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Qualitative and Quantitative Videofluoroscopic Analysis of Basic Temporomandibular Movements

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Abstract— *Background: The temporomandibular joint (TMJ) is a synovial condylar articulation with freedom of movement resulting from bilateral side morphological interrelations. Its basics movements to attend its main function are rotation and translation.*

Material and Methods: A videofluoroscopic study of the left posterior oblique incidence comprising 23 healthy volunteers of both sexes was conducted to qualify and quantify the displacement of the mandible over the temporal surface. This evaluation was performed without using any artificial contrast medium.

Results: From maximum occlusion to maximum mouth opening, three spaces defined as LL1, LL2 and LL3 were established and used to qualify and quantify the limits of mouth opening. Seventeen volunteers could be classified as normal free (NF) and six as suspicious (S) based on this function.

Conclusion: The NF and S groups statistically differed in their mouth opening capabilities ($p < 0.0001$). Measured values for LL3 greater than LL2 as well as positive values for L3-L2 can be considered NF and negative values for L3-L2 can be considered S with a significance of $p < 0.0001$. L2 was statistically confirmed as a good parameter for the distinction between normal and suspicious TMJ functioning.

***Keywords*— temperomandibular joint, pterygoid muscles, temporal bone.**

I. BACKGROUND

The temporomandibular joint (TMJ) is classified morphologically as a synovial condylar articulation, wherein one side interferes with the other, allowing interdependent articulation [1,2]. In theory, the condylar morphology and interdependence [3] may limit its movement pertaining to the opening and closing of the mouth. However, the dynamics of the TMJs allow freedom of movement beyond typical condylar movements. Beside the basic functions of rotation and translation, the jaw is also able to protrude, retract and move laterally both sides owing to spherical articulation to facilitate chewing [4,5,6].

The freedom of movement of TMJ results in bilateral morphological interrelation of the temporal articular surface (temporal fossa and tubercle) with the condyloid process of the jaw and fundamental articular disc interposition [7]. In the resting position, the free interocclusal space, a point at the centre of the condyloid process, is located near the middle projection of the temporal fossa [8], and during mouth opening, the condyloid process moves over the temporal tubercle until an unknown limit. In general, maximum mouth opening is evaluated by measuring the space between the superior and inferior tooth arcade with a ruler [9], a pachymeter [10], or the fingers [11] using the occlusal surface of the right superior and inferior incisors as a reference [10]. This inconsistent methodology suggests that the maximum normal mouth opening varies between 45 and that 60 mm in a normal adult and values <40 mm are indicative of pathology [12]. However, values between 40 and 45 mm, independent of sex, are considered the normal maximum limit of mouth opening [13].

The contract action of the chewing muscles, is the responsible for the displacement of the condyloid process in

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all directions. However, the lateral pterygoid muscles (LPMs) are primarily responsible for mouth opening through two basic movements: rotation and translation [14,15]. Rotation refers to the displacement of the condyloid process into the mandibular fossa of the temporal bone from the centric occlusion until a functional rest position, and translation, which occurs following rotation, is the projection of the condyloid process over the temporal tubercle. Only after the initiation of translation, it is possible for the TMJ to freely produce other movements during chewing.

Into the temporal fossa, the condyloid process cannot achieve free displacement, possibly because of mechanical impairment. Over temporal tubercle, without mechanical impairment, the condyloid process, which is covered by the articular disc, is able to produce all chewing movements in association with the action of other muscles [16,17].

The LPMs have a biceps morphology where the superior and inferior heads function synergistically in three functional directions acting over the jaw in a sequential traction to open the mouth [18,19]. Jaw movement during mouth opening is initiated by the superior head of LPM, which moves the condyloid process forward and upward that leads to an impact on the inferior disc medial concavity, thereby generating a condyle-disc unit, which remains affected during the entire duration of the jaw being displaced. From this time, the intermediate muscular fascicles of both heads of LPM tract the condyle-disc unit forward and in sequence based on the inferior and more strong fascicle of LPM that tracts the condyle-disc unit forward and downward, which determines jaw displacement and consequent mouth opening. In this manner, mouth opening results from three vectorial-associated actions produced by sequential contraction of the LPM heads [20-23].

