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Comprehensive Three Dimensional Cone Beam Computed Tomography Analysis of the Temporomandibular Joint

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ABSTRACT

Background: Temporomandibular joint (TMJ) is an integral part of the masticatory apparatus that is in direct coordination with the teeth and the masticatory muscles. Many connections have been proposed regarding the correlation between malocclusion and temporomandibular disorders (TMD), as well as the effect of orthodontic treatment and orthognathic surgery on the temporomandibular joints. With the advent of new advances in three dimensional imaging modalities as that provided by cone beam computed tomography (CBCT), an accurate method for analyzing this region is now possible. **Objective:** To present a standardized stepwise comprehensive CBCT analysis of the temporomandibular joints including new descriptive measurements in the three orthogonal planes. **Results:** The multiplanar view was selected as the measuring view in this analysis, because in the TMJ view, the area of interest is too small rendering measurements on this view difficult and inaccurate. **Conclusion:** A stepwise standardized CBCT analysis of the TMJ is presented. Through using this detailed analysis, orthodontists can three dimensionally evaluate morphological and positional changes in the TMJ.

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INTRODUCTION

Temporomandibular joint (TMJ) consists of both bony components; mandibular condyle, mandibular fossa and soft tissue components; articular disc and retrodiscal tissue, which are connected to muscles of mastication and dentitions that work together in rhythm and harmony (Okeson, 2012). The relationships between malocclusion and orthodontic treatment with development of signs and symptoms of temporomandibular disorders (TMD) have been widely discussed in the literature. The influence of occlusion on joint morphology is still not completely understood; some studies suggested the existence of direct relation between malocclusion and TMD in some features (Mongini and Schmid, 1987; Pullinger *et al*., 1987) while Vitral *et al*., (2011) failed to find any correlations. The same controversy exists between orthodontic treatment modalities and changes in TMJ region, some suggested that orthodontics have been both accused of causing and complimented for curing temporomandibular disorders based on changes in condylar position (Reynders, 1990), while Hirata *et al*., (1992) concluded that orthodontic treatment has no positive or negative influence. Part of this controversy is due to the difference in the evaluation techniques at the time of study, and the use of subjective scoring systems rather than standardized methods for analyzing this complex region (Mohlin *et al*., 2004).

Historically; transcranial projections, panoramic radiograph and axial corrected tomography were the most commonly used modalities in the radiographic assessment of the TMJ in orthodontic practice because of availability, ease of use, low radiation requirement and low cost (Brooks *et al*., 1997). Many researchers have used the panoramic radiograph to assess changes in the TMJ due to orthopedic appliances (Uematsu *et al*., 2002) and orthodontics (Peltola *et al*., 1995). The inherent anatomic diversity of the TMJ articulation, the factors that influence 2-dimensional (2D) image presentation e.g., anatomic superimposition, beam projection angle and impossibility for proper and reproducible patient positioning made validity of these modalities doubtful (Solberg *et al*., 1985).

Magnetic resonance imaging (MRI) is considered the golden standard for imaging TMJ; but it is mainly designed for examination of soft tissue components, quite expensive and takes long imaging time (Quereshy *et*

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al., 2008). Although multi-slice computed tomography (MSCT) provides optimal imaging of the osseous components of the TMJ, most CT scanners are large, expensive and deliver high radiation dose. They are mainly designed for full-body imaging and are not readily available to the orthodontist. Recently, maxillofacial cone beam CT (CBCT) has developed specifically for the maxillofacial region (Hashimoto *et al*., 2003).

Few studies have discussed different measurements of the temporomandibular joints using CBCT, but none of them completely described the actual three dimensional views. Furthermore, previously published methods have less clear description regarding the way of standardization of the extracted data, which is due to variations in orientation of the condyle in the three planes of space (Vitral and Telles, 2002; Vitral *et al*., 2004; Rodrigues *et al*., 2009[a]; Rodrigues *et al*., 2009[b]) .

