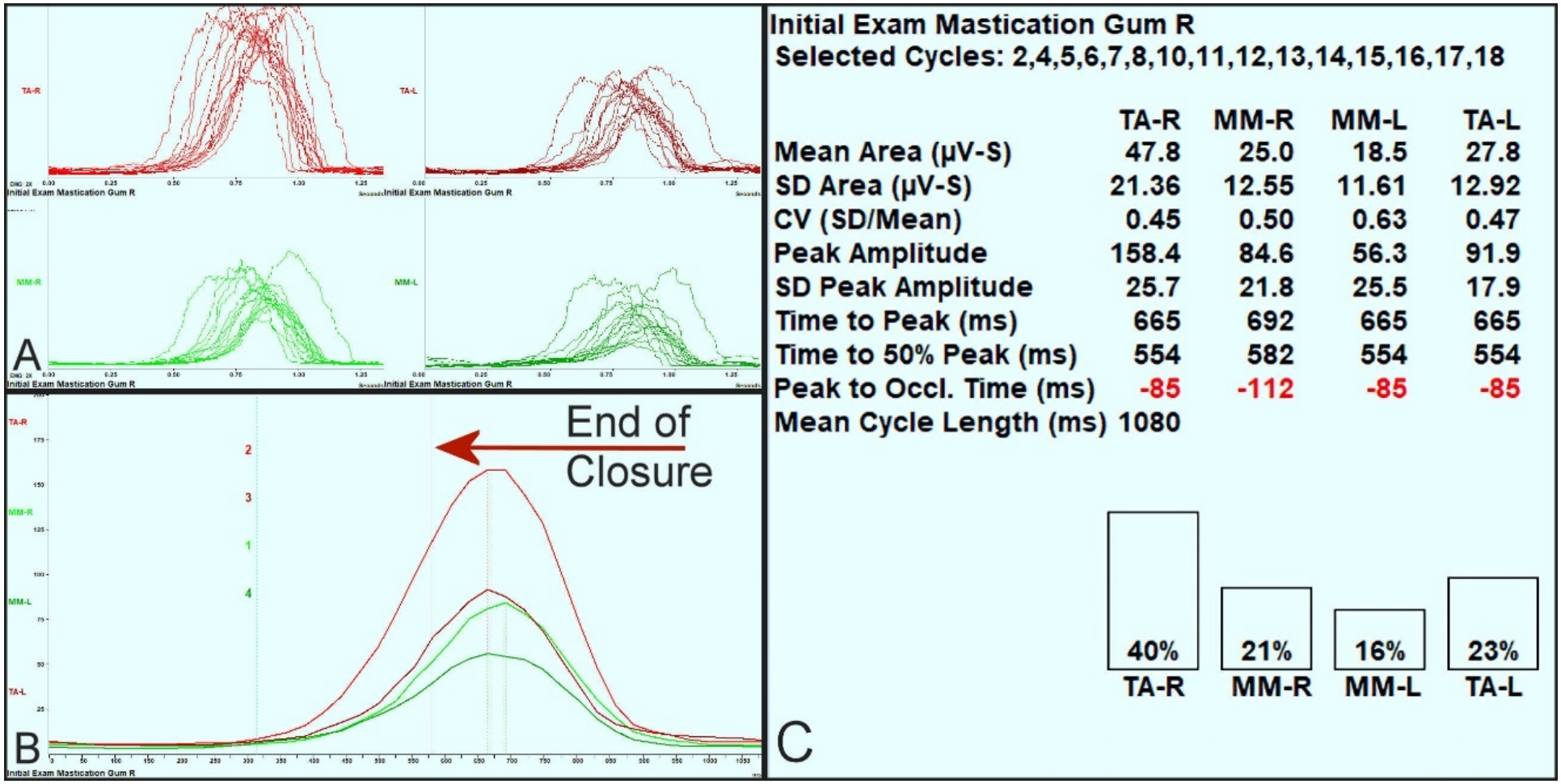

Figure 3. A) The same patient's highly variable firing pattern of elevator muscles cycle to cycle shows poor coordination (gum chewing right side). B) The Average Chewing Cycle (ACC) of this patient's activity shows the peaking of all 4 muscles was delayed abnormally past the end of closure. C) Masseter inhibition, high variability (CV > 0.3), long cycle time (1.08 seconds) and delayed closing peaks (after the end of closure) all reveal dysfunction.

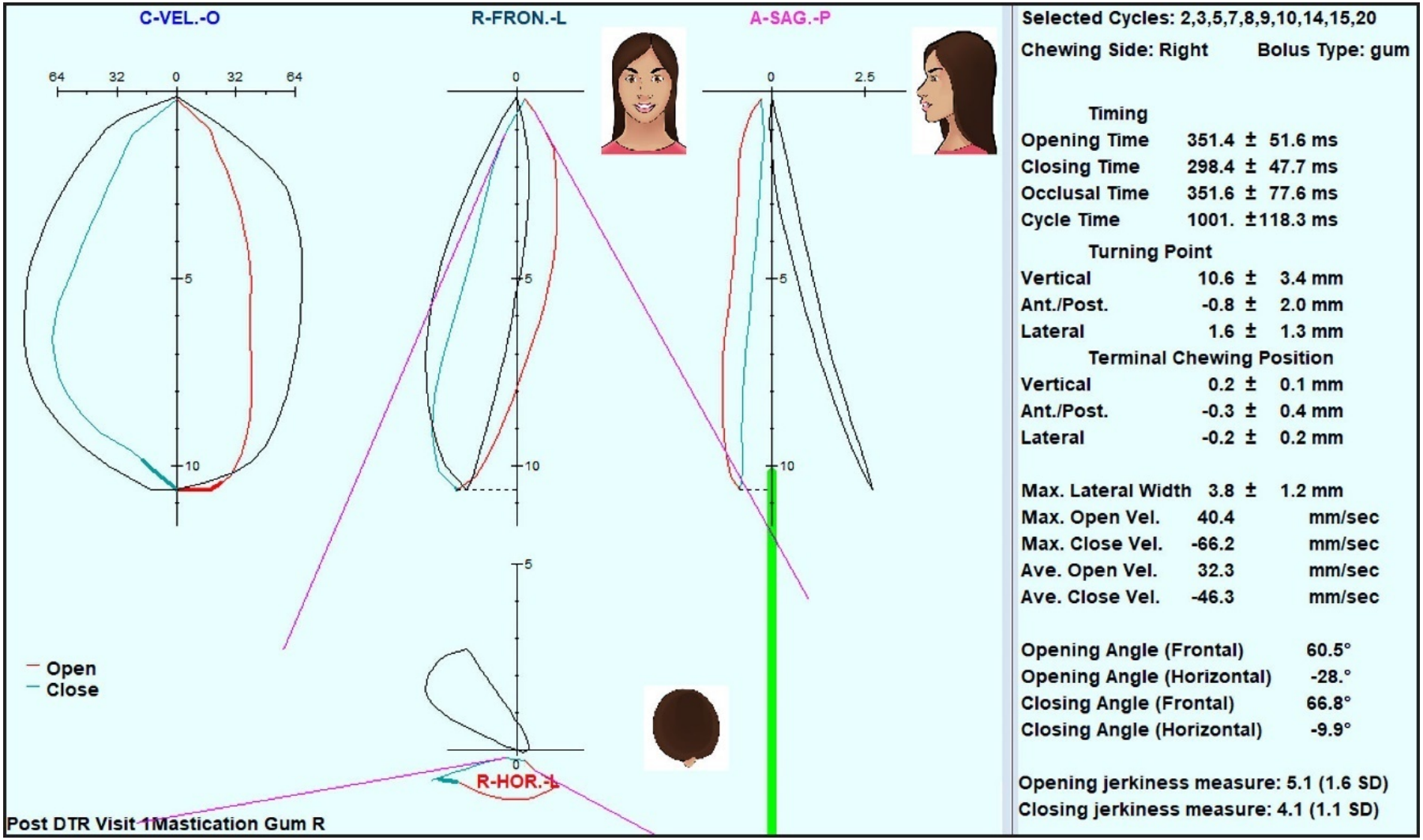

Figure 4. Average Chewing Pattern immediately following DTR treatment showing cycle time and occlusal time have shortened, vertical Turning Point has increased into normal range, lateral Turning Point has been corrected to the right side, and the opening and closing velocities have increased.

