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Evaluation of Mandibular Border Movements and Mastication in Patients with Temporomandibular Disorders: A Pilot Study with 3D Electromagnetic Articulography and Surface Electromyography

Evaluación de los Movimientos Mandibulares Bordeantes y la Masticación en Pacientes con Trastornos Temporomandibulares: Un Estudio Piloto con Articulografía Electromagnética 3D y Electromiografía de Superficie

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SUMMARY: Temporomandibular disorders (TMD) are characterized by pain and restricted functionality of the temporomandibular joint (TMJ). The objective of this study was to characterize the kinematic and electromyographic patterns of mandibular border movements and mastication in patients with different forms of TMD compared with healthy controls, through a simultaneous three-dimensional electromagnetic articulography (EMA-3D) and surface electromyography (sEMG) recording protocol. Sixteen participants were included and divided into three groups according to the TMD diagnosis (articular, muscular and mixed) and one healthy control group. Kinematic data were recorded using EMA-3D, and electromyographic activity of the masticatory muscles was assessed using sEMG. Variables analyzed included trajectories, areas, ranges, and electrical activity during mandibular border movements and mastication. Patients with TMD exhibited reduced movement trajectories but larger areas within the mandibular polygons, particularly in the frontal and sagittal planes. During mastication, the number of cycles was higher in the muscular group and lower in the healthy controls. Patients with TMD showed greater mean electromyographic activity, which could suggest compensatory muscle strain. The EMA-3D system provided an accurate three-dimensional analysis, while sEMG captured detailed patterns of muscle activation and strain, that help better understand the neuromuscular alterations associated with TMD. Differentiation between TMD types (articular, muscular and mixed) for the study of its kinematic and electromyographic characteristics, is essential to improve diagnosis and treatment strategies. This study highlights the relevance of advanced tools such as EMA-3D and sEMG in the evaluation of TMD using a simultaneous recording protocol such as the one proposed in this study.

KEY WORDS: Temporomandibular joint; Joint disorders; Muscle disorders; Border movements; Mastication.

INTRODUCTION

Temporomandibular disorders (TMD) are a set of pathologies affecting the temporomandibular joint (TMJ) and its associated structures (Okeson, 1997). They are the second most common musculoskeletal condition causing pain and disability, affecting approximately 31 % to 34 % of the world population adults/elderly, depending on geographic location (Valesan *et al*., 2021; Zielinski *et al*., 2024). Various instruments have been suggested to diagnose TMD, and these have evolved over time. In 1992, the Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD) were published; this was a dual-axis classification system that included a physical assessment (Axis I) and an assessment of psychosocial status and pain-related disability (Axis II) (Dworkin & LeResche, 1992). The criteria were revised, finalized in 2013, and rebranded as the Dual-Axis Diagnostic Criteria for TMD (DC/TMD), applicable in both clinical and research settings, enabling the identification of patients with a range of simple to complex TMD manifestations through concise screening tools for Axes I and II (Schiffman *et al*., 2014).

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Interest in mandibular mobility was first described by Posselt (1957); today, the study of the biomechanical properties of the TMJ facilitates a more comprehensive assessment of its movement characteristics, categorizing the general movement into its translational and rotational components, which can be quantified using currently available technologies (Woodford *et al*., 2020). Mastication has been increasingly recognized as a key functional domain affected in patients with TMD. Recent research emphasizes the importance of evaluating not only joint mechanics but also the functional performance of orofacial muscles during chewing (Marcelino *et al*., 2023). The different forms of TMD have been associated with limitations in mandibular range of motion, as well as impairments in functions such as chewing and speaking (Ratnayake *et al*., 2020). These findings support the need for integrative assessment tools capable of measuring both kinematic and electromyographic variables during mastication, since muscle activity and movement patterns may vary significantly among different TMD subtypes.

Among the current technologies available for evaluating mandibular movements, electromagnetic articulography (EMA-3D) stands out as a precise and reliable method (Lezcano *et al*., 2020). EMA systems are used in research to track articulator movements in real time across the three spatial axes: frontal, sagittal and horizontal, being a very suitable tool for studying complex mandibular functions, such as mastication and swallowing (Fuentes *et al*., 2015). Surface electromyography (sEMG) in dentistry, has become an important non-invasive method to assess the bioelectrical activity of masticatory muscles both at rest and during function, particularly in the study of physiological functions and masticatory muscle function, allowing for precise assessment of muscle activity during chewing and related movements (Zielinski & Gawda, 2024).