The clinical significance of having a detailed CBCT analysis for TMJ is, that it would aid in evaluating the morphological differences in the TMJ in different maxillofacial configurations and assessing the morphological and positional TMJ changes following orthodontic treatment e.g: extraction and non-extraction treatment, orthopedic treatments e.g: facemask therapy and functional appliances as well as orthognathic surgery. Thus, the aim of this article is to present a comprehensive standardized analysis for measuring the morphology and position of the temporomandibular joint components.

MATERIAL AND METHODS

The CBCT analysis presented was obtained from a full head cone beam CT images of patients in maximum dental intercuspation. During scanning, the patient position was standardized as follow; the Frankfort horizontal plane was parallel to the floor and midsagittal plane was perpendicular to the Frankfort horizontal plane. The CBCT scan was performed with the next generation i-CAT CBCT unit (Imaging Sciences International, Hatfield, PA, USA) at 120 kV, 5 mA and 7 second exposure time with source-to-detector distance of 67.5 cm. The voxel dimension selected was 0.3 mm. The image detector was a flat panel measuring 20 × 25 cm, image acquired at 14 bits in a single 360° rotation. The measurements were determined by tracing the selected image structures using Dolphin software (Dolphin Imaging and Management Solutions, Chatsworth, CA, USA). Unlike images in most CT, the CBCT images dimensions correspond to the real sizes of the structures; therefore, no need for a scale of measurements conversion (Yim *et al*., 2011). TMJ can be visualized in both the multiplanar and TMJ views provided by the software. However, the multiplanar view was selected as the measuring view in this analysis, because in the TMJ view, the area of interest is too small rendering measurements on this view difficult and inaccurate.

Temporomandibular joint analysis:
I- Sagittal section of the multiplanar view:
Method of orientation standardization:

Slicing in the sagittal view should be standardized for more accuracy and reproducibility, for this reason the sagittal cuts should be parallel to the long axes of the condyles, which was achieved by reorientation of each condyle separately in the axial view till the long axis (mediolateral dimension) makes 90^{O} with the midsagittal plane (MSP) (Fig 1, a).

Reference lines:

1- Tuberculo-meatal line (TM): the line between the most inferior point of the articular tubercle to the most inferior point of the auditory meatus (Vitral *et al*.,2004; Vitral *et al*.,2011) (Fig 1, b).
2- Horizontal line: the line parallel to Frankfort horizontal plane and passing tangent to the most superior point of the mandibular fossa (Fig 1, b). Sagittal section measurements (table 1).

II- Axial section of the multiplanar view:
Method of orientation standardization:

The axial section was reoriented so that the midsagittal plane should pass through the most accurately represented points in the midline of the skull base to check the actual orientation and position of the condyles. Those points are; posterior nasal spine, the most inferior point of anterior margin of foramen magnum [basion (Ba)], the most inferior point of posterior margin of the same landmark [opisthion (Op)] and external occipital crest (EOC) which is a ridge structure along the midline at the bottom of the skull (Barkovich *et al*., 1986) (Fig 6).

Reference line:

The mid-sagittal plane: the line bisecting the skull base into two equal halves (Fig 6). Axial section measurements (table 2).

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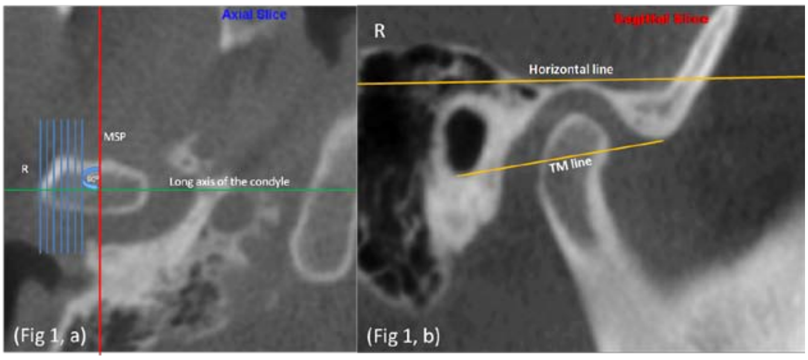

Fig. 1: a) The long axis of right condyle (mediolateral dimension) makes 90^{O} with the midsagittal plane, b) Tuberculo-meatal line (TM) and horizontal line (HL).