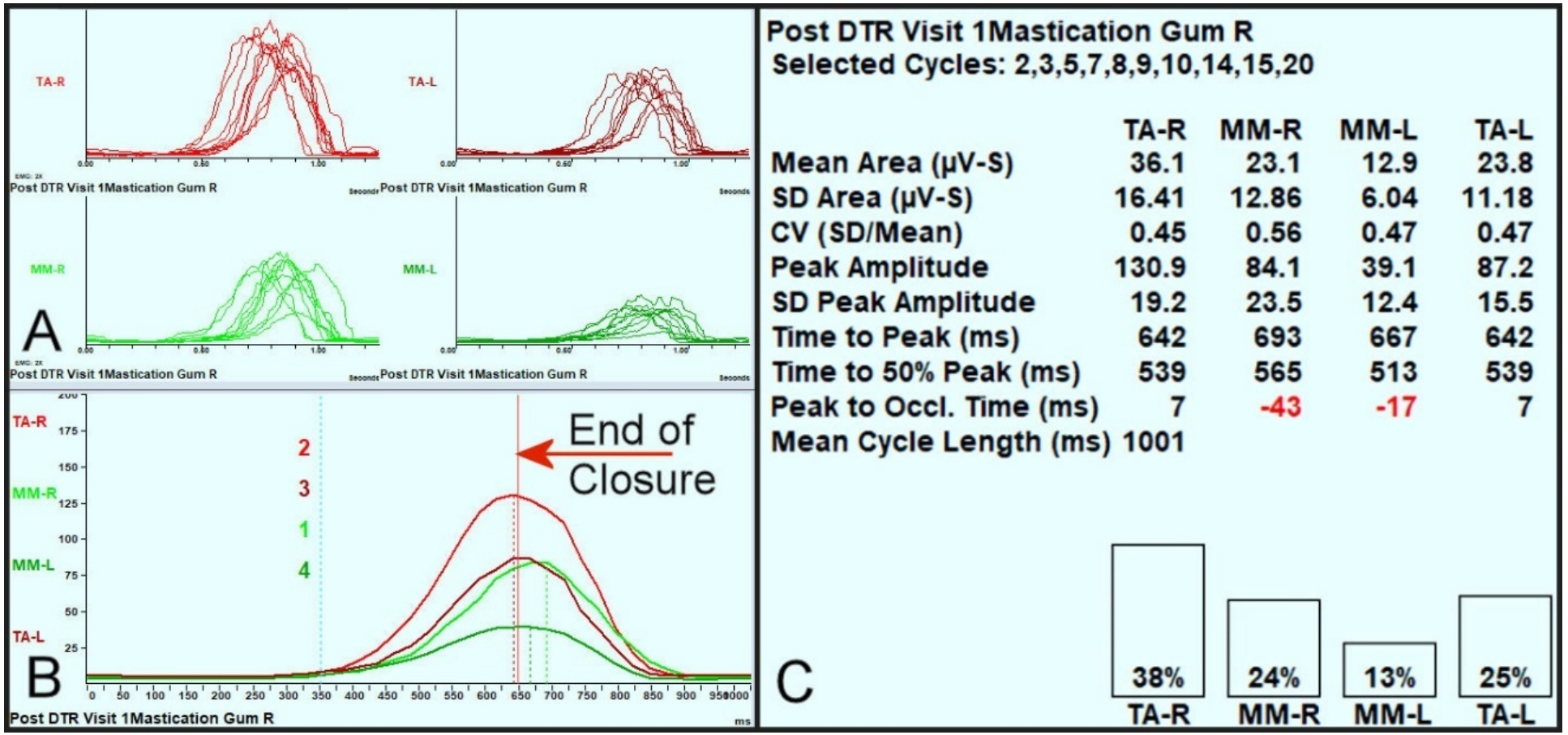

Figure 5. A) Immediately following DTR therapy the standard deviation of each muscle's activity was reduced, B) the peaking of muscle activity occurred closer to the end of closure and C) increased working masseter activity along with reduced working temporalis activity.

Table 6. Left-sided and right-sided gum-chewing effort as indicated by integrated EMG activity of elevator muscles was reduced after treatment.

Left Chewing Overall Effort	Mean Area (mV-seconds)			
	TA-R (NW)	MM-R (NW)	MM-L (W)	TA-L (W)
Mean Activity Pre-treatment	34.7	34.2	40.5	54
Standard Deviation	52.99	44.03	42.74	106.8
Paired T-Test p <	0.0324	0.0230	0.00031	0.0300
Mean Activity Post-treatment	26.9	26.9	22.6	31.4
Standard Deviation	32.11	41.78	16.56	28.61
	Combining all Muscles			
Mean Activity Pre-treatment	40.9 microvolts			
Student's t test p <	0.00001			
Mean Activity Post-treatment	25.9 microvolts			
NW = non-working, W = working, mV = microvolt, ns = not significant				
Right Chewing Overall Effort	Mean Area (mV-seconds)			
	TA-R (W)	MM-R (W)	MM-L (NW)	TA-L (NW)
Mean Activity Pre-treatment	43.0	60.2	42.8	72.9
Standard Deviation	50.97	114.3	69.8	143
Paired T-Test p <	0.0494	0.0428	0.0091	0.0070
Mean Activity Post-treatment	31.8	37.1	24.7	35.9
Standard Deviation	38.31	52.1	25.8	61.6
	Combining all Muscles			
Mean Activity Pre-treatment	54.7 microvolts			
Student's t test p <	0.0000353			
Mean Activity Post-treatment	32.3 microvolts			
NW = non-working, W = working, mV = microvolt, ns = not significant				

peak was still delayed to slightly after the end of closure (by 11 milliseconds) and the other three muscles peaked together prior to the end of closure. The amount of effort of the non-working masseter, an adaptation factor, and its variability were both reduced.

MOVEMENTS

Opening time delays are often caused by TMJ internal derangements, less often by occlusal interferences. Closing delays are more likely due to hesitancy, avoidance of occlusal interferences and uncertainty with respect to the Intercuspal position. For the left-sided gum-chewing (Table 1) the only timing factor of the group that did not show any reduction was the mean closing time. However, the pre-treatment mean closing time already fell within normal limits.[53-55,59] The pre-treatment mean Opening Time was greater than the mean normal value but was reduced to within normal limits after treatment. For right-sided gum-chewing all 4 timing parameters were reduced by treatment to values within normal limits.[53-55,59] Dysfunction slows down masticatory function such that any improvement in function shortens the timings.