The temporomandibular morphofunctional disarrangement (TMD) can be defined as 'with reduction' or 'without reduction', which reinforces the functional concept of this articulation described above. In TMD with reduction, the condyle-disc unit is displaced forward because of its dysfunction, which allows the disc to escape the posterior direction by traction produced by the elastic bi-laminar zone. In TMD without reduction, the disc usually goes ahead of the condyloid process, which impairs normal mouth opening because of the limited space occupation by the disc. Sometime this condition can produce condyloid process impactation over the disc atypically posicioned [2,5,23,24].

Because there is no simple clinical method to evaluate TMJ dysfunction, a comprehensive evaluation is necessary to more clearly elucidate normal and abnormal mechanisms. The videofluoroscopic method is useful to evaluate normal and pathologic dynamics of TMJ with reasonable quality. This radiological method involves low-level X radiation, allowing dynamic measurements in the magnetic media. The analysis and re-analysis of registered dynamics phenomena are the advantages of this method [25-27].

The dysfunction of TMJ, among another problems, produces headache, dizziness and tinnitus, which compromises the quality of life of about 40% of the world population [5,23]. Videofluoroscopic evaluation is a useful method for imaging examinations in TMJ studies and does not required the injection of contrast agents [2].

The objective of this study was to establish, via a videofluoroscopic method, a qualitative pattern of basic TMJ dynamics and to generate quantitative values of functional mouth opening throughout the displacement of the intra-articular condyloid process. This dynamic in TMJ articulation can be non-invasively assessed without using additional contrast agents with a method that is suitable even in non-sophisticated medical centres.

II. MATERIALS AND METHODS

TMJ dynamics were observed by the videofluoroscopic method in 23 volunteers (18 females, 5 males and age range, 19–51 years) who were self-declared as healthy with respect to chewing and swallowing. All volunteers underwent clinical evaluations to observe the structural and functional integrity of the dental arcades, freedom of movements of TMJ and tonus and sensibility of the chewing muscles. Complaints and alterations during the clinical evaluation were not considered sufficient to exclude any of the volunteers.

The videofluoroscopic evaluations were performed in a seated position on a specially equipped chair [28] fitted with radiologic equipment (BV-22 C-Arm, 100 KV, 25 mA, Phillips Corporation, Hanover, MD, USA) and a B/W Progressive Scan CCD Remote Head Video Camera (Mythos, 400 resolution lines, 31 × 31, 0.1 lux, f 3.6 mm, Sony Corporation, Tokyo, Japan). The exams were registered in digital media using a DVD recorder (DVDR3455H HDD & DVD Player/Recorder, Phillips Corporation).

The videofluoroscopic images of the left posterior oblique (LPO) incidence were captured over about 15^0 degrees, as estimated from a coupled protractor over the specially equipped chair. The contrasts registered in the obtained images were because of regional densities. No other type of contrast was used.

TMJ dynamics were assessed throughout rotation and translation of the condyloid process over the articular surface of the temporal bone (fossa and temporal tubercle) obtained by requesting mouth opening movements. At least five mouth opening and closing movements from intercuspation (centric occlusion) to maximum opening were registered.

The displacement of the condyloid process over the articular temporal surface was measured in millimetres using Vidiomed software (1-16-9.2002, Multimedia Lab, Computer Centre Electronics, Federal University of Rio de Janeiro). This software was used to for the qualitative and quantitative assessment. An acrylic plate marked with radiopaque squares of 2×2 cm^2 was fixed over the left side of the face of each volunteer as a metric reference to calibrate the software.

Qualitative and quantitative analyses of rotation and translation during basics movements of TMJ were performed. The extent of condyloid process displacement was measured based on the selected images of the series. These selected DVD images were converted to MPEG-4 (Moving Picture Experts Group) using Adobe Premiere Pro CS5 5.5.2 software (Adobe Systems Incorporated, San Jose, CA, USA) and a personal computer (Pentium D 820, 2800 MHz, Intel Corporation, Santa Clara, CA, USA) with a Microsoft Windows system (Microsoft Corporation, Redmond, WA, USA).