Table 1: Definition of the TMJ measurements in the sagittal view.

Measurement	Abbreviation	Definition
Mandibular fossa height	MFH	The perpendicular linear distance from the most superior point in the mandibular fossa to the TM line (Fig 2).
Condylar height	CH	The perpendicular linear distance from the most superior point in the condylar head to the TM line (Fig 2).
Mandibular fossa width	MFW	The linear distance from the most inferior point of the articular tubercle to the junction between the TM line and the posterior slope of the mandibular fossa parallel to the TM line (in case of flat articular tubercle the anterior point of this line should be the most posterior point in the tubercle area) (Fig 2).
Height of articular tubercle	HAT	The perpendicular linear distance from the most inferior point in the articular tubercle to the horizontal line (Fig 2).
Anterior Joint Space	AJS	The shortest distance between the most anterior point of the condyle and the posterior wall of the articular tubercle (Fig 3).
Superior Joint Space	SJS	The shortest distance between the most superior point of the condyle and the most superior point of the mandibular fossa (Fig 3).
Posterior Joint Space	PJS	The shortest distance between the most posterior point of the condyle and the posterior wall of the mandibular fossa (Fig 3).
Anterior Fossa Inclination Angle	AFIA	The formed angular measurement between the line tangent to the anterior slope of the mandibular fossa and the TM line (Fig 4).
Posterior Fossa Inclination Angle	PFIA	The angle formed between the line tangent to the posterior slope of the mandibular fossa and the TM line (Fig 4).
Sagittal Condylar Surface Area	SCSA	The total anterior, superior and posterior surface area of the condylar head bounded by the TM line in mm (Fig 5, a).
Mandibular Fossa Surface Area	MFSA	The total anterior, superior and posterior surface area of the mandibular fossa bounded by the TM line in mm (Fig 5, a).
Total Joint Spaces	TGS	The total slice area of anterior, superior and posterior joint spaces bounded by the TM line and measured by mm^2 (Fig 5, b).
Total Joint Area	TJA	The overall area of the whole joint including the condylar head occupying area which measured in mm^2 (Fig 5, c).

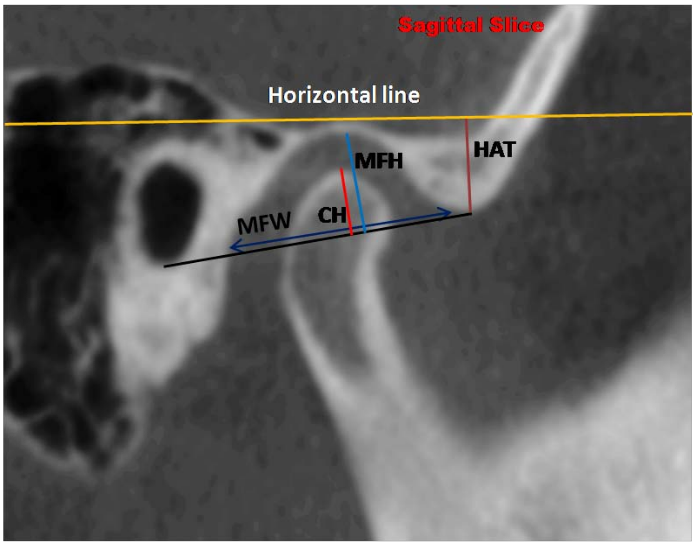

Fig 2: Mandibular Fossa Height (MFH), Condylar Height (CH), Mandibular Fossa Width (MFW) and Height of Articular Tubercle (HAT).