Mandibular border movements are those performed at the anatomical limits of the temporomandibular joint, constrained by ligaments and bone morphology. They are highly reproducible and define the envelope of motion, serving as a reference for evaluating functional deviations during mastication and other non-border activities (Farfán *et al*., 2023). Our research team developed updated protocols for the three-dimensional assessment of mandibular border movements, mastication, and swallowing using EMA-3D (Fuentes *et al*., 2015, 2018), in addition to the recording of electromyographic activity of the superficial muscles of mastication (masseter and anterior temporalis muscle) through sEMG (Farfán *et al*., 2022). Given the constraints imposed by TMD on mandibular movements and functions, it is important to persist in the study of oral functions in individuals with these disorders, utilizing objective approaches to provide comparability with other populations. In a previous study, we analyzed mandibular postural position and mouth opening in healthy individuals and patients with articular and/or muscular TMD using EMA-3D and sEMG (Cerda *et al*., 2023). Building on this foundation, the present pilot study aimed to characterize the kinematic and electromyographic patterns of mandibular border movements and mastication in patients diagnosed with articular, muscular and mixed TMD compared with healthy controls, through a simultaneous 3D-EMA and sEMG recording protocol.

MATERIAL AND METHOD

Participants. A pilot study was conducted with sixteen participants (14 women, 2 men) recruited from the Temporomandibular Disorders and Orofacial Pain Polyclinic at the Universidad de La Frontera, Temuco, Chile. Sample selection was performed using non-probability consecutive convenience sampling, enrolling individuals who met the defined inclusion and exclusion criteria and voluntarily agreed to participate. This study was designed as a pilot study because the application of combined three-dimensional EMA-3D and sEMG to characterize mandibular border movements and mastication in TMD populations has been scarcely explored. Therefore, this approach allowed us to generate preliminary evidence, refine assessment protocols, and establish methodological feasibility for future larger-scale investigations. The composition of the sample reflected the availability and willingness of patients during the recruitment period.

The diagnosis of TMD was made following the Diagnostic Criteria for Temporomandibular Disorders: Scoring Manual for Self-Report Instruments, Spanish version (International Network for Orofacial and Related Disorders Methodology, 2018).

Eligibility criteria. The study included patients aged 18 to 25 years who attended the Temporomandibular Disorders and Orofacial Pain Polyclinic at the Universidad de La Frontera for TMD. Four groups were formed and differentiated according to the TMD diagnosis: articular, muscular, mixed and asymptomatic according to the Diagnostic Research Criteria for TMD (DC/TMD). Patient selection was performed by a dentist specializing in temporomandibular disorders and orofacial pain (C.C.), previously calibrated for diagnosis with the DC/TMD.

Patients with orofacial movement disorders, unable to follow instructions, with one or more missing teeth, with orthodontic appliances, peanut allergy, or with oral lesions, such as angular cheilitis and trauma permanently affecting mandibular movement, such as a mandibular fracture or injuries occurring within the last year that could explain or mask symptoms, as well as sequelae of cancer and lichen planus, was excluded.

Consistent with the aforementioned criteria, participants were invited to take part in the study after signing an informed consent form approved by the Universidad de La Frontera's Scientific Ethics Committee (File N° 087_18).

Records. The study was carried out at the "Oral Physiology Laboratory" in the Research Center for Dental Sciences (CICO), Faculty of Dentistry, Universidad de La Frontera (Temuco, Chile). The masticatory kinematics and electromyographic activity of the masseter muscles and the anterior temporalis muscle were recorded simultaneously using different equipment:

3D electromagnetic articulograph (EMA-3D): The electromagnetic articulograph AG501 (Carstens Medizinelektronik, Bovenden, Germany) was specifically used to evaluate the kinematic characteristics of mandibular border movements and mastication. This included the measurement of spatial trajectories, movement ranges, and polygonal areas formed during mandibular border movements in the frontal, sagittal, and horizontal planes. It works with 9 transmitter coils that generate alternating electromagnetic fields at different frequencies and 16 sensors in the areas to be studied and that, when under the influence of these electromagnetic fields, generate a small alternating electric current, which is recorded by the equipment and converted to spatial position data (Fuentes *et al*., 2015, 2018). The EMA-3D system has been previously validated in studies assessing mandibular kinematics with high spatial and temporal accuracy (Fuentes *et al*., 2018).

Seven sensors were used: three reference sensors, placed at the cutaneous points of the right and left mastoid and glabella to eliminate involuntary head movements, thus preventing them from being recorded as mandibular movement; an active sensor placed on the mandibular interincisal line (Fig. 1), and three sensors were attached to the EMA-3D accessory, "biteplane", which can locate the origins of the coordinates in the occlusal plane (Fig. 2). In addition, the articulograph had a ground connector placed on the patient's wrist. Biocompatible tissue glue (Epiglu®, Meyer Haake, Germany) was used to set the sensors on the participants after adequately cleaning the areas with 70 % alcohol. To correct for head movements during data acquisition, the "Head Correction" function of the EMA-3D system was used, which transforms raw coordinates into normalized coordinates relative to the position of the three reference sensors (Lezcano *et al*., 2020).

