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Original Research Article

The Morphometric Analysis of Mandibular Condyle, Coronoid Process and Body of Mandible in Different Malocclusions in 3D CBCT

Dr. Hema Y[1], Dr. Akhilanand Chaurasia[1*], Dr. Chetana Arora[2], Dr. Ranjitkumar Patil[1], Dr. Saman Ishrat[3]

[1]Department of Oral Medicine and Radiology, King George Medical University, Lucknow, India
[2]Department of Conservative Dentistry and Endodontics, Santosh Dental College Ghaziabaad, U. P, India
[3]Department of Oral Medicine and Radiology, Rama Dental College, Rama University, Kanpur, U. P, India

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***Corresponding author:** Akhilanand Chaurasia

Abstract

Background: The aim of present study is to determine the volume of the mandibular condyle, coronoid process and mandibular body and it's correlation with age and sex in malocclusions with the help of 3D Cone Beam Computed Tomography (CBCT) scans. ***Materials and Methods:*** 3D CBCT (Care stream 9000cc, USA) scans of 150 patients who had Class I, II, and III malocclusions were analyzed with Dolphin Imaging Software V11.9 to measure the volumes of mandibular condyle, coronoid process and mandibular body. ***Results:*** In the age group 14.1-18 years, the volume of condyle, coronoid process and body of mandible was noted to be highest. Among the malocclusions studied, the volumes of all 3 variables were maximum in Class I malocclusion. Mean coronoid volume and volume of body of mandible was noted to be higher in males than females while mean condylar volume was higher in females. ***Conclusions:*** 3D CBCT morphometry shows volumetric variations in mandible are related to age and type of occlusion. Mandible bone volume also shows sexual dimorphism.

Keywords: 3D CBCT, Morphometry, Malocclusion, Age estimation, Mandibular Condyle, Coronoid Process, Body of Mandible.

INTRODUCTION

Between 1895 and 1898, German scientist Wilhelm Conrad Roentgen published two communications reporting the discovery of a unique "discharge" to which "all bodies are transparent" [1]. The said agent is X-rays and its property to be able to pass through opaque objects allowed scientists for the first time to view the internal structure of an object without destroying it. Within 8 years of the discovery, Gorjanovic-Kramberger used X-rays to perform a non-invasive study of crania of Krapina Early Man [2].

August J. Pacini in 1921 put forward the use of X-rays in anthropometry. He standardised the method of acquiring image by fixing the distance between X-ray source and receptor and by aligning the median sagittal plane of patient's head parallel to the film [3]. L B Higley elaborated the use of dental X-ray machine for the purpose of cephalometric roentgenography [4]. Updegrave described principles for imaging of temporomandibular joint [5].

The techniques to study temporomandibular joint for the purpose of orthodontic treatment were being rapidly refined with the advent of X-rays. Yet despite of its novelty, the limitation of using X-ray film imaging soon became obvious. Even the best made film radiographs are still a two dimensional representation of a three dimensional structure. The distortion then in final image and the actual structure it represents is along the same lines as flattening a globe to a map and the consequent changes in distances measurable on either form. This problem was solved by Godfrey Hounsfield [6]. The advantage of CT imaging and research into concerns for limiting radiation exposure and reducing imaging time has led to the development of cone beam computed tomography in recent times.

Computed tomography allowed researchers to finally see a three dimensional object as a three dimensional one and even assess its internal structure. The applications of such advancement are manifold. In anthropology, especially large volumes of data can be analysed and a huge database of populations can be created for understanding the structure and variations in bones. A serious drawback of CT however is the high exposure to radiation. Brenner and Hall published a review of radiation exposure in CT in which they extrapolated the estimated lifetime risk of death from cancer to be as high as 1.5 to 2.0% that could be attributed to the use of CT. One of the ways in which the authors suggested reduction in radiation dose to the patient is exploring other imaging options wherever practical [7].