The measured values were obtained from the maximum occlusion to maximum mouth opening produced after solicitation of the volunteers. As a pattern to analyse the condyloid process displacement over the temporal surface, a horizontal line (line H) was projected over the TMJ level and subdivided into three spaces, defined as LL1, LL2 and LL3 (Figure 1)

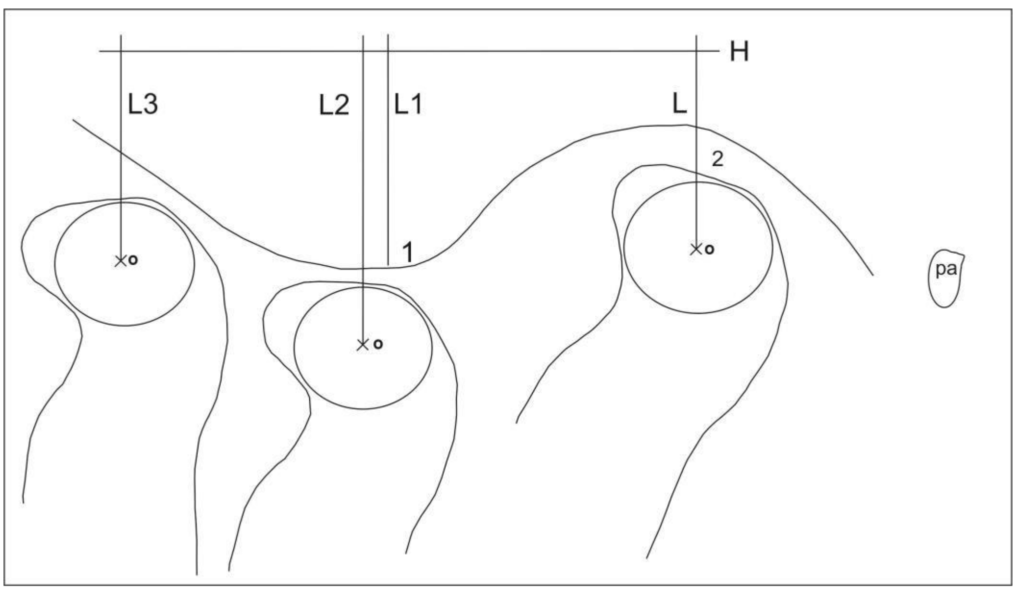

Fig.1: Draw representing the open mouse displacing with definitions of the points and lines to be used to quantify TMJ displacement.

LL1 represents the condyloid process displacement from line L (perpendicular from the mandibular condyle centre during the maximum occlusion position to line H) to line L1 (perpendicular from the temporal tubercle middle convexity to line H).

LL2 represents a displacement 5% in excess of LL1. Mouth opening until this individual point was considered to be an indication of the adequate possibility of TMJ free chewing movements because the condyloid process is already liberated from the temporal fossa and can freely accomplish other chewing movements.

LL3 represents condylar displacement obtained by maximum mouth opening after the solicitation of volunteers. LL3 is the value in millimetres from line L to line L3 (perpendicular

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from the mandibular condyle centre during maximum mouth opening to line H). Note that this value can be much larger or smaller than that of LL2.

A representation of displacement of mouth opening with definitions of the points and lines for quantification of TMJ displacement where pa = acustic porus, 1 = articular tubercle of the temporal bone, 2 = mandible fossa, 0 = mandibular condyle centre, H = horizontal line traced above the TMJ displacement surface, L = perpendicular line traced from the mandibular condyle centre, during the maximum occlusion position, to line H, L1 = perpendicular line traced from the temporal tubercle middle convexity to line H, L2 = perpendicular line traced to be 5% in excess of the LL1 value and L3 = perpendicular line traced from the mandibular condyle centre, during maximum mouth opening, to line H.

The methodology and purpose of the research as well as details of the videofluoroscopic study were fully explained to each volunteer. Written informed consent was obtained, and the study was performed in full compliance with the ethical tenets of the World Medical Association (WMA) Declaration of Helsinki, adopted by the 18th General Assembly, Finland, June 1964 and complemented by the 61a General Assembly of the WMA in Fortaleza, Brazil, 2012.