Fig. 1. Reference sensors, positioned on the glabella (1), right mastoid (2), left mastoid (3) and the active sensor located in the interincisive line of the incisors of the mandible (4).

To ensure standardization, all participants were seated upright in a chair with their Frankfurt horizontal plane parallel to the floor and instructed to maintain a relaxed but stable posture throughout the recordings. All recordings were performed under identical environmental conditions, including ambient temperature, lighting, and equipment settings, with the same operator conducting all data acquisitions to ensure procedural consistency. The duration of the recordings varied depending on the task but was kept within a consistent time frame across participants to minimize fatigue or behavioral variability.

Surface electromyograph (sEMG): The surface electromyograph sEMG VIII (ArtOficio, Santiago, Chile) was used. Eight of its disposable pregelled adhesive electrodes (Kendall™ H124SG, Waukegan, Ill) were used to record muscle activity. Two electrodes were positioned over each muscle, bilaterally on the masseter and anterior temporalis muscles, following standard anatomical landmarks: over the belly of each muscle and aligned parallel to the direction of the muscle fibers. Before placement, the skin was cleaned with 70 % alcohol to remove fat and dead cells and to facilitate the fixation of the electrode and the transmission of the electrical activity. These electrodes were positioned parallel to the orientation of the muscle fibers at the most prominent region of the muscular belly during isometric contraction. To palpate it, the subject was asked to make a maximum squeezing effort in the maximum intercuspation position (MIP). In the case of the temporalis muscle, the sensor is placed on the anterior border of the muscle, at the level of the coronal suture, 2 cm above the zygomatic arch (Fig. 3). Furthermore, a reference electrode was required; in this instance, it was positioned on the participant's elbow, which is devoid of innervation or underlying musculature.

Fig. 2. Biteplane with sensors located in the central (5) and lateral areas (6 y 7) of the grooves of the accesory.

Fig. 3. EMA sensors and sEMG electrodes, positioned on the masseter and anterior portion of temporalis muscle.

Test food: This study used roasted peanuts with no additives as the test food (Fuentes *et al*., 2018; Farfán *et al*., 2023).

Mandibular movement protocol: The range, trajectory, and area of the movements were measured, incorporating the distance, time, and speed of the subsequent movements, the protocol of Farfán *et al*. (2023).

1. Border movement in the frontal plane: Participants were asked to slide the mandible from maximum intercuspation position (MIP) to lateral maximum movement with dental contact right (MLC-R) and from that point to the maximum opening (MO), maintaining the movement from the border, then the procedure was repeated, but towards the left side (Fig. 4).

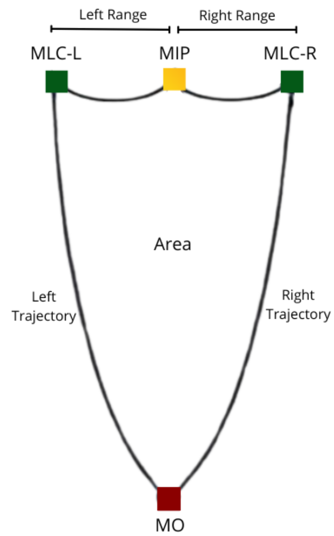

Fig. 4. Frontal polygon. MIP: maximum intercuspation position, MO: maximum opening, MLC-L: maximum laterotrusive dental contact point left, MLC-R: maximum laterotrusive dental contact point right.

2. Border movement in the sagittal plane: Participants were asked to slide the mandible to the maximum retrusion position (MRP) and, from that point, perform a MO while maintaining the movement from the border. The participants then returned to MIP and, from there, slid into a maximum protrusion position (MPP), maintaining dental contact, and, from that point, performed a MO (Fig. 5).

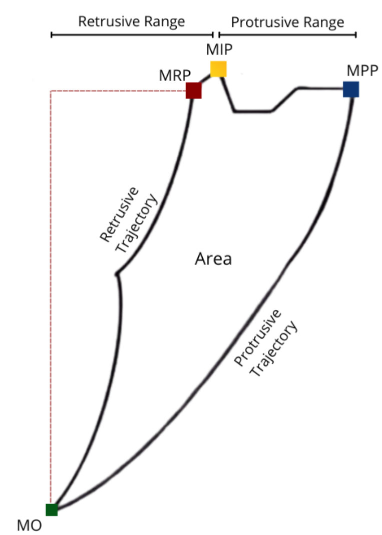

Fig. 5. Sagittal Polygon. MIP: maximum intercuspation position, MO: maximum opening, MPP: maximum protrusion position, MRP: maximum retrusion position.