In later part of nineties, a new technology called Cone Beam Computed Tomography (CBCT) became available to do just that acquired cross sectional images of bone and reduce radiation exposure. Because an entire Field of View (FoV) is covered in one single or partial scan, no translation of receptor is involved and radiographs can be made rapidly and with much less radiation dose in imaging than in a helical or spiral CT [8]. This was an advantage over conventional CT with reduced radiation exposure. In our study, we have used CBCT images of patients having different malocclusions to evaluate the volume of the mandibular condyle, coronoid process, and mandibular body and the calculated volume is correlated with age and sex.

MATERIALS AND METHODS

3D CBCT scans of 150 Indian subjects aged between 10 to 24 years were obtained with Care stream 9000cc (USA) CBCT machine at the Radiology Clinic of the Department of Oral Medicine and Radiology. Scans has been performed at 90kVp, 4mA for 11.3 seconds within a FoV (field of view) of 17”x13.5” and a voxel size of 300. The image collection was done retrospectively with informed consent obtained from patients. The dicom files of CBCT (Malocclusion class 1, II and III) has been imported in Dolphin imaging software version 11.9 and analyzed to measure volume of mandibular condyle, coronoid process and body. Recorded data was statistically analyzed with SPSS software (24.v). This study has been approved by institutional ethical committee of King George’s Medical University having reference no. 101 ECMIIA/P13,785/Ethics/2020 dated 01/09/2020.

3D CBCT scans imaged in maximum inter-cuspation with bilateral condylar and coronoid processes of mandible clearly visible were included in the study. Scans of patients with symptomatic TMJ disorders, history of previous facial surgeries and/or degenerative/metabolic bone diseases like osteomalacia, osteosclerosis and osteoporosis were excluded from the study.

RESULTS

Statistical Tools

Categorical variables were presented in number and percentage and continuous variables were presented as mean ± SD and median. Quantitative variables were compared using unpaired t-test between two groups and ANOVA between three groups. Qualitative variables were compared using Chi-Square Test /Fisher’s Exact Test as appropriate. Pearson correlation coefficients were used to determine the relationship of age between different parameters, while correlation was defined as a measure of the strength of a linear relationship between two variables. A p value of <0.05 was considered statistically significant. The data was entered in MS EXCEL spreadsheet and analysis was done using Statistical Package for Social Sciences (SPSS) version 16.0.

The study population consisted of 150 subjects having different classes of malocclusions. The study subjects ranged in age from 10 years to 24 years (Table 1), with 90 males and 60 females (Table 2). Class I malocclusion was most common (52%) followed by Class II malocclusion (26 %), and Class III malocclusion (22%) was found to be the least in our study set (Table 3).

In acquired CBCT images on measurement, we found the volume of condyle to be higher on the left side of mandible (892.71 mm^3) than on the right side (795.83mm^3). The volume of coronoid process was also higher in case of left side of mandible (401.42 mm^3) compared to right side (353.26 mm^3). The mean condylar volume (Right side+Left side) of mandible was found to be 844.27mm^3 while the mean coronoid volume (Right side+Left side) came out to be 377.34mm^3. The mean volume of body of mandible is 3.85E4 mm^3 (Table 4).

In our study sample, the volume of condyle, coronoid process and body of mandible has been compared within the age groups by applying one way ANOVA test for significance. In right side of mandible, the volume of condyle was highest in 14.1-18 years age group (835.15±381.90mm^3) which was statistically significant (P<.05) while in left side of mandible the condylar volume was highest in 14.1-18 years age group, but it was statistically not significant (P>.05). The coronoid volume in both right and left side of mandible was highest in 14.1-18 years age group (368.11±143.11 and 408.94±143.84respectively). However, the association between Coronoid volume and age group was statistically insignificant (P>.05). The mean condylar volume and mean Coronoid volume was highest in 14.1-18 years age group but statistically not significant (P>.05). The volume of body of mandible also was highest in 14.1-18 years age group. In study population the volume of condyle, coronoid process and body of mandible was highest in age group of 14.1-18 years (Table 5). In the study population, one way ANOVA test for significance has been used to compare the volume of condyle, coronoid process and body of mandible in different class of malocclusions.