The Turning Point (TP) is the point at the furthest opening where the transition occurs from opening to closing. The mean normal for vertical dimension is 16 mm with a range of 10 to 22 mm. The mean Vertical and Antero-posterior Turning Points increased significantly towards the mean normal value for left-sided gum-chewing, but the increase in the A/P Turning Point for right-sided gum-chewing did not achieve significance.[53-55,59] The left gum-chewing lateral turning point showed a trend towards an increase ($p < 0.10$), while the right gum-chewing lateral turning point was already close to the mean normal value (2.3 mm) prior to treatment and changed little post-treatment. **See Table 2.**

The Terminal Chewing Position (TCP) indicates the extent of the bolus crush with smaller numbers indicating a more crushed bolus. Although the left-sided Terminal Chewing Position decreased in all three dimensions, only the lateral dimension decreased significantly. No significant changes were found in any dimension of the Terminal Chewing Position for right-sided gum-chewing. Since gum is a very soft bolus easily crushed, this result was not surprising and it means that as a group, most of these subjects were muscularly accommodating to their existing malocclusions. **See Table 3.**

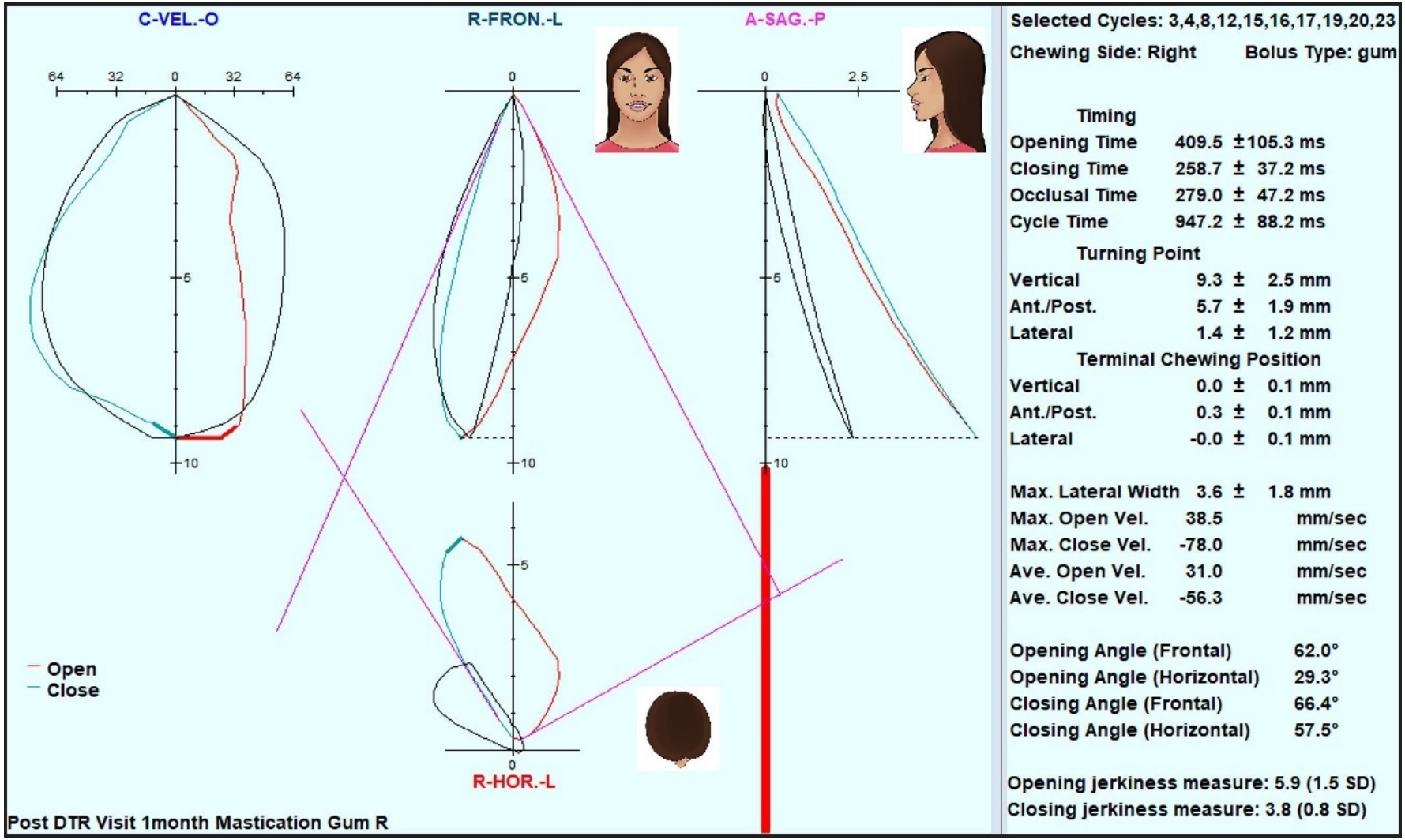

Figure 6. Further reduction in the cycle time towards the normal range with reduced. The Average Chewing Pattern shapes are closer to matching the mean normal patterns. The Terminal Chewing Position is normalized (very close to MIP). Closing velocity increased toward the normal range.

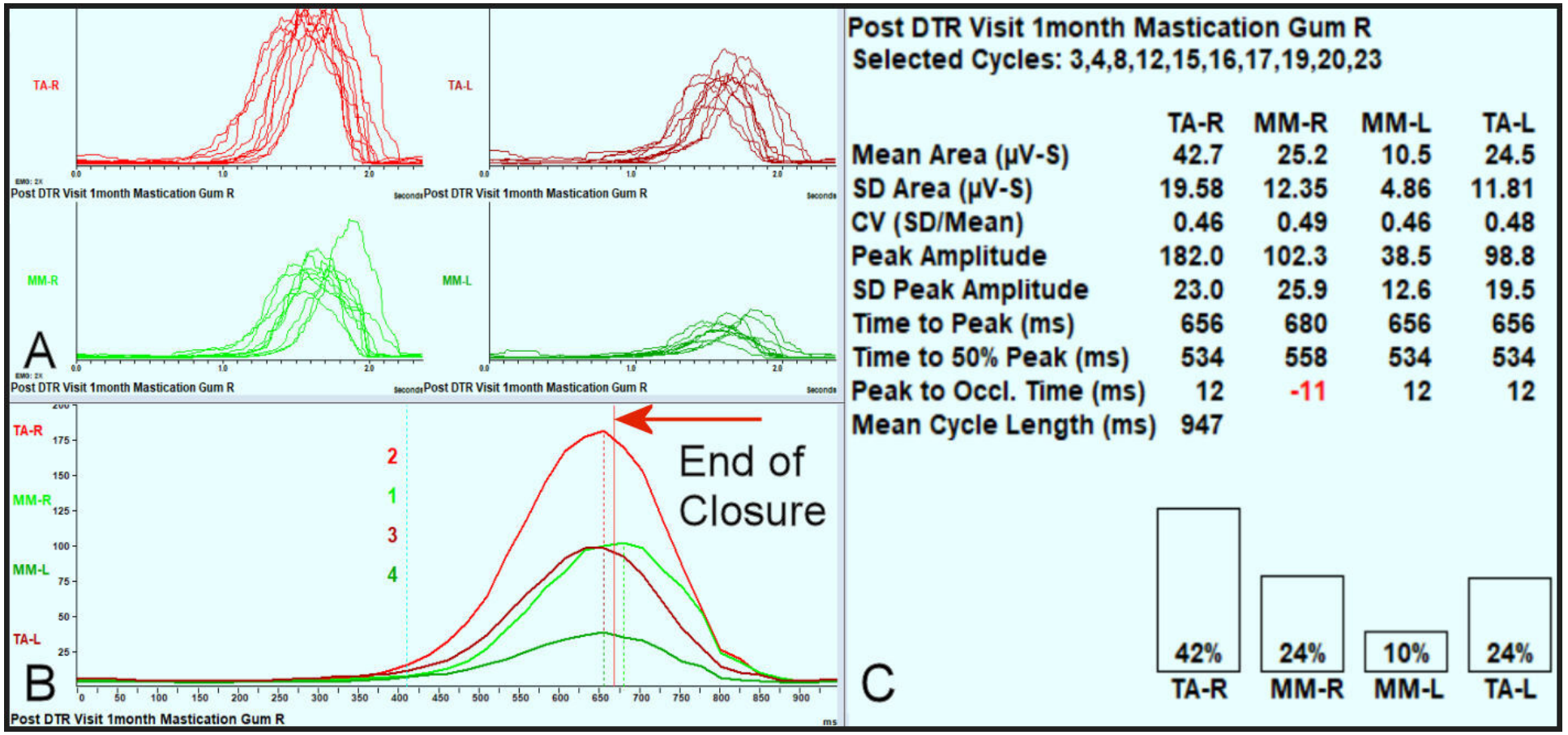

Figure 7. A) Four months post therapy the variability was more consistent between muscles, B) working masseter activity is increased and non-working masseter activity decreased and C) three of four muscles peak their activity before the end of closure.