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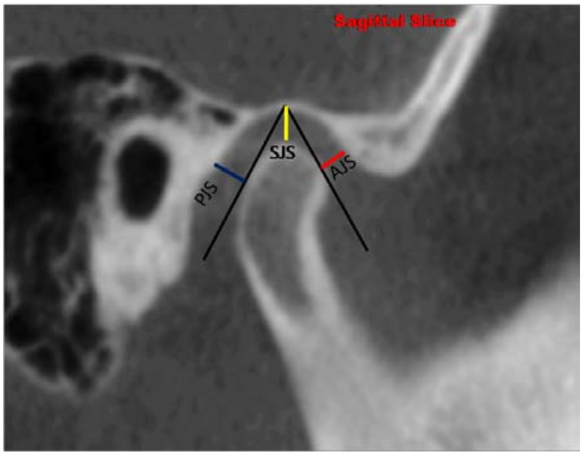

Fig. 3: Anterior joint space (AJS)**,** Superior Joint Space (SJS) and Posterior Joint Space (PJS).

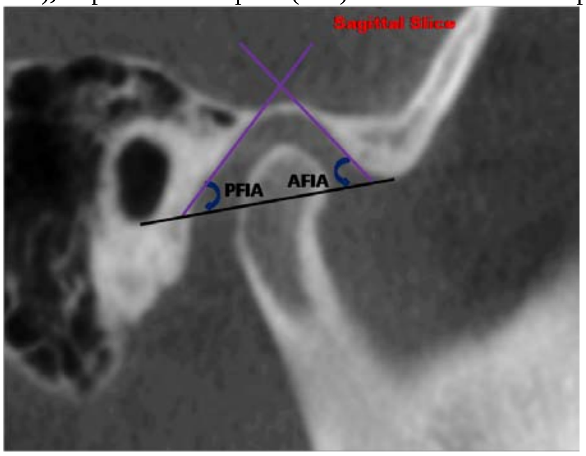

Fig. 4: Anterior Fossa Inclination Angle (AFIA) and Posterior Fossa Inclination Angle (PFIA).

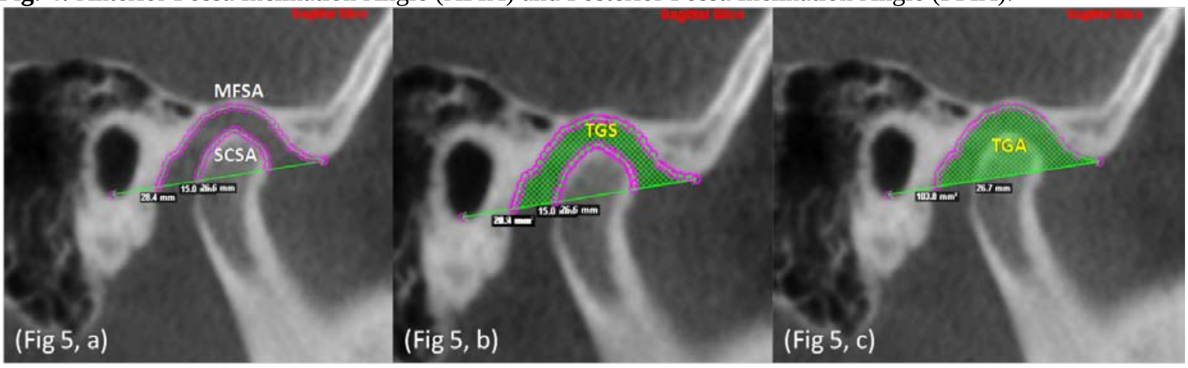

Fig. 5: a) Sagittal Condylar Surface Area (SCSA), Mandibular Fossa Surface Area (MFSA), b) Total Joint Spaces (TGS) and c) Total Joint Area (TJA).

Table 2: Definition of the TMJ measurements in the axial view.