In Class I malocclusions volume of right side mandibular condyle was noted to be highest, followed by class III and class II malocclusion. The volume of mandibular condyle (Right side) was highest in Class I malocclusion (1021.38±330.28) followed by Class III and Class II have least volume (528.33±180.10). This association was statistically highly significant (p value <<0.001). In left side of mandible, the volume of condyle was highest in Class I malocclusion (1163.36±1043.80) followed by Class III and Class II have least volume (564.92±185.58).This association was highly significant (p value <0.001) (Table 6). The volume of coronoid process (right side) was highest in Class I malocclusion (408.18±151.99) followed by class II and Class III have least volume (346.06±140.92) which was statistically highly significant (p value <<0.001) While in left side of mandible the volume of coronoid process in Class I malocclusion (454.80±155.35) followed by class III and Class II have least volume (341.52±55.33) which was statistically highly significant (p value <<0.001) (Table 6). However, the mean volume of condyle was highest in Class I followed by Class III and Class II have least volume. In all class of malocclusions, the mean volumes of mandibular condyle were statistically not significant (p value >0.001). The mean coronoid volume was highest in class I followed by Class II and Class III have least volume. In all class of malocclusions, the mean volumes of mandibular coronoid process were statistically not significant (p value >0.001) (Table 6). The volume of body of mandible of mandible was highest in Class I (41500±8623.39) followed by class III and Class II malocclusion has least volume (34000±3505.45). The volume of body of mandible, which was statistically highly significant (p-value <<0.001) in all class of malocclusions (Table 6).

Intra-group comparison of volume of condyle, coronoid process and body of mandible in different class of malocclusions was done by Tukey's HSD (honestly significant difference) test. The mean difference in volume of condyle (right side and left side) of mandible in Class I was statistically highly significant (p value <0.05) in comparison to Class II and Class III. However, in class II malocclusion it was statistically highly significant (p value <<0.05) with Class I and not significant with class III (p value >0.05). In Class III malocclusion, the volume of condyle was found highly significant when compared with Class I however with class II, it was not significant. The mean difference in volume of coronoid Process (right side and left side) of mandible in Class I was statistically highly significant (p value <0.05) in comparison to Class II and Class III However in class II it was statistically highly significant (p value <<0.05) with Class I and not significant with class III (p value >0.05). In Class III malocclusion, the volume of coronoid process was found highly significant when compared with Class I however with class II, it was not significant (p value >0.05).The mean condylar volume and coronoid process volume of mandible in Class I was statistically highly significant (p value <<0.05) in comparison to Class II and Class III However in class II it was statistically highly significant (p value <<0.05) with Class I and not significant with class III (p value >0.05). In Class III malocclusion, both (mean condylar volume and coronoid process volume of mandible) was found highly significant when compared with Class I however with class II, it was not significant (p value >0.05).The volume of mandibular condyle, coronoid process and mandibular body was compared between the genders in the study sample. The volume of mandibular condyle, coronoid process and mandibular body was found to be not significant statistically in either gender. The mean condylar volume was higher in females than males however mean coronoid volume was higher in males than females. The volume of body of mandible was higher in males (39200±7564.64 mm^3) than females (37500±7159.08mm^3) (Table 7). The co-relation between age and volume of mandibular condyle, coronoid process and body of mandible was estimated by Pearson Correlation Coefficient and mathematical equations were derived on the basis of which the age of a subject can be estimated if volume of condyle, coronoid process and body of mandible are known (Table 8, Fig 1).