Table 7. Mean relative chewing variability significantly decreased after DTR treatments.

Left Chewing Gum Variability	Coefficient of Variation			
	TA-R (NW)	MM-R (NW)	MM-L (W)	TA-L (W)
Mean Activity Pre-treatment	0.44	0.40	0.46	0.45
Standard Deviation	0.32	0.22	0.24	0.23
Paired T-Test p <	0.0115	0.0698 T	0.172 ns	0.0971 T
Mean Activity Post-treatment	0.35	0.35	0.42	0.41
Standard Deviation	0.18	0.20	0.20	0.20
	Combining all Muscles			
Average Effort Pre-treatment	0.436			
Student's t test p <	0.00063			
Average Effort Post-treatment	0.383			
NW = non-working side, W = working side, **T = trend**, ns = not significant				
Right Chewing Gum Variability	Coefficient of Variation			
	TA-R (W)	MM-R (W)	MM-L (NW)	TA-L (NW)
Mean Activity Pre-treatment	0.48	0.45	0.43	0.42
Standard Deviation	0.238	0.187	0.184	0.164
Paired T-Test p <	0.00014	0.0001	0.0052	0.00373
Mean Activity Post-treatment	0.36	0.37	0.37	0.36
Standard Deviation	0.202	0.222	0.201	0.195
	Combining all Muscles			
Average Effort Pre-treatment	0.446			
Student's t test p <	0.000001			
Average Effort Post-treatment	0.361			
NW = non-working side, W = working side, **T = trend**, ns = not significant				

The Maximum Lateral Width is the extreme lateral dimension of the frontal chewing pattern. While there was a significant decrease during right-sided gum chewing and a trend towards an increase in left-sided gum-chewing, all four mean values were found to be within normal limits prior to and post treatment.[53-55,59] **See Table 4.** Significant increases in Maximum Opening Velocity were observed post-treatment in both the left and right-sided gum-chewing. The left-sided gum-chewing closing velocity increased significantly, while the right-sided gum-chewing only exhibited a trend towards a significant increase ($p < 0.10$). The mean normal values for opening (≥ 100 mm/second) and closing (≥ 120 mm/second) were nearly all achieved by this group post treatment.

The frontal opening angles did not change significantly for left-sided or right-sided gum chewing because both sides were within normal limits prior to treatment. Significant decreases towards more normal values (less restrictive) for frontal closing angles were found for both left-sided and right-sided gum-chewing. While opening jerkiness decreased significantly for both sides of gum-chewing, the closing jerkiness only decreased significantly for right-sided gum chewing because the left-sided gum-chewing was already within normal limits prior to treatment (3.2). Patients with un-adapted dysfunction tend to close carefully, which often reduces their closing jerkiness to within normal limits. **See Table 5**.

MUSCLE FUNCTION

The overall effort of chewing was significantly reduced for all four muscles after treatment (Bilateral masseter and anterior temporalis). When the need for accommodation to structural issues like malocclusion and/or temporomandibular joint dysfunction is reduced, the muscular effort required to chew is lessened. A simple change like removing pre-mature occlusal contacts, as done in this study, can significantly reduce extra muscular effort, especially from the non-working side muscles. **See Table 6.**

The coefficient of variation (CV) is a relative indicator of variability (the standard deviation divided by the mean). Although variability is expected with good masticatory function, excess variability occurs when dysfunction is present. For right-sided gum-chewing the variability was reduced significantly after treatment for all four muscles. For left-sided gum-chewing the variability decreased but significantly only for the non-working temporalis. The non-working masseter and the working temporalis exhibited a trend towards reduced variability ($p < 0.10$), but not the working masseter. **See Table 7.**

Table 8. Significant decreases were recorded in the Peak Amplitude levels of the EMG activity during maximum bolus crush after DTR treatment. The decreases were greater for left-sided gum-chewing, but also significant for the whole musculature for Right-sided Gum-chewing.

Highest Intensity of Left Chewing	Peak Amplitude (microvolts)			
	TA-R (NW)	MM-R (NW)	MM-L (W)	TA-L (W)
Mean Activity Pre-treatment	93.3	79.5	108.8	135.0
Standard Deviation	93.19	64.23	79.24	145.72
Paired T-Test p <	0.0068	0.0005	0.0350	0.0507 T
Mean Activity Post-treatment	63.5	52.8	80.1	110.4
Standard Deviation	45.15	30.90	52.96	81.84
	Combining all Muscles			
Average Activity Pre-treatment	101.6 microvolts			
Student's t test p <	0.000047			
Average Activity Post-treatment	75.7 microvolts			
NW = non-working side, W = working side, **T = trend**				
Highest Intensity of Right Chewing	Peak Amplitude (microvolts)			
	TA-R (W)	MM-R (W)	MM-L (NW)	TA-L (NW)
Mean Activity Pre-treatment	112.1	114.3	73.4	102.2
Standard Deviation	103.4	109.7	70.6	139.9
Paired T-Test p <	0.0722 T	0.225 ns	0.282 ns	0.0943 T
Mean Activity Post-treatment	94.6	105.1	68.9	79.1
Standard Deviation	76.7	75.5	47.5	85.2
	Combining all Muscles			
Average Activity Pre-treatment	100.5 microvolts			
Student's t test p <	0.0188			
Average Activity Post-treatment	86.9 microvolts			
NW = non-working side, W = working side, **T = trend towards significance**				

The Peak Amplitude represents the highest effort exhibited by the muscle. As the term suggests, it is a momentary level of highest intensity contraction within each cycle. In all muscles under both left and right-sided conditions there were reductions in all mean peak amplitudes. The changes were significant in 3 of the 4 muscles for left-sided gum-chewing, but not for right-sided gum-chewing. Only a trend towards a reduction occurred in both temporalis muscles ($p < 0.10$), but no significant change in the masseter peak contraction levels. See **Table 8**.

Table 9 concurs with Table 1 in that the significantly reduced cycle times post treatment also resulted in significantly reduced times from the onset of opening to the peak of the muscle activity for all 4 muscles and for both left-sided and right-sided gum-chewing.

The time from the peak of muscle activity to the onset of occlusion (end of closure) is normally a positive value meaning the peak occurs prior to the end of closure. Within this group of subjects, the mean values were positive both prior to and post treatment, but with significant reductions for right-sided gum-chewing ($p < 0.05$). For left-sided gum-chewing only the working temporalis timing was significantly reduced ($p < 0.05$). However, the variability was reduced for all muscles and for both chewing sides. **See Table 10.**

SUMMARY OF SIGNIFICANT FINDINGS

Improvements towards normality were seen in all 10 parameters used to evaluate the masticatory function of these Meniere's Disease patients.

1. The mean chewing timings improved towards mean normal values after DTR.
2. The mean vertical turning point increased significantly towards the mean normal.
3. The left-sided gum-chewing mean lateral terminal chewing position (TCP) significantly reduced.
4. The mean opening and closing chewing velocities either increased significantly or showed a trend.
5. The mean frontal closing angles significantly decreased towards more normal (less restrictive) values.
6. The mean EMG chewing activity was significantly reduced for working and non-working muscles.
7. The mean variability in the EMG muscle contraction activity patterns decreased for all muscles.

Table 9. Time from onset of opening to the peak of the EMG activity showed a significant decrease for the four elevator muscles during both left-sided and right-sided gum-chewing.