Measurement	Abbreviation	Definition
Condylar Length	CL	The largest mediolateral dimension of the mandibular condylar head (Fig 7).
Condylar Width	CW	The largest anteroposterior dimension of the mandibular condylar head (Fig 7).
Geometric Condylar Position	GCP	The distance between the geometric centers of the condylar processes perpendicular to the midsagittal plane (Fig 7).
Point Condylar Position	PCP	The distance between the most medial point of the condylar processes perpendicular to the midsagittal plane (Fig 7).
Inter-condylar Distance	ICD	The distance either between the two geometric centers or the most medial points of both condylar heads (Fig 7).
Condylar Inclination Angle	CIA	The angle between the long axis of the mandibular condylar process and the midsagittal plane (Fig 8).
Axial Condylar Surface Area	ACSA	The total anterior, posterior, medial and lateral surface area of the mandibular condyle in mm (Fig 8).

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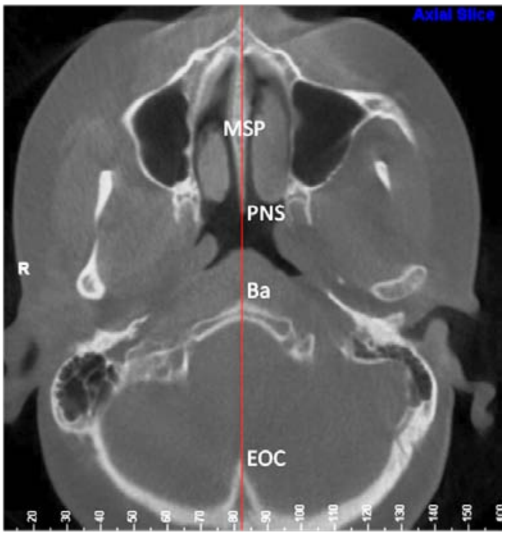

Fig. 6: Method of standard orientation and reference line in axial view.

III- Coronal section of the multiplanar view:
Method of orientation standardization:

For proper assessment of the condylar position in the vertical direction an accurate orientation of the midsagittal plane is required. If only measurements are needed in this view, reorientation of this view is essential, so that the midsagittal plane coincide with the external occipital crest; because it is the only anatomical landmarks in the midline that can be displayed in coronal section (Barkovich *et al*., 1986).

Reference line:

True Horizontal Line (THL): it is the line perpendicular to the midsagittal plane in the coronal view (Fig 9). Coronal section measurements (table 3).

Table 3: Definition of the TMJ measurements in the coronal view.

Measurement	Abbreviation	Definition
Medial Joint Space	MJS	The shortest distance between the most medial point of the condylar head and the most lateral point of the mandibular fossa (measuring this space from axial view is inaccurate and unreliable due to sutural variation in the medial aspect of the mandibular fossa) (Fig 9).
Vertical Condylar Position	VCP	The perpendicular vertical distance between the most superior point of condylar head and the true horizontal line (Fig 9).

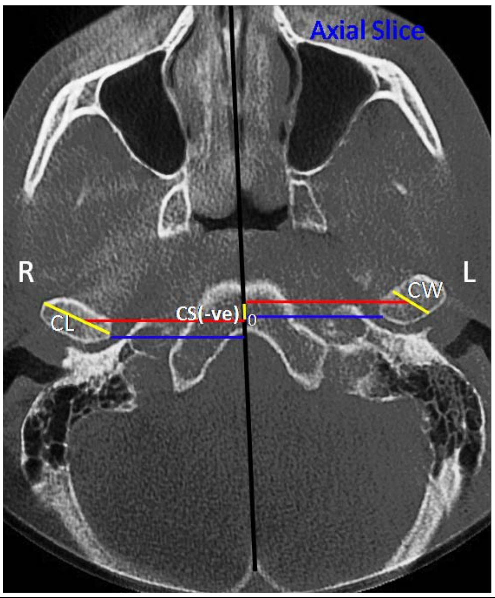

Fig. 7: Condylar Length (CL), Condylar Width (CW), Geometric Condylar Position (GCP), Point Condylar Position (PCP) and Condylar Symmetry (CS).