Table 1: Showing age groups in study population

Age groups	Frequency	Percent
10-14 years	11	7.3
14.1-18 years	65	43.3
18.1-24 years	74	49.3
Total	150	100.0

Table 2: Showing gender wise distribution of study population

Gender	Frequency	Percent
Male	90	60.0
Female	60	40.0
Total	150	100.0

Table 3: Showing malocclusion wise distribution of study population

Class of Malocclusion	Frequency	Percent
Class I	78	52.0
Class II	39	26.0
Class III	33	22.0
Total	150	100.0

Table 4: Showing the volumes of Condyle, Coronoid and Body of mandible

	Mean(mm^3)	SD	Median	N
Right side of Mandible Condyle volume	795.83	361.96	727.70	150
Left side of Mandible Condyle volume	892.71	813.92	744.98	150
Right side of Mandible Coronoid Volume	353.26	135.88	320.80	150
Left side of Mandible Coronoid Volume	401.42	143.62	374.54	150
Mean_Condyler	844.27	503.88	770.00	150
Mean_Coronoid	377.34	133.96	351.58	150
Body of Mandible Volume	3.85E4	7426.15	3.70E4	150

Table 5: Showing volume of Condyle, Coronoid and body of Mandible in age groups

	10-14 years	14.1-18 years	18.1-24 years	F value	P-value
Right side of Mandible Condyle volume **(mm^3)**	1006.70±419.18	835.15±381.90	729.94±320.93	3.597	**.030***
Left side of Mandible Condyle volume**(mm^3)**	973.13±409.33	946.26±869.53	833.72±811.95	.386	.681
Right side of Mandible Coronoid Volume**(mm^3)**	337.37±124.68	368.11±143.11	342.59±131.34	.688	.504
Left side of Mandible Coronoid Volume**(mm^3)**	416.97±132.61	408.94±143.84	392.50±146.24	.293	.746
Mean_condyler Volume **(mm^3)**	989.92±408.18	890.71±535.52	781.83±484.67	1.309	.273
Mean_coronoid Volume **(mm^3)**	377.17±119.94	388.52±135.51	367.55±135.47	.421	.657
Body of Mandible Volume **(mm^3)**	36981.00±12321.51	39128.00±6586.92	38188.00±7275.22	.524	.593

Table 6: Showing volume Condyle, Coronoid and body of Mandible in Malocclusions

	Class of Malocclusion			F value	p-value
	Class I	Class II	Class III		
	Mean±SD	Mean±SD	Mean±SD		
Right side of Mandible Condyle volume	1021.38±330.28	528.33±180.10	578.83±221.97	54.509	**<0.001***
Left side of Mandible Condyle volume	1163.36±1043.80	564.92±185.58	640.41±216.55	26.673	**<0.001***
Right side of Mandible Coronoid Volume	408.18±151.99	298.12±57.48	288.64±105.34	10.177	**<0.001***
Left side of Mandible Coronoid Volume	454.80±155.35	341.52±55.33	346.06±140.92	15.992	**<0.001***
Mean condylar	1092.37±573.40	546.63±178.95	609.62±195.53	2.138	0.122
Mean coronoid	431.49±145.21	319.82±52.43	317.35±121.12	1.063	0.349
Body of Mandible	41500±8623.39	34000±3505.45	36700±3619.96	13.046	**<0.001***

Table 7: Showing volume of Condyle, Coronoid Process and Body of Mandible in males and females

	Gender		t-value	p-value
	Male	Female		
	Mean±SD	Mean±SD		
Right side of Mandible Condyle volume	790.93±378.49	803.18±338.64	-.202	.840
Left side of Mandible Condyle volume	876.13±761.52	917.58±892.84	-.305	.761
Right side of Mandible Coronoid Volume	370.03±152.56	328.11±102.22	1.866	.064
Left side of Mandible Coronoid Volume	412.12±152.01	385.38±129.62	1.118	.265
Mean Condyle	833.53±489.64	860.38±528.30	-.319	.750
Mean Coronoid	391.08±146.84	356.74±109.90	1.545	.125
Body of Mandible	39200±7564.64	37500±7159.08	1.352	.179

Table 8: **Showing Mathematical equations for age prediction for volume of Condyle, Coronoid Process and Body of Mandible**