Left-side Time to Peak Activity	Time to Peak (milliseconds)			
	TA-R (NW)	MM-R (NW)	MM-L (W)	TA-L (W)
Mean Time Pre-treatment	470	479	495	468
Standard Deviation	294.3	231.9	278.9	174.4
Paired T-Test p <	0.01011	0.00683	0.0086	0.00217
Mean Time Post-treatment	396	410	424	414
Standard Deviation	167.9	159.3	153.3	145.2
	Combining all Muscles			
Average Time Pre-treatment	478 milliseconds			
Student's t test p <	0.000001			
Average Time Post-treatment	411 milliseconds			
NW = non-working side, W = working side				
Right-side Time to Peak Activity	Time to Peak (milliseconds)			
	TA-R (W)	MM-R (W)	MM-L (NW)	TA-L (NW)
Mean Time Pre-treatment	554	615	568	615
Standard Deviation	626	937	654	880
Paired T-Test p <	0.0144	0.0311	0.00596	0.0241
Mean Time Post-treatment	414	424	389	427
Standard Deviation	197	176	152	208
	Combining all Muscles			
Average Time Pre-treatment	588 milliseconds			
Student's t test p <	0.000017			
Average Time Post-treatment	413 milliseconds			
NW = non-working side, W = working side				

8. The means of the peaks of EMG activity decreased for all muscles post treatment.
9. Mean time to peak muscle activity was reduced significantly for all muscles and conditions.
10. Time from peak muscle activity to the end of closure appeared to increase for all muscles.

These findings do correlate with MD symptoms improving as the mastication improves and support the findings of others investigating masticatory disfunction.[63-69] We reject the null hypothesis.

LIMITATIONS

The ICAGD treatments via DTR therapy are standardized and have been successfully reported from different practitioners in previous studies.[47,60-62,70-73] This study's primary focus was treatment outcomes. No control subjects were utilized, but rather each subject served as their own control being compared to themselves pre vs post therapy. This was intentional in the study design because denying symptomatic subjects' treatment or giving a placebo for several months carries ethical concerns and are difficult to maintain.

CONCLUSION

Eighty-six subjects with a confirmed diagnosis of Meniere's Disease experienced reductions in frequency, duration and intensity of their MD symptoms following reductions in Disclusion Time and muscle activity via DTR through computer guided coronoplasty (Part 1). This study shows definitively that the pretreatment evaluation of masticatory function (through EGN and EMG) reveals dysfunction. The post therapy mastication data indicates more normalized function after therapy. Although occlusion has been overlooked in most of the medical and dental literature as a possible etiology of MD, the results of this study point to malocclusion, specifically bite force and bite timing, as the etiology for the symptoms in this group of subjects diagnosed with MD. These findings support occlusion as a major contributor to the function and disfunction of the masticatory system thus playing a significant role in symptomology. This includes symptoms such as hearing loss, vertigo, tinnitus and fullness of the ear, which in isolation from other symptoms suggests MD.

Table 10. Timing from the peak of each muscle's activity to the end of closure (beginning of occlusal phase of the chewing cycle). Left-sided gum-chewing showed a significant increase for the whole musculature, but the right-sided Gum-chewing only indicated a trend.

Left Timing from Peak to Occlusion	Peak to Occlusion (milliseconds)			
	TA-R (NW)	MM-R (NW)	MM-L (W)	TA-L (W)
Mean Times Pre-treatment	23.4	29.6	12.8	36.0
Standard Deviation	164.6	122.2	160.1	222.5
Paired T-Test p <	0.145 ns	**0.04701**	**0.04194**	**0.097 T**
Mean Times Post-treatment	47.0	59.5	49.0	47.2
Standard Deviation	115.8	117.7	104.2	109.4
	Combining all Muscles			
Mean Time Pre-treatment	23.1 milliseconds			
Student's t test p <	**0.0021**			
Mean Time Post-treatment	50.7 Milliseconds			
NW = non-working side, W = working side, ns = not significant				
Right Time Peak to Occlusion	Peak to Occlusion (milliseconds)			
	TA-R (W)	MM-R (W)	MM-L (NW)	TA-L (NW)
Mean Times Pre-treatment	46	33	43	24
Standard Deviation	115	116	112	123
Paired T-Test p <	0.143 ns	0.244 ns	0.449 ns	0.236 ns
Mean Times Post-treatment	62.4	43.2	45.0	35.0
Standard Deviation	126	111	97	117
	Combining all Muscles			
Mean Time Pre-treatment	36.6 milliseconds			
Student's t test p <	**0.0898 T**			
Mean Time Post-treatment	46.4 Milliseconds			
NW = non-working side, W = working side				

DECLARATION OF CONFLICTS STATEMENT

Drs. Ben Sutter, Prafulla Thumati, and Roshan Thumati claim no conflict of interest. John Radke is the Chairman of the Board of BioResearch Associates, Inc., the manufacturer of the BioEMG III and a distributor of the T-Scan. He receives no commission or other monetary incentive based upon sales of the T-Scan or the BioEMG III.

FUNDING STATEMENT

No funding from any source was provided to complete this study.

Submitted: June 07, 2023 CDT, Accepted: August 15, 2023 CDT

REFERENCES

1. Méniere P. "Sur une forme de surdité grave dépendant d'une lésion de l'oreille interne" (On a form of severe deafness dependent on a lesion of the inner ear). *Bulletin de l'Académie impériale de médecine*. 1861;26:26241.

2. Perez-Carpena P, Lopez-Escamez JA. Current Understanding and Clinical Management of Meniere's Disease: A Systematic Review. *Semin Neurol*. 2020;40(1):138-150. doi:10.1055/s-0039-3402065

3. Mancini F, Catalani M, Carru M, Monti B. History of Meniere's disease and its clinical presentation. *Otolaryngol Clin North Am*. 2002;35(3):565-580. doi:10.1016/s0030-6665(02)00017-8

4. Oberman BS, Patel VA, Cureoglu S, Isildak H. The aetiopathologies of Ménière's disease: a contemporary review. *Acta Otorhinolaryngol Ital*. 2017;37(4):250-263. doi:10.14639/0392-100x-793

5. Harris JP, Nguyen QT. Meniere's disease: 150 years and still elusive. *Otolaryngol Clin North Am*. 2010;43(5):xiii-xiv. doi:10.1016/j.otc.2010.05.011

6. Basura GJ, Adams ME, Monfared A, et al. Clinical Practice Guideline: Ménière's Disease. *Otolaryngol Head Neck Surg*. 2020;162(S2):S1-S55. doi:10.1177/0194599820909438

7. Hegemann SCA. Menière's disease caused by CGRP - A new hypothesis explaining etiology and pathophysiology. Redirecting Menière's syndrome to Menière's disease. *J Vestib Res*. 2021;31(4):311-314. doi:10.3233/ves-200716

8. Gürkov R, Pyykö I, Zou J, Kentala E. What is Menière's disease? A contemporary re-evaluation of endolymphatic hydrops. *J Neurol*. 2016;263(S1):71-81. doi:10.1007/s00415-015-7930-1

9. Christopher LH, Wilkinson EP. Meniere's disease: Medical management, rationale for vestibular preservation and suggested protocol in medical failure. *Am J Otolaryngol*. 2021;42(1):102817. doi:10.1016/j.amjoto.2020.102817

10. Merchant SN, Adams JC, Nadol JBJr. Pathophysiology of Meniere's syndrome: are symptoms caused by endolymphatic hydrops? *Otol Neurotol*. 2005;26(1):74-81. doi:10.1097/00129492-200501000-00013

11. Morgan DH. Tinnitus of TMJ Origin: A Preliminary Report. *Cranio*. 1992;10(2):124-129. doi:10.1080/08869634.1992.11677900

12. Iwasaki S, Shojaku H, Murofushi T, et al. Diagnostic and therapeutic strategies for Meniere's disease of the Japan Society for Equilibrium Research. *Auris Nasus Larynx*. 2021;48(1):15-22. doi:10.1016/j.anl.2020.10.009

13. Foster CA, Breeze RE. Endolymphatic hydrops in Ménière's disease: cause, consequence, or epiphenomenon? *Otol Neurotol*. 2013;34(7):1210-1214. doi:10.1097/mao.0b013e31829e83df