3. Border movement in the horizontal plane: Participants were asked to slide their mandible from MIP to MLC-R, and from that point, move their mandible towards maximum protrusion, maintaining the movement from the border, then the same was repeated, but to the left side (Fig. 6).

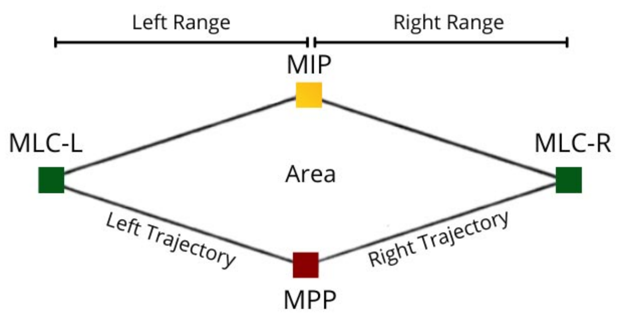

Fig. 6. Horizontal polygon. MIP: maximum intercuspation position, MPP: maximum protrusion position, MLC-L: maximum laterotrusive dental contact point left, MLC-R: maximum laterotrusive dental contact point right.

4. Peanut chewing: This recording began with the volunteers in MIP with the 3 g of peanuts placed between the tongue and the palate. Participants were asked to begin chewing freely, without indicating either side or the number of chewing cycles, when instructed, and once they felt like swallowing, they would raise their hand to stop the recording.

Data processing: The files generated from each simultaneous EMA and sEMG recording were processed using custom-developed scripts in MATLAB (MathWorks®, Natick, MA, USA). These scripts, composed of a sequence of programmed instructions, performed mathematical operations on the raw data to extract numerical parameters and generate graphical representations for further analysis.

Data analysis: Data collection was recorded on a Microsoft Office Excel spreadsheet, and a descriptive analysis of the data was performed to determine the mean and its respective standard deviation.

RESULTS

This study analyzed the kinematic and electromyographic characteristics of mandibular border movements and mastication in patients with TMD and healthy controls, through a protocol simultaneous recording of EMA 3D and sEMG. These findings expand upon our previous results (Cerda *et al.*, 2023), where only was evaluated for mandibular postural position and maximum mouth opening the same cohort. In the present analysis, different functional tasks were assessed, focusing specifically on border mandibular movements and masticatory function. By broadening the range of motor tasks studied, we aimed to provide a more comprehensive understanding of the functional alterations associated with TMD with the proposed protocol.

The polygon measurements were performed in the 3 planes of space: frontal, sagittal and horizontal; the results are presented separately, first those of the EMA and then those of the EMG.

1. Frontal polygon. For this study, it was defined in the frontal plane (Fig. 4):

Range: Distance at the starting point (MIC) and indicated point consistent with maximum contact laterality.

Trajectory: Path of the complete movement performed from laterality to maximum lateral border opening.

Area: The sum of the diagram.

Table I shows the average of the frontal polygon's areas, trajectories and ranges evaluated with EMA-3D.

This was highest in the healthy cohort (348.8 ± 178.3 mm^2), and the lowest average was in the mixed group (251.1 ± 65.0 mm^2). Concerning the trajectories, the highest averages were observed in the muscular group, 57.4 ± 4.2 mm (right) and 56.9 ± 5.6 mm (left), and the lowest in the articular group with 47.3 ± 6.5 mm (right) and 46.9 ± 5.7 mm (left). The largest ranges were noted in the healthy group for the right side (8.2 ± 2.4 mm) and in the mixed group for the left side (7.4 ± 2.3 mm), and the smallest were in the muscular group, with 6.9 ± 0.4 mm (right) and 6.5 ± 2.7 mm (left).

Table I. Average of the areas, trajectories and ranges in the frontal polygon of the 4 study groups.

	FRONTAL POLYGON (EMA-3D)				
	Area (mm^2)	Right trajectory (mm)	Left trajectory (mm)	Right range (mm)	Left range (mm)
Articular N=3	315.2 ± 139.3	47.3 ± 6.5	46.9 ± 5.7	7.8 ± 1.4	8.4 ± 3.8
Mixed N=5	251.1 ± 65.0	50.6 ± 11.1	46.3 ± 7.2	8.0 ± 1.9	7.4 ± 2.3
Muscular N=3	341.0 ± 141.3	57.4 ± 4.2	56.9 ± 5.6	6.9 ± 0.4	6.5 ± 2.7
Healthy N=5	348.8 ± 178.3	55.6 ± 6.2	50.8 ± 20.3	8.2 ± 2.4	6.9 ± 4.4

Table II presents the average electrical activity during border movements in the frontal plane. The values recorded in the mixed group, for both the right and left trajectories, were lower than those of the other study groups in most of the muscles examined, with the highest values noted in the articular and muscular groups.