All statistical analysis were performed using the Mann–Whitney U test with GraphPad Prism version 4.00 (GraphPad Software, Inc., La Jolla, CA, USA). A probability (p) value of <0.05 was considered statistically significant.

III. RESULTS

Anamnesis and physical evaluation of the stomatognathic system were performed for all 23 volunteers, preliminary self-declared to be healthy and without any chewing or swallowing dysfunction. Distinct abnormalities, not considered sufficient for exclusion, were observed by direct evaluation in 11 of the volunteers (2 males and 9 females and age range, 19–51 years). Complaints included discreet pain during maximum mouth opening, clicking of TMJ, pain during the deep palpation of the temporal muscle and parotideomasseteric region, teeth clenching and wear, absence of two teeth (first molar and canine), absence of one teeth (first molar or canine) and crossbite (Table 1).

Table 1 - Functional and structural founds

Clinical evaluation									
Volunteers	*Sex*	*age*	*found A*	*found B*	*found C*	*found D*	*found E*	*found F*	*found G*
5	*F*	*28*	*X*	*X*	*X*	*X*			
7	*M*	*50*						*X*	
9	*F*	*21*		*X*					
10	*F*	*24*		*X*					
15	*F*	*21*		*X*			*X*		
16	*F*	*24*	*X*		*X*	*X*			*X*
17	*F*	*20*					*X*		*X*
18	*F*	*20*		*X*					
21	*F*	*19*	*X*		*X*	*X*			
22	*F*	*22*				*X*			
23	*M*	*51*				*X*	*X*	*X*	*X*
	Total		*3*	*5*	*3*	*5*	*3*	*2*	*3*

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Percent	*27%*	*45%*	*27%*	*45%*	*27%*	*18%*	*27%*

Table 1: obtained from clinical evaluation accomplished before video fluorsocopic study where was found functional and structural alterations considered as not able to exclude the volunteers because all of them refers no difficult in its chewing and swallow. The observed founds were A= dificult or discret pain during the maximum open mouth , B= complain of the eventual click in the TMJ, C= Pain complain during temporal and parotideomasetrin region palpation ,D= teeth clenching or teeth wear, E= absence up two teeth that no first molar and canine , F= Absence of the first molar or of the canine (occlusion keys), G= crossbite

LPO incidence was selected for the videofluoroscopic study because it allows the decomposition of the high-density profile produced by TMJ superposition with a clear identification of displacement of the mandibular condyle over the temporal surface, which can easily change the structural TMJ identification during mouth opening to identify and analyse the movement of the mandibular condyle over the temporal surface.

Qualitative analyses from the maximum occlusion to maximum mouth opening produced after solicitation of the volunteers were performed to establish a horizontal line (H) over the TMJ level. Three spaces, defined as LL1, LL2 and LL3, were used to qualify the limits of mouth opening. These three spaces were also used to quantify basic movements of TMJ (Figure 2).