Parameters	R	p-value	Mathematical Equations
Right side of Mandible Condyle volume	-.205*	**.012**	Y= -.001 x Right side of Mandible Condyle + 19.285
Left side of Mandible Condyle volume	-.083	.314	Y= 0.000 x Left side of Mandible Condyle volume + 18.360
Right side of Mandible Coronoid Volume	-.040	.627	Y= 0.000 x Right side of Mandible Coronoid+ 18.393
Left side of Mandible Coronoid Volume	-.044	.590	Y= 0.000 x Left side of Mandible Coronoid volume + 18.444
Mean condylar	-.141	.086	Y= 0.000 x Mean condylar + 18.731
Mean coronoid	-.044	.593	Y= 0.000 x Mean coronoid + 18.445
Body of Mandible	-.035	.667	Y= -1.225E-5x Body of Mandible+ 18.598

Co-relation with Age=Y

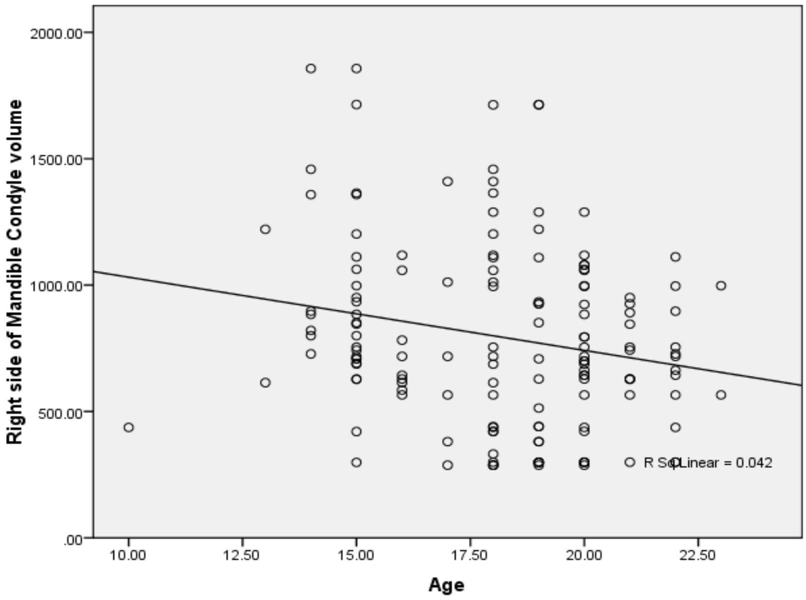

Fig 1: Showing correlation (Pearson) volume of right mandibular condyle and age of patient

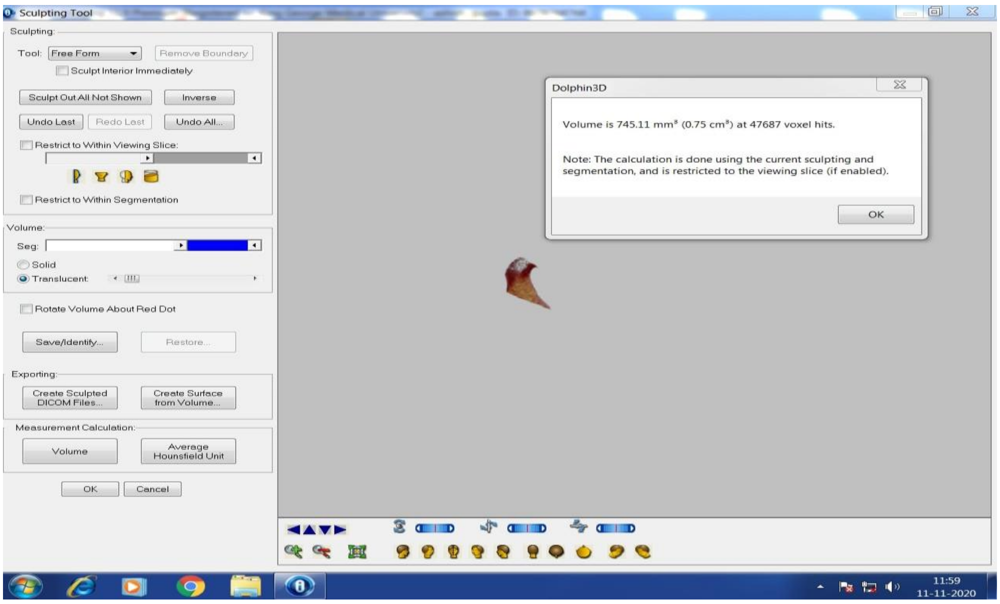

Fig 2a: Showing volume of mandibular condyle in class I, Class II and class III malocclusions respectively measured with Dolphin imaging software V11.9