2. Sagittal Polygon.

For this study, the following was defined (Fig. 5):

Protrusive range in the sagittal plane: Distance between the starting point (MIC) and the point indicated as the maximum protrusive contact movement.

Retrusive range: Distance from the starting point (MIC) to the end of the movement corresponding to the maximum opening.

Protrusive trajectory: Path from MIC to the maximum border opening movement.

Retrusive trajectory: Path from MIC to the maximum posterior border opening movement.

Area: The inside of the complete diagram.

Table III shows the average of the areas, trajectories, and ranges of the sagittal polygon evaluated with EMA-3D. This was highest in the healthy cohort (253.2 ± 81.1 mm2), and the lowest average was in the mixed group (183.8 ± 53.8 mm^2). Concerning the trajectories, the highest averages were observed in the muscular group, 66.4 ± 17.0 mm (protrusion) and 55.4 ± 12.3 mm (retrusion), and the lowest in the articular and mixed groups. The highest ranges were observed in the articular and healthy groups.

The highest average electrical activity during border movements in the sagittal plane was in the muscular group for most of the muscles and lowest in the healthy and mixed groups, as detailed in Table IV.

Table II. sEMGrms of the muscles of the right masseter (RM), left masseter (LM), right temporalis (RT), and left temporalis (LT) during border movements in the frontal plane.

AVERAGE ELECTROMYOGRAPHIC ACTIVITY (sEMGrms) DURING BORDER MOVEMENTS IN THE FRONTAL PLANE								
	Right trajectory (µv±SD)				Left trajectory (µv±SD)			
	RM	LM	RT	LT	RM	LM	RT	LT
Articular N=3	11.2 ± 6.0	7.8 ± 3.8	10.9 ± 6.1	8.4 ± 2.6	8.6 ± 4.4	9.1 ± 6.4	6.5 ± 1.8	11.5 ± 7.0
Mixed N=5	5.6 ± 1.6	5.5 ± 2.0	5.9 ± 1.5	6.4 ± 3.6	5.5 ± 2.3	7.0 ± 4.6	5.4 ± 1.7	8.5 ± 4.6
Muscular N=3	6.6 ± 2.2	7.8 ± 1.6	9.3 ± 4.0	10.3 ± 1.7	9.5 ± 4.0	8.8 ± 4.0	7.7 ± 2.0	13.4 ± 5.1
Healthy N=5	7.6 ± 3.4	8.4 ± 4.1	6.2 ± 1.4	7.6 ± 5.2	9.3 ± 7.5	7.4 ± 5.2	6.0 ± 2.8	7.4 ± 2.7

µv: microvolts.

Table III. Average of the areas, trajectories and ranges in the sagittal polygon of the 4 study groups.

SAGITTAL POLYGON (EMA-3D)					
	Area (mm^2)	Protrusion trajectory (mm)	Retrusion trajectory (mm)	Protrusive range (mm)	Retrusive range (mm)
Articular N=3	204.2 ± 25.5	58.3 ± 6.1	45.5 ± 4.1	8.4 ± 1.8	16.5 ± 1.1
Mixed N=5	183.8 ± 53.8	54.4 ± 10.5	47.2 ± 12.6	5.7 ± 2.6	11.0 ± 3.1
Muscular N=3	233.7 ± 89.1	66.4 ± 17.0	55.4 ± 12.3	6.1 ± 1.9	16.4 ± 3.7
Healthy N=5	253.2 ± 81.1	58.0 ± 12.3	48.8 ± 10.8	6.9 ± 2.1	17.2 ± 6.7

Table IV. sEMGrms of the muscles of the right masseter (RM), left masseter (LM), right temporalis (RT), and left temporalis (LT) during border movements in the sagittal plane.

AVERAGE ELECTROMYOGRAPHIC ACTIVITY (sEMGrms) DURING BORDER MOVEMENTS IN THE SAGITTAL								
	Protrusion Trajectory (µv±SD)				Retrusion Trajectory (µv±SD)			
	RM	LM	RT	LT	RM	LM	RT	LT
Articular N=3	11.6 ± 7.2	7.8 ± 2.4	7.1 ± 2.6	7.3 ± 2.1	7.5 ± 2.2	7.1 ± 2.5	14.7 ± 5.7	12.7 ± 6.4
Mixed N=5	6.6 ± 2.3	9.7 ± 9.6	5.3 ± 1.3	7.1 ± 3.5	5.9 ± 2.1	5.6 ± 2.5	7.0 ± 2.6	9.2 ± 5.0
Muscular N=3	16.3 ± 5.7	10.8 ± 5.3	7.4 ± 2.3	10.0 ± 3.3	8.5 ± 4.1	9.7 ± 4.5	18.7 ± 7.3	21.4 ± 10.7
Healthy N=5	9.6 ± 2.5	10.1 ± 2.5	11.2 ± 9.0	11.4 ± 7.6	5.7 ± 1.9	5.6 ± 1.6	7.5 ± 2.3	6.7 ± 2.7

µv: microvolts.