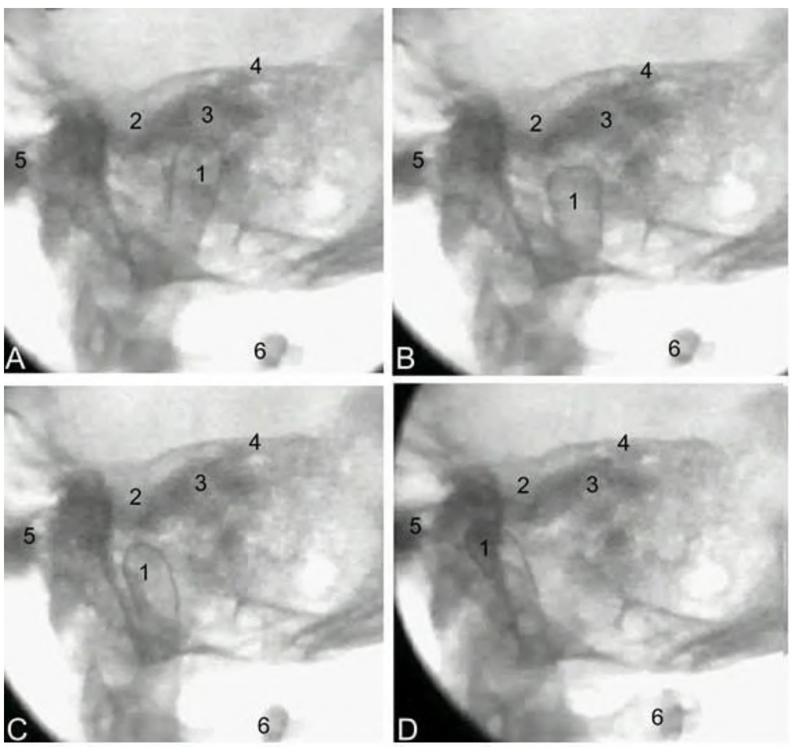

Fig.2. Oblique left profile images obtained from healthy volunteer video fluoroscopic exam in video pause where (A), the maxim intercuspidation (B and C) open mouse with TMJ displacement (D) maximum open mouth. 1- articular tubercle of left temporal bone , 2- mandible fosse of left temporal bone, 3- left condilus of mandible bone. There are A,B,C and D didactic accentuation of the mandible condilus outline.

A static video fluoroscopic image of occlusion was used to quantify condyle displacement (maximum intercuspid relation) after translation movement as well as other abnormalities possibly produced by maximum mouth opening (Figure 3*)*

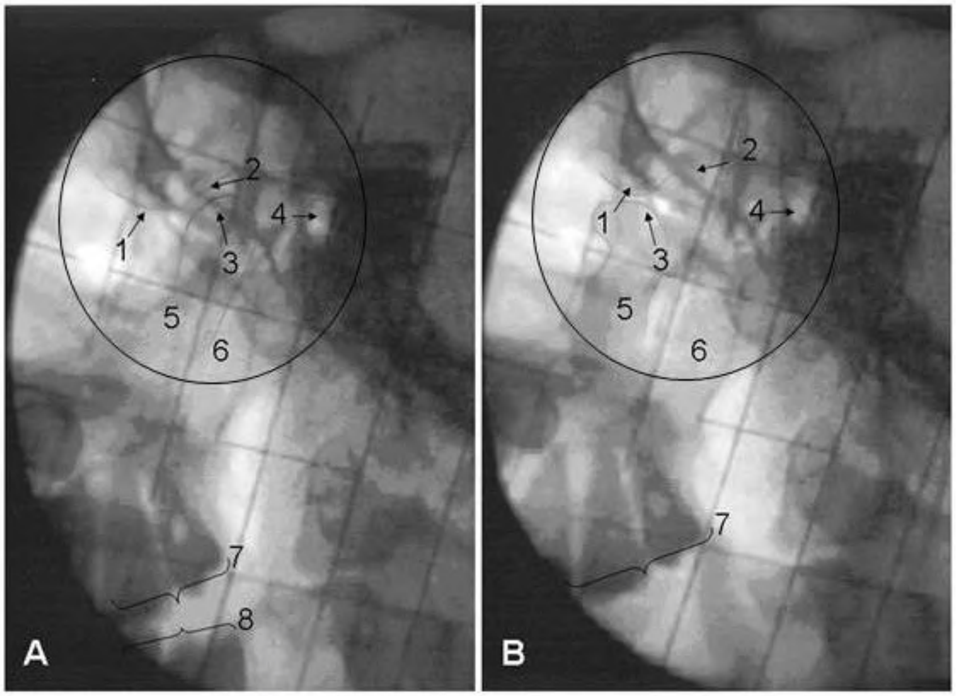

Fig.3: Oblique left profile images (180^0 rotated) obtained from healthy volunteer videofluoroscopic exam in video pause where (A), the maxim intercuspidation (B) maximum open mouth; where 1- articular tubercle of left temporal bone , 2- mandible fosse of left temporal bone, 3- left condilus of mandible bone, 4- left acoustic pore, 5- Left ascending branch of the jaw, 6- right ascending branch of the jaw, 7- projection of superior dental arcade and 8- projection of inferior dental arcade. See overlapping of acrylic plate with 2X2 cm squares used to metric calibration. There are A and B didactic accentuation of mandible condilus and temporal surface outline.