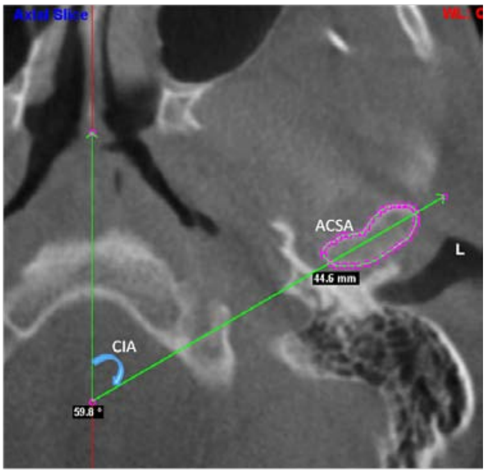

Fig. 8: Condylar Inclination Angle (CIA) and Axial Condylar Surface Area (APCSA).

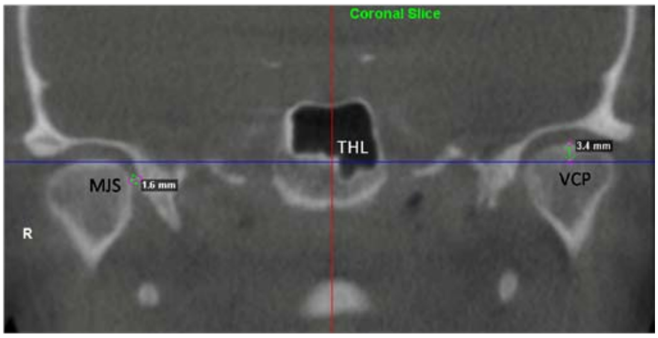

Fig. 9: True Horizontal line (THL), Medial Joint Space (MJS) and Vertical Condylar Position (VCP).

VI- Assessment of condylar position and symmetry:

According to the former described analysis, any morphological changes can be detected. Furthermore, accurate three dimensional assessments of the condylar position as well as condylar symmetry would be feasible as follows:

A- Within the joint space:

1- Antero-posterior condylar position in joint space: represents the position of the condylar head inside the joint, it depends on the anterior and posterior joint spaces, and is calculated by the following equation [(PJS- AJS / PJS + AJS) × 100] (Pullinger and Hollender, 1986).
2- Vertical condylar position in joint space: assesses the position of the condylar head inside the joint that based on the superior joint spaces and calculated by the equation [(MFH) - (CH)].
3- Medio-lateral position in joint space: this position can be determined only based on obtaining norms of the medial joint space.

B- Condylar symmetry evaluation:

1- Antero-posterior condylar symmetry: assessed by the anteroposterior difference between the geometric center or the most medial point of the right and left condylar processes in relation to the midsagittal plane. The point representing the geometric center of the right condylar process is considered the 0 point. If the geometric center of left side is posterior to the 0 point, it is considered positive, but if it is anterior to it, it is considered negative (Vitral *et al*., 2002; Vitral *et al*., 2004).
2- Vertical condylar symmetry: assessed by the vertical difference between the most superior point of the right and left condylar processes in relation to the horizontal line. If the most superior point of left side is inferior to the horizontal line, it is considered positive, but if it is superior to it, it is considered negative.
3- Medio-lateral condylar symmetry: assessed by the mediolateral difference between the geometric center or the most medial point of the right and left condylar processes in relation to the midsagittal plane. If the point representing the geometric center or the most medial point of the right condylar process is medial to midsagittal plane, it is considered positive, but if it is lateral to it, it is considered negative.