3. Horizontal polygon

For this study, the following was defined (Fig. 6):

Range: Distance for the horizontal polygon between the starting point (MIC) and the point indicated as the maximum lateral contact movement.

Trajectory: Path from MIC maximum contact laterality then protrusion.

Area: This is the inside of the complete diagram.

Table V shows the average of the horizontal polygon's areas, trajectories, and ranges evaluated with EMA-3D. This was highest in the articular group (56.6 ± 29.1 mm^2), and the lowest average was in the healthy group (45.0 ± 18.6 mm^2). Regarding the trajectories, the highest averages were observed in the muscular group, 26.0 ± 11.8 mm (right) and 19.7 ± 4.3 mm (left), and the lowest in the articular group with 18.1 ± 3.1 mm (right) and 18.2 ± 4.9 mm (left). The ranges presented similar averages in the mixed, muscular, and healthy groups; the average was lower in the articular group (5.3 ± 0.5 mm on the right side and 5.6 ± 2.1 mm on the left side).

Table VI shows the average of the electrical activity generated by the masseter muscles and anterior temporalis during border movements in the horizontal plane. The values observed in the mixed group, both in the right and left trajectories, were lower than those of the other study groups in most of the muscles studied, and the highest values were observed in the muscular group.

4. Mastication

After evaluating mastication by EMA-3D, the following kinematic characteristics were obtained: number of cycles, masticatory frequency, the cycle area, and the speed of ascent and descent. Then, the average was calculated for each group. The group that performed the highest number of masticatory cycles was the group with

Table V. Averages of the areas, left and right trajectories, and left and right ranges of the horizontal polygon of the 4 groups of study.

	HORIZONTAL POLYGON (EMA-3D)				
	Horizontal Area (mm^2 ± SD)	Right trajectory (mm)	Left trajectory (mm)	Right range (mm)	Left range (mm)
Articular N=3	56.6 ± 29.1	18.1 ± 3.1	18.2 ± 4.9	5.3 ± 0.5	5.6± 2.1
Mixed N=5	52.5 ± 42.6	19.5 ± 8.9	19.0 ± 9.8	6.7 ± 2.6	6.2 ± 2.9
Muscular N=3	49.5 ± 25.6	26.0 ± 11.8	19.7 ± 4.3	6.5 ± 1.0	6.5 ± 2.6
Healthy N=5	45.0 ± 18.6	22.6 ± 8.9	18.4 ± 5.6	6.5 ± 1.9	6.0 ± 2.2

Table VI. sEMGrms of the muscles of the right masseter (RM), left masseter (LM), right temporalis (RT), and left temporalis (LT) during border movements in the horizontal plane.

	Right trajectory (µv±SD)				Left trajectory (µv±SD)			
	RM:	LM	RT	LT	RM	LM	RT	LT
Articular	11.8 ±	8.8 ± 4.0	14.8 ±	8.4 ± 3.9	10.0 ± 4.8	9.2 ± 4.5	6.4 ± 1.3	12.5 ± 8.0
Mixed	6.3 ±	13.0 ±	6.8 ± 1.8	6.8 ± 3.8	7.0 ± 3.1	8.8 ± 8.2	5.1 ± 1.3	7.7 ± 3.7
Muscular	16.8 ±	11.7 ± 2.2	12.4 ± 5.4	12.4 ± 3.7	20.6 ± 8.5	12.2 ± 1.9	8.6 ± 2.8	15.2 ± 4.3
Healthy	8.7 ±	8.6 ± 4.1	7.8 ± 2.6	7.0± 3.7	10.0 ± 2.7	11.0 ± 5.7	7.9 ± 4.1	9.2 ± 4.3

µv: microvolts.

Table VII. Number and frequency of cycles, areas (frontal, sagittal, and horizontal), and ascent/descent velocities in the four study groups.