The video fluoroscopic study of mouth opening included a reference point at the central projection of the mandibular condyle, in the 17 volunteers, from line L, maximum inter-cuspid relation, to line L3. A line beyond L2, which is 5% (in millimetres) larger than line L1, is a perpendicular line that passes through the centre of the mandibular tubercle of the temporal bone. These volunteers were considered to be normal free (NF).

Six volunteers with a displacement of less than L2 were considered to be suspicious with respect to function (Table 2).

Table 2-volunters quantification displacement

Volunteers	**Sex**	**Age**	**LL1**	**LL2 = LL1 + 5%LL1**	**LL3**	**LL3 - LL2**	**Function**
V1	**M**	50	11,90	12,50	15,19	2,70	**NF**
V2	**M**	22	13,21	13,87	16,57	2,70	**NF**
V3	**F**	19	12,28	12,89	12,28	-0,61	**S**

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V4	**F**	27	11,64	12,22	16,00	3,78	**NF**
V5	**F**	28	9,84	10,33	13,12	2,79	**NF**
V6	**M**	23	13,22	13,88	16,51	2,63	**NF**
V7	**M**	50	15,82	16,61	16,72	0,11	**NF**
V8	**F**	21	12,51	13,14	13,99	0,85	**NF**
V9	**F**	21	16,84	17,68	18,01	0,33	**NF**
V10	**F**	24	11,25	11,81	12,53	0,72	**NF**
V11	**F**	20	12,25	12,86	14,44	1,58	**NF**
V12	**F**	23	13,17	13,83	15,41	1,58	**NF**
V13	**F**	19	12,81	13,45	10,29	-3,16	**S**
V14	**F**	24	13,17	13,83	15,21	1,38	**NF**
V15	**F**	21	8,77	9,21	5,84	-3,37	**S**
V16	**F**	24	13,02	13,67	16,74	3,07	**NF**
V17	**F**	20	11,99	12,59	9,03	-3,56	**S**
V18	**F**	20	15,56	16,34	19,30	2,96	**NF**
V19	**F**	27	17,01	17,86	18,52	0,66	**NF**
V20	**F**	25	12,47	13,09	10,63	-2,46	**S**
V21	**F**	19	11,88	12,47	12,55	0,08	**NF**
V22	**F**	22	13,24	13,90	12,68	-1,22	**S**
V23	**M**	53	11,63	12,21	14,81	2,60	**NF**

V - 23 M - 5 F - 18 NF -17 S - 6

Table 2- Quantification table where , (LL1)- it is the individual measure, in millimeters, of the mandible condilus displacement from the maxim occlusion (L) until the perpendicular line traced over temporal tubercle meddle convexity L1, (LL2)- LL1 value with 5% in excess, LL3- individual measure, in millimeters, of the obtained condilus displacement in the maxim open mouth, L3-L2 value when positive means functioal normality of TMJ displacement function . When negative possible TMJ functional limitation, *V – Volunteers, M – Male, F – Female, NF - Normal Free, S – Suspicious.*

Of the 17 volunteers with TMJ considered to be NF, nine had no complaints during mouth opening, whereas eight did. Of these eight volunteers, four had measurements of 1.58 mm larger than L2, two complained of masseter muscle compression pain maximum during mouth opening and two complained of clicking and crashing (bruxism).

Pain during mouth opening or digital compression of the masseter muscle also was detected in one of four volunteers determined to be NF with a measurement of less than 1.58 mm larger than L2. In this group, a second volunteer presented with crossbite and absence of the first molar and crashing (bruxism). The third and fourth volunteers complained of TMJ clicking. Of the six volunteers with a measurement of less than L2, considered to be suspicious (a measurement less than that expected as functional), three had no complaints and the other three complained of crashing, crossbite and clicking.