14. Cureoglu S, da Costa Monsanto R, Paparella MM. Histopathology of Meniere's Disease. *Oper Tech Otolayngol Head Neck Surg*. 2016;27(4):194-204. doi:10.1016/j.otot.2016.10.003

15. Harris JP, Nguyen QT. Meniere's disease: 150 years and still elusive. *Otolaryngol Clin North Am*. 2010;43(5):xiii-xiv. doi:10.1016/j.otc.2010.05.011

16. Lopez-Escamez JA, Carey J, Chung WH, et al. Diagnostic criteria for Menière's disease. *J Vestib Res*. 2015;25(1):1-7. doi:10.3233/ves-150549

17. Takumida M, Akagi N, Anniko M. A new animal model for Ménière's disease. *Acta Otolaryngol*. 2008;128(3):263-271. doi:10.1080/00016480701497436

18. Kumagami H, Loewenheim H, Beitz E, et al. The effect of anti-diuretic hormone on the endolymphatic sac of the inner ear. *Pflugers Arch*. 1998;436(6):970-975. doi:10.1007/s004240050731

19. Feldman AM, Brusilow SW. Effects of cholera toxin on cochlear endolymph production: model for endolymphatic hydrops. *Proc Natl Acad Sci USA*. 1976;73(5):1761-1764. doi:10.1073/pnas.73.5.1761

20. Cooper BC, Kleinberg I. Examination of a Large Patient Population for the Presence of Symptoms and Signs of Temporomandibular Disorders. *Cranio*. 2007;25(2):114-126. doi:10.1179/crn.2007.018

21. Peroz I. Dysfunctions of the stomatognathic system in tinnitus patients compared to controls. *HNO*. 2003;51(7):544-549. doi:10.1007/s00106-002-0750-5

22. Bjorne A, Agerberg G. Craniomandibular disorders in patients with Menière's disease: a controlled study. *J Orofac Pain*. 1996;10(1):28-37.

23. Björne A. Assessment of temporomandibular and cervical spine disorders in tinnitus patients. *Prog Brain Res*. 2007;166:215-219. doi:10.1016/s0079-6123(07)66019-1

24. Gelb H, Gelb ML, Wagner ML. The relationship of tinnitus to craniocervical mandibular disorders. *Cranio*. 1997;15(2):136-143. doi:10.1080/08869634.1997.11746004

25. Ferendiuk E, Zajdel K, Pihut M. Incidence of otolaryngological symptoms in patients with temporomandibular joint dysfunctions. *Biomed Res Int*. 2014;2014(824684):1-5. doi:10.1155/2014/824684

26. Wright EF, Syms CA III, Bifano SL. Tinnitus, dizziness, and nonotologic otalgia improvement through temporomandibular disorder therapy. *Mil Med*. 2000;165(10):733-736. doi:10.1093/milmed/165.10.733

27. Wright EF, Bifano SL. The Relationship between Tinnitus and Temporomandibular Disorder (TMD) Therapy. *Int Tinnitus J*. 1997;3(1):55-61.

28. Di Berardino F, Filipponi E, Schiappadori M, Forti S, Zanetti D, Cesarani A. The occlusal imaging and analysis system by T-scan III in tinnitus patients. *Biomed J*. 2016;39(2):139-144. doi:10.1016/j.bj.2016.04.001

29. Kusdra PM, Stechman-Neto J, de Leão BLC, Martins PFA, de Lacerda ABM, Zeigelboim BS. Relationship between Otological Symptoms and TMD. *Int Tinnitus J*. 2018;22(1):30-34. doi:10.5935/0946-5448.20180005

30. Ramirez Aristeguieta LM, Sandoval Ortiz GP, Ballesteros LE. Theories on otic symptoms in temporomandibular disorders: past and present. *Int J Morphol*. 2005;23(2):141-156. doi:10.4067/s0717-95022005000200009

31. Stechman-Neto J, Porporatti AL, Porto de Toledo I, et al. Effect of temporomandibular disorder therapy on otologic signs and symptoms: a systematic review. *J Oral Rehabil*. 2016;43(6):468-479. doi:10.1111/joor.12380

32. Costen JB. A syndrome of ear and sinus symptoms dependent upon disturbed function of the temporomandibular joint. *Ann Otol Rhinol Laryngol*. 1934;43(1):1-15. doi:10.1177/000348943404300101

33. Bjorne A, Agerberg G. Symptom relief after treatment of temporomandibular and cervical spine disorders in patients with Meniere's disease: a three-year follow-up. *Cranio*. 2003;21(1):50-60. doi:10.1080/08869634.2003.11746232

34. Bjorne A, Agerberg G. Reduction in sick leave and costs to society of patients with Meniere's disease after treatment of temporomandibular and cervical spine disorders: a controlled six-year cost-benefit study. *Cranio*. 2003;21(2):136-143. doi:10.1080/08869634.2003.11746242

35. Bjorne A, Berven A, Agerberg G. Cervical signs and symptoms in patients with Meniere's disease: a controlled study. *Cranio*. 1998;16(3):194-202. doi:10.1080/08869634.1998.11746057

36. Sutter BA. Two Case Reports of Meniere's Disease That Responded to Computer-guided Occlusal Therapy. The Application of the Principles of Neuromuscular Dentistry to Clinical Practice. *Anthology Vol XI, The International College of Cranio-Mandibular Orthopedics*. 2016;11:89-98.

37. Sutter BA. Complex Medical Diagnoses with an Underlying Dental Etiology; Case Reviews. In: Kerstein RB, ed. *Handbook of Research on Clinical Applications of Computerized Occlusal Analysis in Dental Medicine*. IGI Global; 2019:1243-1315.

38. Kerstein RB. Disclusion Time reduction therapy with immediate complete anterior guidance development: the technique. *Quintessence Int*. 1992;23(11):735-747.

39. Kerstein RB, Radke J. Masseter and temporalis excursive hyperactivity decreased by measured anterior guidance development. *Cranio*. 2012;30(4):243-254. doi:10.1179/crn.2012.038

40. Kerstein RB, Radke J. Average Chewing Pattern improvements following Disclusion Time Reduction. *Cranio*. 2017;35(3):135-151. doi:10.1080/08869634.2016.1190526

41. Kerstein RB, Chapman R, Klein M. A comparison of ICAGD (Immediate Complete Anterior Guidance Development) to "mock ICAGD" for symptom reductions in chronic myofascial pain dysfunction patients. *Cranio*. 1997;15(1):21-37. doi:10.1080/08869634.1997.11745990

42. Thumati P, Sutter BA, Kerstein RB, Yiannios N, Radke J. Beck Depression Inventory changes in muscular TMD subjects after measured occlusal treatment. *Adv Dent Tech*. 2018;1(1):1-13. https://adtt.scholasticahq.com/article/5019-changes-in-the-beck-depression-inventory-ii-scores-of-tmd-subjects-after-measured-occlusal-treatment

43. Kerstein RB, Wright NR. Electromyographic and computer analyses of patients suffering from chronic myofascial pain-dysfunction syndrome: before and after treatment with immediate complete anterior guidance development. *J Prosthet Dent*. 1991;66(5):677-686. doi:10.1016/0022-3913(91)90453-4

44. Thumati P, Manwani R, Mahantshetty M. The effect of reduced Disclusion Time in the treatment of myofascial pain dysfunction syndrome using immediate complete anterior guidance development protocol monitored by digital analysis of occlusion. *Cranio*. 2014;32(4):289-299. doi:10.1179/2151090314y.0000000004

45. Thumati P, Thumati RP. The effect of disocclusion time-reduction therapy to treat chronic myofascial pain: A single group interventional study with 3 year follow-up of 100 cases. *J Indian Prosthodont Soc*. 2016;16(3):234-241. doi:10.4103/0972-4052.176529

46. Yiannios N, Kerstein RB, Radke J. Treatment of frictional dental hypersensitivity (FDH) with computer-guided occlusal adjustments. *Cranio*. 2017;35(6):347-357. doi:10.1080/08869634.2016.1251692