	KINEMATIC CHARACTERISTICS OF MASTICATION ASSESSED WITH EMA-3D						
	Number of cycles	Mastication frequency (cycles/s)	Areas (mm^2)			Speed (mm/s)	
			Front	Sagittal	Horizontal	Ascent	Descent
Articular N=3	18.6 ± 2.1	1.3 ± 0.2	40.2 ± 23.5	9.0 ± 7.2	10.1 ± 9.0	53.1 ± 9.0	52.3 ± 9.4
Mixed N=5	20.8 ± 7.1	1.3 ± 0.1	39.2 ± 35.1	7.2 ± 7.2	6.2 ± 8.5	44.7 ± 9.1	48.6 ± 10.1
Muscular N=3	23.3 ± 5.5	1.5 ± 0.2	39.5 ± 27.8	8.2 ± 8.6	5.8 ± 6.1	56.9 ±13.1	56.3 ± 13.8
Healthy N=5	15.6 ± 6.8	1.2 ± 0.2	39.3 ± 26.5	8.1 ± 6.2	4.5 ± 3.9	44.0 ± 11.6	49.1 ± 13.3

Values are expressed as mean ± standard deviation.

muscular pathology (23.3 ± 5.5), while the lowest number of cycles was the healthy group (15.6 ± 6.8). The sagittal and horizontal areas of mastication were largest in the articular group (9.0 ± 7.2 and 10.1 ± 9.0 mm, respectively), the sagittal area was smallest in the mixed group, and the horizontal area was smallest in the healthy group. The frontal area of mastication presented similar values in the four cohorts. Ascending and descending velocities were highest in the muscular group (56.9 ±13.1 and 56.3 ± 13.8 mm/s, respectively) and lowest in the healthy group (44.0 ± 11.6 and 49.1 ± 13.3 mm/s, respectively) (Table VII).

Table VIII shows the average electrical activity generated by the masseter and anterior temporalis muscles during mastication. The values observed in the muscular group on the right side were higher than those of the other study groups, and for the muscles on the left side, the values were highest in the articular group.

Table VIII. sEMGrms of the muscles of the right masseter (RM), left masseter (LM), right temporalis (RT), and left temporalis (LT) during mastication. µv: microvolts.

	AVERAGE ACTIVITY (sEMGrms) DURING MASTICATION			
	RM (µv)	LM (µv)	RT (µv)	LT (µv)
Articular N=3	37.8 ± 1.6	34.7 ± 12.0	44.8 ± 5.8	49.7± 18.4
Mixed N=5	24.6 ± 19.5	24.8 ± 16.7	24.0± 15.8	26.3 ± 15.7
Muscular N=3	59.9 ± 33.5	50.0± 18.6	37.3 ± 9.5	46.7 ± 24.8
Healthy N=5	20.9 ± 4.6	25.9 ± 1.8	30.3 ± 16.1	22.3 ± 7.1

DISCUSSION

This study aimed to characterize mandibular border movements and mastication in patients with articular, muscular and mixed TMD diagnosed with DC-TMD and a control group of healthy individuals through a simultaneous 3D-EMA and sEMG recording protocol. Long-standing TMD can adversely affect food processing, eating and overall quality of life. An early diagnosis can improve the prognosis (De Felício *et al*., 2013); thus, understanding normal values during different movements is crucial. Our findings provide preliminary insights into the kinematic and electromyographic differences among patients across various groups. Due to the limited sample size, no statistical analysis was performed. Further studies with larger samples are needed to confirm the trends observed in this pilot study.

Patients with TMD generally exhibited reduced mandibular trajectories when compared to healthy individuals, with the exception of the muscular TMD group, which showedthe highest average displacement values. In contrast, the articular and mixed groups presented shorter trajectories, suggesting more restricted mandibular movement. Despite these reductions in linear displacement, all TMD groups demonstrated larger polygonal areas, particularly in the frontal and sagittal planes, which may indicate more irregular or compensatory movement patterns. This aligns with previous studies describing biomechanical and functional alterations associated with TMD, including limitations in lateral, protrusive, and opening movements (List & Jensen, 2017). In this context, limitations could refer not only to reduced range of motion but also to impaired motor control, including altered movement coordination, variability, and efficiency, clinical studies have shown that patients with TMD often exhibit unsteady or asymmetric mandibular motion paths, likely reflecting neuromuscular adaptations to pain or joint instability (Szyszka-Sommerfeld *et al*., 2023).

The number of chewing cycles was highest in the muscular group and lowest in the healthy group; this difference could be due to the TMD affecting the masticatory function, increasing the number of cycles needed to process food properly (Rodrigues *et al*., 2015). Felício *et al*. (2007), also observed a longer chewing time and greater changes in the masticatory pattern in people with TMD than in healthy people. This indicates that the severity of TMD may influence the adaptability and coordination of mandibular movements as a conscious or unconscious attempt to avoid painful stimuli in the proprioceptive scheme, reflecting the chewing pattern (Felício *et al*., 2007; Rodrigues *et al*., 2015).

sEMG is widely applied as a noninvasive tool to assess patients with TMD (Szyszka-Sommerfeld *et al*., 2020). Several studies have shown that individuals with TMD exhibit alterations in the electromyographic activity of the superficial masticatory muscles, often characterized by hyperactivity at rest compared to healthy subjects, and decreased activity during maximal voluntary clenching, this may occur due to the disorder or a symptom-related compensatory mechanism (Chaves *et al*., 2017; Szyszka-Sommerfeld *et al*., 2020). The foundation of numerous therapeutic approaches for TMD is the "vicious circle theory", which posits that pain leads to muscle hyperactivity, causing spasms and fatigue, which in turn generate more pain and dysfunction, perpetuating the cycle (Sutter & Radke, 2022). In this context, the elevated EMG activity observed in our muscular TMD group during mastication and border movements may reflect the presence of such a compensatory mechanism or ongoing muscle hyperactivity contributing to the cycle. Although muscle pain is known to affect muscle function and activity, the small sample size in our study limits the strength of these conclusions.