Of the 17 volunteers considered to be NF, nine had no complaints during mouth opening and eight did. Of six volunteers with a measurement of less than L2 (considered to be suspicious pertaining to their mouth opening function),

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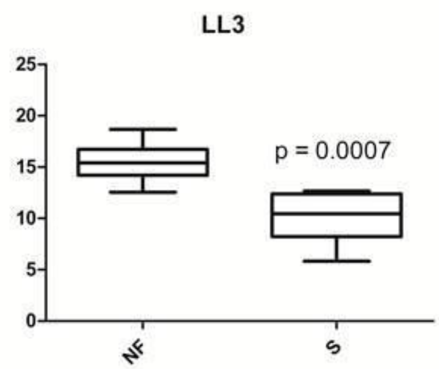
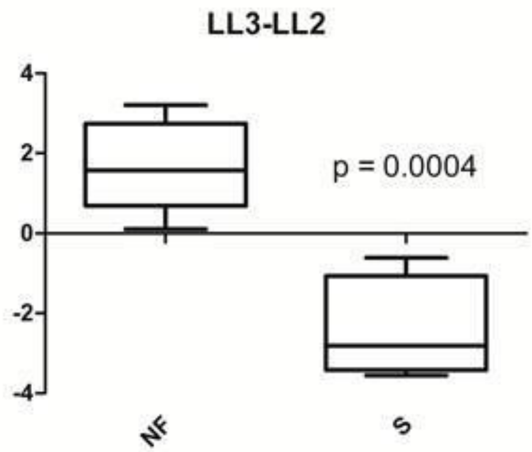
three had complaints. The presence or absence of complaints does not necessarily define normal or limited TMJ function.

The Mann–Whitney U test, a non-parametric test, revealed a clear distinction in the LL3 values between the NF and suspicious groups ($p < 0.0001$). Significance was also confirmed by the values L3-L2 ($p < 0.0001$). The measured L1 values and corresponding L2 values (with a 5% increase) showed no distinction between the NF and suspicious groups according to the maximum mouth opening results (GRAPHIC 1, 2)

GRAPHIC 1 - Displacement from L to L3



GRAPHIC 2 - Displacement >/< to LL2



IV. DISCUSSION

TMJ disturbances produce headache, dizziness and tinnitus, among other discomforts. Pain, in the projection of the TMJ, is a common complaint, affecting approximately 40% of the world adult population [9,29]. Women experience TMJ disturbances more frequently than men in a proportion that varies from 3:1 to 8:1. However, factors responsible for this predominance remain unknown [30,31].

Our study cohort included 23 volunteers of both sexes with none citing spontaneous clinical complaints or difficulties regarding chewing or swallowing. However, the preliminary evaluation found that 47.83% of the volunteers had some structural or functional abnormalities, not previously noticed by the volunteers. We did not exclude any of the volunteers from the study to compare volunteers with and without TMJ structural or functional abnormalities.

None of the selected volunteers had complaints, particularly pertaining to pain when chewing. However, six of the volunteers experienced pain because of the digital compression of the the masseter muscle or maximum mouth opening during clinical evaluation (26.08%), which was less than the 40% reported in the literature [9]. On the other hand, some structural or functional abnormalities with the possibility of interfering with TMJ function were detected in 47.83% of the volunteers.

Our cohort comprised 78.26% females and 21.73% males, thus comparisons between sexes could not be well established. However, alterations were detected in 50% of the 18 woman who initially declared no alterations or complaints. Of the five men, alterations were found in 40%. Although there was no statistical significance, TMJ dysfunction was predominant among females in the literature [30,31].

The videofluoroscopic method with low radiation exposition [25-27] and without contrast injection into TMJ allowed in the LPO incidence showed that the density of the mandibular condyle from the occluded centric was relative to the maximum mouth opening in each of the 23 studied volunteers.

Dynamic function of TMJ was evaluated by analysing rotation and translation movements of the mandibular condyle over the articular surface of the temporal bone. The concept of mandibular condyle displacement is that motion is limited until beyond the middle line of the articular tubercle of the temporal bone. Motion beyond this limit is considered subluxation when TMJ returns to the previous position either spontaneously or by luxation, during which the return may require external help [31]. The articular tubercle of the temporal bone is considered a mechanical barrier that is able to block the displacement of the mandibular condyle [32]. Displacement of the mandibular condyle beyond the maximum limit of natural mouth opening can occur in a forced manner. This condition is typically present among persons predisposed to subluxation [31].