47. Sutter B, Teragawa S, Radke J. Trigeminal Neuralgia Patients Treated with Disclusion Time Reduction (DTR): A Retrospective Cohort Study. *Adv Dent Tech*. 2020;2(2):90-105. https://adtt.scholasticahq.com/article/16786-trigeminal-neuralgia-patients-treated-with-disclusion-time-reduction-dtr-a-retrospective-cohort-study

48. Radke JC, Kamyszek GJ, Kull RS, Velasco GR. TMJ symptoms reduce chewing amplitude and velocity, and increase variability. *Cranio*. 2019;37(1):12-19. doi:10.1080/08869634.2017.1365421

49. Kerstein RB, Radke J. Average chewing pattern improvements following Disclusion Time reduction. *Cranio*. 2017;35(3):135-151. doi:10.1080/08869634.2016.1190526

50. Andrade KM, Alfenas BFM, Campos CH, Rodrigues Garcia RCM. Mandibular movements in older people with rheumatoid arthritis. *Oral Surg Oral Med Oral Pathol Oral Radiol*. 2017;123(5):e153-e159. doi:10.1016/j.oooo.2017.01.014

51. Vilanova LSR, Gonçalves TMSV, Pimentel MJ, Bavia PF, Rodrigues Garcia RCM. Mastication movements and sleep quality of patients with myofascial pain: occlusal device therapy improvements. *J Prosthet Dent*. 2014;112(6):1330-1336. doi:10.1016/j.prosdent.2014.07.008

52. Radke JC, Ketcham R, Glassman B, Kull R. Artificial neural network learns to differentiate normal TMJs and nonreducing displaced disks after training on incisor-point chewing movements. *Cranio*. 2003;21(4):259-264. doi:10.1080/08869634.2003.11746260

53. Kuwahara T, Bessette RW, Maruyama T. Characteristic chewing parameters for specific types of temporomandibular joint internal derangements. *Cranio*. 1996;14(1):12-22. doi:10.1080/08869634.1996.11745944

54. Kuwahara T, Bessette RW, Maruyama T. Chewing pattern analysis in TMD patients with unilateral and bilateral internal derangement. *Cranio*. 1995;13(3):167-172. doi:10.1080/08869634.1995.11678063

55. Kuwahara T, Bessette RW, Maruyama T. Chewing pattern analysis in TMD patients with and without internal derangement: Part I. *Cranio*. 1995;13(1):8-14. doi:10.1080/08869634.1995.11678035

56. Sfondrini G, Schiavi A, Mandurino M, de Rysky C. Electromyographic and electrognathographic analysis of patients with juvenile rheumatoid arthritis. *Mondo Ortod*. 1991;16(5):535-555.

57. Radke J, Ruiz-Velasco G, Kadamati P. Measuring the jerkiness of gum chewing: Verified TMJ internal derangement patients Vs control Subjects. *Adv Dent Tech*. 2020;2(2):77-84. https://adtt.scholasticahq.com/article/14592-measuring-the-jerkiness-of-gum-chewing-verified-tmj-internal-derangement-patients-vs-control-subjects

58. Ayinala M, Poovani S, Thumati P, Shetty G, Radke J. Mastication analysis of patients with mandibular Kennedy's Class I situation with or without modifications, before & after treatment partial denture insertion; an in vivo study. *Adv Dent Tech*. Published online December 30, 2020. https://adtt.scholasticahq.com/article/18648-mastication-analysis-of-patients-with-mandibular-kennedy-s-class-i-situation-with-or-without-modifications-before-after-treatment-partial-denture-i

59. Radke JC, Kull RS, Sethi MS. Chewing movements altered in the presence of temporomandibular joint internal derangements. *CRANIO*. 2014;32(3):187-192. doi:10.1179/0886963413z.00000000028

60. Kerstein RB, Radke J. Masseter and temporalis excursive hyperactivity decreased by measured anterior guidance development. *Cranio*. 2012;30(4):243-254. doi:10.1179/crn.2012.038

61. Thumati P, Poovani S, Bharathi B, Mounika A, Kerstein RB, Radke J. A disclusion time reduction randomized controlled adjustment trial. *Adv Dent Tech*. Published online April 27, 2020. https://adtt.scholasticahq.com/article/12683-a-disclusion-time-reduction-randomized-controlled-occlusal-adjustment-trial

62. Yiannios N, Coleman T, Radke J. Digitally measured anterior guidance development reduces cold-water and air-indexing hypersensitivity. *Adv Dent Tech*. Published online June 20, 2019. https://adtt.scholasticahq.com/article/9673-digitally-measured-anterior-guidance-development-reduces-cold-water-and-air-indexing-tooth-hypersensitivity

63. Radke J, Velasco GR, Kadamati P. Measuring the Jerkiness of Gum Chewing: Verified TMJ Internal Derangement Patients Vs Control Subjects. *Adv Dent Tech*. Published online August 17, 2020. https://adtt.scholasticahq.com/article/14592-measuring-the-jerkiness-of-gum-chewing-verified-tmj-internal-derangement-patients-vs-control-subjects

64. Thumati P, Radke J, Thumati RP, Vijayakumar M. EMG and Jaw Tracking Evaluation of Masticatory Function after Full Mouth Reconstruction. *Adv Dent Tech*. Published online August 30, 2021. https://adtt.scholasticahq.com/article/27923-emg-and-jaw-tracking-evaluation-of-masticatory-function-after-full-mouth-reconstruction

65. Matos M, Thumati P, Sutter B, et al. Are Temporomandibular Disorders Really Somatic Symptom Disorders? Part III – Masticatory Function as Revealed by EMG and EGN. *Adv Dent Tech*. Published online November 22, 2021. https://adtt.scholasticahq.com/article/30028-are-temporomandibular-disorders-really-somatic-symptom-disorders-part-iii-masticatory-function-as-revealed-by-emg-and-egn

66. Radke J, Kadamati P, Velasco GR. Delayed Peak sEMG of Elevator Muscles in Dysfunctional Mastication. *Adv Dent Tech*. Published online August 4, 2020:68-76. https://adtt.scholasticahq.com/article/14486-delayed-peak-semg-of-elevator-muscles-in-dysfunctional-mastication

67. Kerstein RB, Radke J. Computer-guided Occlusal Treatment Improves the Smoothness Timing and Velocity of Gum Chewing Galley Proof 3-12-2018. *Adv Dent Tech*. Published online March 6, 2019:12-22. https://adtt.scholasticahq.com/article/7829-computer-guided-occlusal-treatment-improves-the-smoothness-timing-and-velocity-of-gum-chewing-galley-proof-3-12-2018

68. Radke JC, Kull RS, Sethi MS. Chewing movements altered in the presence of temporomandibular joint internal derangements. *Cranio*. 2014;32(3):187-192. doi:10.1179/0886963413z.00000000028

69. English JD, Buschang PH, Throckmorton GS, Austin D, Wintergerst AM. Does malocclusion affect masticatory performance? *Angle Orthod*. 2002;72:21-27.

70. Radke J, Yiannios N, Sutter B, Kerstein RB. TMJ vibration changes following Immediate Complete Anterior Guidance Development. *Adv Dent Tech*. Published online September 7, 2018. https://adtt.scholasticahq.com/article/5018-tmj-vibration-changes-following-immediate-complete-anterior-guidance-development

71. Sutter BA, Girouard P. Posture Stability and Forward Head Posture Before and After Disclusion Time Reduction (DTR). A Five-Year Cohort Study. *Adv Dent Tech*. Published online July 20, 2021. https://adtt.scholasticahq.com/article/25911-posture-stability-and-forward-head-posture-before-and-after-disclusion-time-reduction-dtr-a-five-year-cohort-study

72. Kerstein R, Sutter B, Radke J. Increased Mastication Smoothness After Disclusion Time Reduction. *Adv Dent Tech*. Published online December 30, 2021. https://adtt.scholasticahq.com/article/31750-increased-mastication-smoothness-after-disclusion-time-reduction

73. Shopova D, Bozhkova T, Yordanova S, Yordanova M. Case Report: Digital analysis of occlusion with T-Scan Novus in occlusal splint treatment for a patient with bruxism. *F1000Res*. 2021;10:915. doi:10.12688/f1000research.72951.2

APPENDIX

DEFINITIONS

Timings: The averaged opening, closing, occlusal and cycle times of gum-chewing movements.