The EMA-3D system allowed for the precise and detailed recording of three-dimensional mandibular movements, capturing spatial trajectories, ranges, and polygonal areas across all study participants. When combined with surface sEMG, this approach enabled a more comprehensive understanding of the neuromuscular alterations associated with TMD. These findings highlight the value of integrating advanced mandibular motion-tracking systems and muscle activity analysis (such as simultaneous recordings with 3D-EMA and sEMG) to objectively assess these pathologies, both in clinical and research settings, s a complementary method for the diagnosis or differential diagnosis of TMD. Studies comparing mandibular movements and masticatory function in TMD populations generally group all types of TMD into one (Rodrigues *et al*., 2015) or divide them based on the presence or absence of pain (Szyszka-Sommerfeld *et al*., 2020), rather than differentiating between articular, muscular, and mixed forms, as done in this study. Therefore, we underscore the need for additional research to support the differences found in our study.

CONCLUSIONS

This study presents novel contributions by simultaneously analyzing mandibular kinematics and muscle activity using EMA-3D and sEMG in patients categorized by specific TMD subtypes (articular, muscular and mixed), rather than grouping all TMD cases together. To our knowledge, this is one of the few studies that applies this multimodal and subtype-specific approach, providing preliminary insights that may inform future diagnostic and therapeutic strategies in TMD management. The major limitation of this study was the sample size, which restricted statistical analysis and limits the generalizability of the findings. Additionally, the sample was recruited through convenience sampling, which may introduce selection bias, and the gender distribution was unbalanced, with a predominance of female participants. In the future, studies with larger samples and longitudinal designs will help validate these findings and assess the impact of specific interventions based on individual patient characteristics.

CERDA, C.; MARINELLI, F.; JARPA, M; NAVARRO, P.; FUENTES, R. & VENEGAS-OCAMPO, C. Evaluación de los movimientos mandibulares bordeantes y la masticación en pacientes con trastornos temporomandibulares: Un estudio piloto con articulografía electromagnética 3D y electromiografía de superficie. *Int. J. Morphol., 43(6)*:2079-2088, 2025.

RESUMEN: Los trastornos temporomandibulares (TTM) se caracterizan por dolor y funcionalidad limitada de la articulación temporomandibular (ATM). El objetivo de este estudio fue caracterizar los patrones cinemáticos y electromiográficos de los movimientos de borde mandibular y la masticación en pacientes con diferentes tipos de TTM en comparación con controles sanos, mediante un protocolo de registro simultáneo de articulografía electromagnética tridimensional (EMA-3D) y electromiografía de superficie (sEMG). Se incluyeron dieciséis participantes, divididos en tres grupos según el diagnóstico de TTM (articular, muscular y mixto) y un grupo control sano. Los datos cinemáticos se registraron mediante EMA-3D y la actividad electromiográfica de los músculos masticatorios se evaluó mediante s EMG. Las variables analizadas incluyeron trayectorias, áreas, rangos y actividad eléctrica durante los movimientos de borde mandibular y la masticación. Los pacientes con TTM mostraron trayectorias de movimiento reducidas, pero áreas más grandes dentro de los polígonos mandibulares, especialmente en los planos frontal y sagital. Durante la masticación, el número de ciclos fue mayor en el grupo muscular y menor en los controles sanos. Los pacientes con TTM mostraron una mayor actividad electromiográfica media, lo que podría sugerir tensión muscular compensatoria. El sistema EMA-3D proporcionó un análisis tridimensional preciso, mientras que la sEMG capturó patrones detallados de activación y tensión muscular, lo que ayuda a comprender mejor las alteraciones neuromusculares asociadas con el TTM. La diferenciación entre los tipos de TTM (articular, muscular y mixto) para el estudio de sus características cinemáticas y electromiográficas es esencial para mejorar las estrategias de diagnóstico y tratamiento. Este estudio destaca la relevancia de herramientas avanzadas como EMA-3D y sEMG en la evaluación de los DTM mediante un protocolo de registro simultáneo como el propuesto.

PALABRAS CLAVE: Articulación temporo-mandibular; Trastornos articulares; Trastornos musculares; Movimientos fronterizos; Masticación.

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