Based on the anatomical description of TMJ, we do not consider the articular tubercle of the temporal bone to be a mechanical obstacle pertaining to condyle displacement. Both the mandibular condyle and articular tubercle of the temporal bone are joined with the articular disk and other structures by the articular capsule of TMJ. Thus, the temporal tubercle surface is necessarily in a relation with the articular disk and consequently with the mandibular condyle, as already stated.

Qualitative analyses of mandibular condyle displacement over the articular temporal surface was used to create a diagram of mouth opening movements with specific marks as reference quantification of movement, as described in the Materials and Methods section.

Seventeen volunteers of both sexes (74% female) were able, without any discomfort, to undergo videofluoroscopy. Condyle displacement was beyond 5% of the temporal tubercle middle line (L2). A central mark in the mandibular condyle went beyond L2 from 0.08 to 3.78 mm (average, 1.79 mm). Of these 17 volunteers, L2 was extended by at least 1.38 mm in 11. Free and natural displacement of the mandibular condyle over the articular tubercle of the temporal bone was observed in all 17 volunteers. Moreover, all were able to easily close their mouths without any discomfort and none reported a history of luxation or any discomfort when chewing or mouth opening and closing.

Quantitative analyses of mandibular condyle displacement over the temporal bone articular surface, as already observed by qualitative analysis, showed that displacement beyond what is considered as usual was limited by the temporal tubercle not passing L1, which includes the temporal tubercle centre. Mandibular condyle centre displacement from the maximum intercuspid relation of at least 5% more than L1 was observed in all 17 volunteers. This new point, called L2, was considered normal and functional and could less likely to limit condylar centre displacement (NF).

Of the 17 volunteers with normal and functional mouth opening (NF), L2 was greater than 1.58 mm in 10. Only two of these 10 volunteers and one more with normal and functional displacement less than 1.58 mm complained of pain during maximum mouth opening or pressure at the masseter region. Fourteen volunteers had no complaint, indicating that mouth opening beyond L2 is (with statistical significance) normal and functional.

Of the 23 studied volunteers, six had suspected function with mouth opening, as condyle displacement was equivalent or less than L1. However, none complained of difficulty during chewing or swallowing. The clinical evaluation results showed that three of the volunteers had no problems with mouth opening, whereas three other present troubles also observed at volunteers classified as normal and functional. Although mouth opening classified as NF could be considered as desired, TMJ functionality was not significantly compromised if the mandibular condyle displacement reached the temporal bone articular tubercle without impairment. However, persons with suspicious condilar displacement and NF persons with clinical founds must, both, pay larger professional attention.

Mouth opening is TMJ dependent. However, TMJ efficiency can be indirectly measured according to the space between the superior and inferior incisors, resulting in conflicting values several times [12,13]. The mandibular condyle, in its normal course during maximum mouth opening in health volunteers can be displaced, and should not be considered as indicative of TMJ subluxation or predisposition to luxation. It is possible that this flawed theory was because of indirect observation of TMJ function, which is nowadays visualized by videofluoroscopy, a dynamic radiological method that allows necessary revision of this erroneous concept.

V. CONCLUSIONS

Although fundamental, the clinical evaluation with slight structural abnormalities and complaints does not represent functional limitations of TMJ, as observed by the videofluoroscopic study. Comparative analysis of the clinical and videofluoroscopic results showed that the videofluoroscopic exam is a useful method to evaluate TMJ function and clarified that clinical complaints do not define functional limitations of TMJ that was classified as normal in 17 (74%) of the 23 volunteers.

The non-parametric statistical analyses using the Mann–Whitney U test revealed significant differences in mouth opening capability between the NF and suspicious groups ($p < 0.0001$). Measured values for LL3 greater than LL2 as well positive values for L3-L2 can be considered as NF and negative values for L3-L2 can be considered as suspicious, with a significance of $p < 0.0001$. L2 was statistically confirmed as a good parameter for the distinction of normal and suspicious functionality of TMJ.

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