Discussion:

According to the most recently conducted systematic reviews addressing the correlation between malocclusion, orthodontic treatment modalities and changes induced in the temporomandibular joints, the subject is still controversial (Mohlin *et al*., 2007; Luther *et al*., 2010; Antoszewska and Kosior, 2012) . The need for evidence based studies investigating this issue and resolving this dilemma is essential. The use of reliable 3D imaging and the presence of standardized and comprehensive analysis of the complex TMJ region would strengthen the evidence in such studies. CBCT has emerged several years ago with vast applications in craniofacial region. This technology provides increased precision, rapid scan time, reduced dose, display modes unique to maxillofacial imaging, reduced image artifacts and lower costs compared with medical fan beam CT (Rugani, 2009).

One of the most challenging problems in evaluating TMJs is the great variation in the orientation of the condyle even in the same individual between the right and the left sides. Upon imaging TMJ with CBCT; if measurements are done directly on the sagittal slice of the multiplanar view without considering variability in condylar orientation, inconsistent data will be yielded. In some softwares e.g: Dolphin and Anatomage softwares; TMJ view is an option that is supplied with a scout image that allows reorientation of slices to be perpendicular to the long axis of the condylar, but this view is extremely small to measure on, making accuracy and reproducibility difficult to achieve. For those reasons, orientation of the axial section in the multiplanar view based on the long axis of the condyle in each side is mandatory when deciding to perform a standard TMJ analysis.

In the presented analysis; the method of orientation was based on the long axis of the condyle in the sagittal section and midsagittal plane in both axial and coronal sections of the multiplanar view. The best reference lines to be used were the tuberculo-meatal line in sagittal view, midsagittal plane in axial view and true horizontal line in coronal view, but in case of active sutural growth the TM line can be substituted with horizontal line or a line parallel to it and tangent to the most superior point of bony mandibular fossa in the sagittal section; as the anterior point of the TM line might be considered unstable landmark in this case (Sülün *et al*., 2001).

In the sagittal view; the significance of measuring the mandibular fossa height can be explained as follows; the decrease in height is directly correlated to a decrease in the superior joint space, which will subsequently reduce articular disc space inferring an anterior disc displacement (Pancherz and Michailidou, 2004). Downward and forward movement of mandibular fossa in cases of functional appliances therapy might be associated with reduction of mandibular fossa height (Uysal, 2009).

There are three clinical values for measuring condylar height; 1) Assessment of the right and the left side symmetry as in cases of posterior crossbite or asymmetric molar relationship. 2) Assessment of vertical condylar position inside the joint. 3) Evaluation of surface irregularity or osteophytes that may appears in specific TMJ disorders or following any type of treatment (Kiki *et al*., 2007). Mandibular fossa width is one of the main variables that affect the anteroposterior condylar position in the joint space, as it is wider in cases of anterior condylar position as Class III malocclusion (Oztan *et al*., 2005).

The height of articular tubercle is directly related to anterior guidance and cuspal steepness of the primary and permanent dentition; as it is increased throughout the growth period and reduced with age. It is also an important measurement in cases of chronic recurrent dislocation, as the possibility of dislocation increased with reduction of articular tubercle (Vasconcelos *et al*., 2009). Articular eminence inclination seems to be related to overbite and overjet in both protrusive and laterotrusive excursions. It has been suggested that a steeper articular eminence may predispose to temporomandibular joint dysfunction, as seen in Class II division 2 malocclusion cases which are characterized by steeper and higher articular eminences. This emphasizes the importance of such measurement in the evaluation of the possibility of relapse following orthopedic treatment of Class II malocclusion with functional appliances (Sülün *et al*., 2001).

Anterior and posterior joint spaces are determinants for condylar fossa relationship and anteroposterior condylar position based on the formula presented by (Pullinger and Hollender, 1986) or by posterior to anterior joint space ratio. Giuntini *et al*., (2008) concluded that anterior joint space might be increased in Class II malocclusion and reduced in Class III malocclusion. Wang *et al*., (2010) stated that decreased anterior joint space might be an indication of anterior disc displacement specially when accompanied with reduced superior joint space and vice versa. Leonardi *et al*., (2012) found that all three joint spaces might be increased following rapid maxillary expansion in cases of posterior crossbite.