Turning Point (TP): The point most open and furthest from the intercuspal position that marks the transition from opening to closing.

Terminal Chewing Position (TCP): The most closed position crushing the bolus maximally.

Maximum Lateral Width: The maximum left to right distance produced while chewing.

Maximum Velocities: The fastest mean speed at any point of opening or closing.

Frontal Angles: The angle of opening from or closing into occlusion during chewing.

Jerkiness: The number transitions between acceleration and deceleration during opening or closing while chewing.

Mean Area: The EMG activity rectified and integrated for each chewing burst.

Coefficient of Variation: The standard deviation of the mean area divided by the mean area.

Peak Amplitude: The point of the highest intensity muscle contraction within the chewing burst of each cycle.

Time to Peak Amplitude: The time from the beginning of opening to the peak activity of the muscle contraction.

Peak to Occlusion: The time from the peak activity of the muscle contraction to the end of closure.

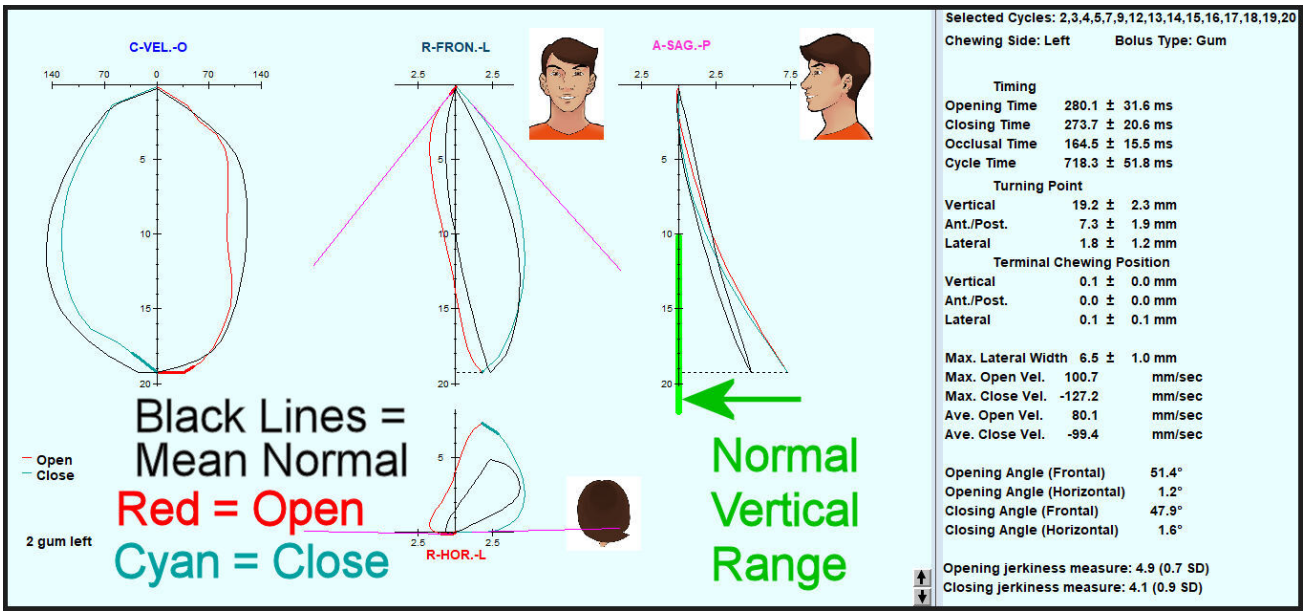

Figure 1A. Mean Normal Average Chewing Pattern (ACP) of chewing motion (black lines) with a control subject's data superimposed (red opening and cyan closing). Normal vertical range of Turning Point combining both sexes is 10 to 22 mm for one stick of chewing gum.

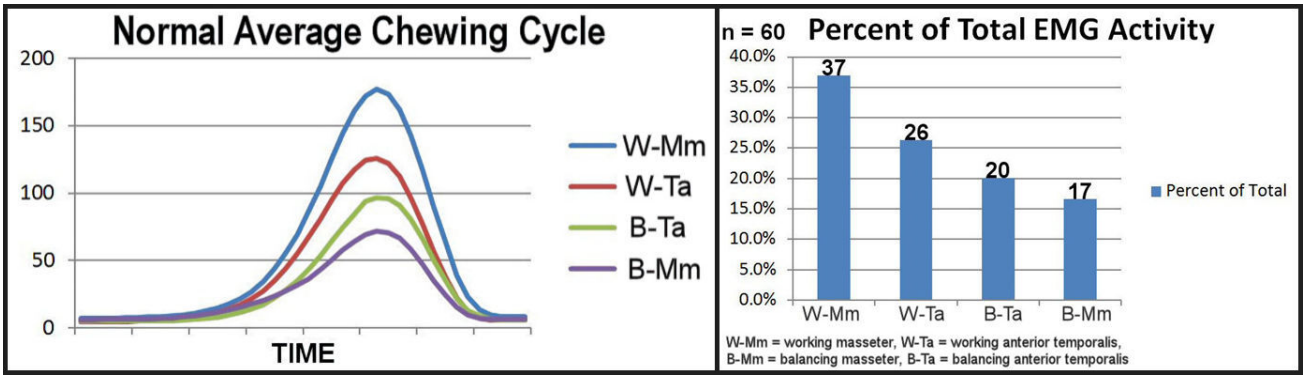

Figure 2A. Mean Normal Average Chewing Cycle (ACP) of bilateral masseter and anterior temporalis muscles' chewing EMG activity. The working masseter is most active, and the balancing masseter is the least active in Angle's Class I patients. In Class II patients the temporalis is more active with a W-Ta, B-Ta, W-Mm, B-Mm normal pattern.

Table 1A. TMD vs MD Symptomology Comparison indicates that Menière's Disease symptoms fall within the broad category of temporomandibular disorders.

MENIERE'S SYMPTOMS	
Vertigo/Dizziness	
Fullness of the ear	
Tinnitus	
Decreased hearing	
TMD SYMPTOMS	
HEAD PAIN	**EAR PROBLEMS**
Headaches	**Vertigo /Dizziness**
Forehead	**Fullness of the Ear**
Temples	**Tinnitus**
Migraine type	**Decreased Hearing**
Sinus type	Ear pain/ache but no infection
Shooting pain up the back of the head	
Hair or scalp painful to touch	**JAW PROBLEMS**
Brain fog	Clicking or popping jaw joints
	Grating sounds
EYES	Pain in cheek muscles
Pain behind the eyes	Uncontrollable jaw movements
Bloodshot eyes	Uncontrollable tongue movements
Eyes Bulge out	
Sensitive to sunlight	**NECK PROBLEMS**
Weeping eyes	Lack of mobility or stiffness
double vision	Neck pain
Problems tracking while reading	Tired, sore muscles
Eye muscle twitching	Shoulder or back aches
	Arm or finger numbness
MOUTH	
Discomfort	**THROAT**
Limited amount of opening	Swallowing difficulties
Inability to open smoothly	Laryngitis
Jaw deviates to one side	Sore throat no infection
Locks open or shut	Voice irregularities
Can't find the bite	Feeling of object stuck in throat
	Frequent coughing or clearing of throat
TEETH	Feeling of hand resting on throat
Clenching and/or grinding	
Looseness and soreness of teeth	
Sensitivity to cold or ice	