In cases of active craniofacial growth and the use of orthopedic appliances, the accompanied remodeling process may change the surface area of the condyle as well as the mandibular fossa outline. For these reasons linear and angular measurements are not as accurate as surface area of mandibular condylar head, mandibular fossa, total joint space and total joint area in assessing the effect of such appliances on the TMJs. All these variable are totally related to each other, as any changes in condylar or mandibular fossa outline will directly affect the total joint space while total joint area is mainly affected by the mandibular fossa. If total joint space decreased, this might be due to reduced surface area of it is boundaries (mandibular condyle and / or mandibular fossa) or change in position of both. This could be valuable in 1) Evaluation of effect of functional appliance therapy, whether skeletal Class II correction is due to condylar growth (increased surface area) or condylar repositioning only (Woodside *et al*., 1987). 2) Assessment of the effect of different treatment modalities in treating skeletal Class III malocclusion on condylar surface area (De Clerck *et al*., 2012). 3) Determination the incidence of condylar resorption following orthodontic treatment or orthognathic surgery (Kurita *et al*., 2011).

Condylar length and width should be measured in the axial view, although condylar length can be measured from the coronal view and condylar width can be measured from the sagittal view, but the full dimension will appears only when cuts are parallel to long axis of the condyle in both views. Most of studies assessed anteroposterior position of the condyles used their geometric center (Vitral *et al*., 2002; Vitral *et al*., 2004; Vitral *et al*., 2011). The presented analysis suggests adding a measurement in evaluating anteroposterior and mediolateral condylar position based on the most medial point of the condyle because geometric center may change with increased or decreased condylar size even with the most medial point is in its position. All these measurements together with axial condylar inclination angle are mainly assessed following craniofacial growth, changes following the use of orthopedic appliances in correction of skeletal problems and long term follow up of corrected orthognathic surgical cases as the risk of relapse is mainly due to mediolateral torquing or posterior displacement of the condyle with rigid fixation (Arici *et al*., 2008; Moraes *et al*., 2102).

In the coronal view; Almăşan *et al*., (2013) suggested that the medial joint space might be increased in cases susceptible to disc displacement as this displacement mostly occurs in anteromedial direction. This space might be reduced in cases of functional shift in the side opposite to this shift as a result of long term remodeling process.

In orthodontic literature, there is diversity of results regarding the condylar position in different malocclusions; Giuntini *et al*., (2008) stated that condyle was more posteriorly positioned in Class II malocclusion. Prabhat *et al*., (2012) concluded that the condyle is centered in this type of malocclusion. Gianelly *et al*., (1991) showed that the condyle was anteriorly positioned in Class II malocclusion. The same controversy exists regarding other type of malocclusion, relationship between TMD and condylar position as well as the effect of orthodontic and orthopedic treatment on the same variable (Cholasueksa *et al*., 2004).

Borstlap *et al*., (2004) concluded that condylar position was significantly associated with disc displacement, especially in joints with reducible disk displacement. The condyle was dislocated posteriorly in these joints compared with normal TMJs, concentric condyle may be an indication for permanent disc displacement for long period of time. If condyle is more inferiorly positioned in vertical direction, this will be a risk factor for anterior disc displacement and condylar dislocation.

The presented stepwise standardized three dimensional TMJ analysis would aid in future objective evidence based assessment of the effect of different orthodontic treatment protocols on the TMJ, and whether correlation exists between malocclusion, orthodontic or orthopedic treatment and temporomandibular disorders.

Conclusions:

1- A stepwise standardized CBCT analysis of the TMJ is presented. Through using this detailed analysis, orthodontists can three dimensionally evaluate morphological and positional changes in the TMJ.
2- The analysis provided descriptive measurements for condylar position in the three orthogonal planes in relation to the joint spaces and for assessment of condylar symmetry.
3- Slice area and polygonal measurements presented in this analysis are capable of detecting even small osseous changes in the temporomandibular joint components.

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