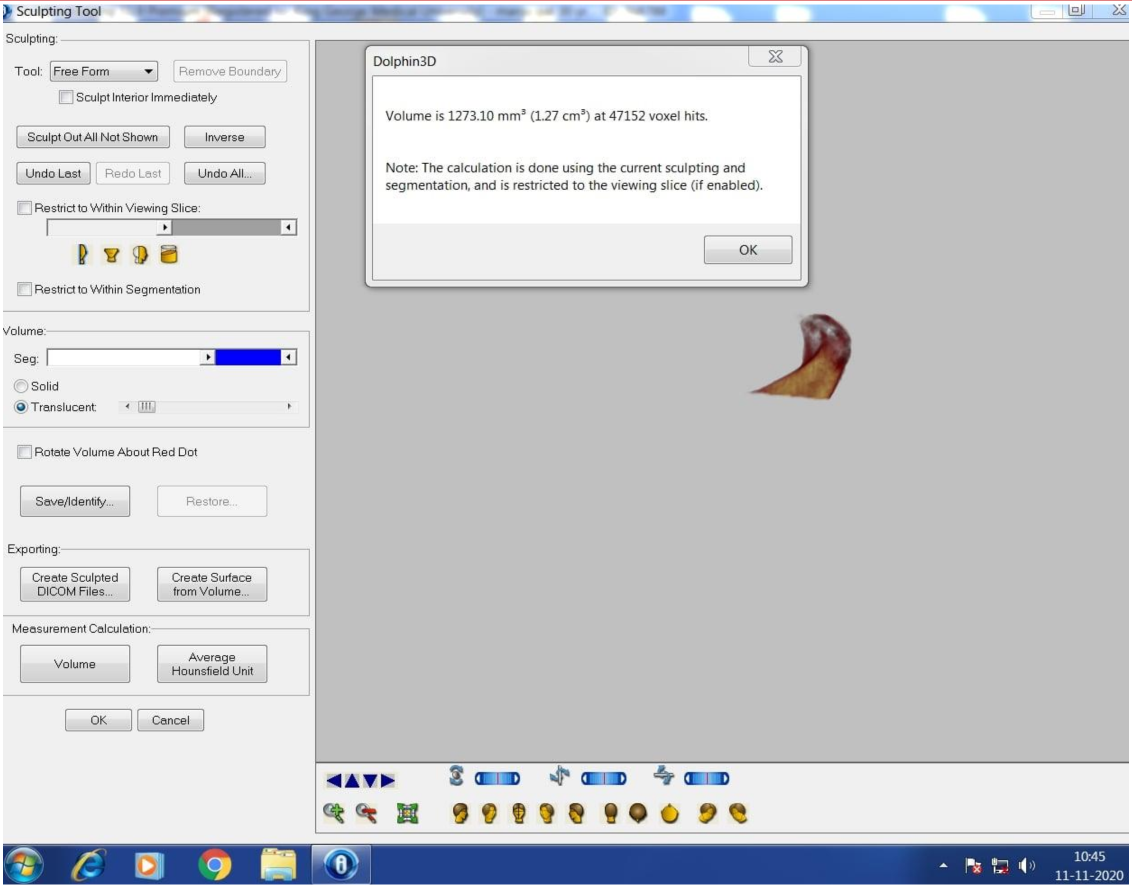

Fig 2b: Showing volume of mandibular condyle in class I, Class II and class III malocclusions respectively measured with Dolphin imaging software V11.9

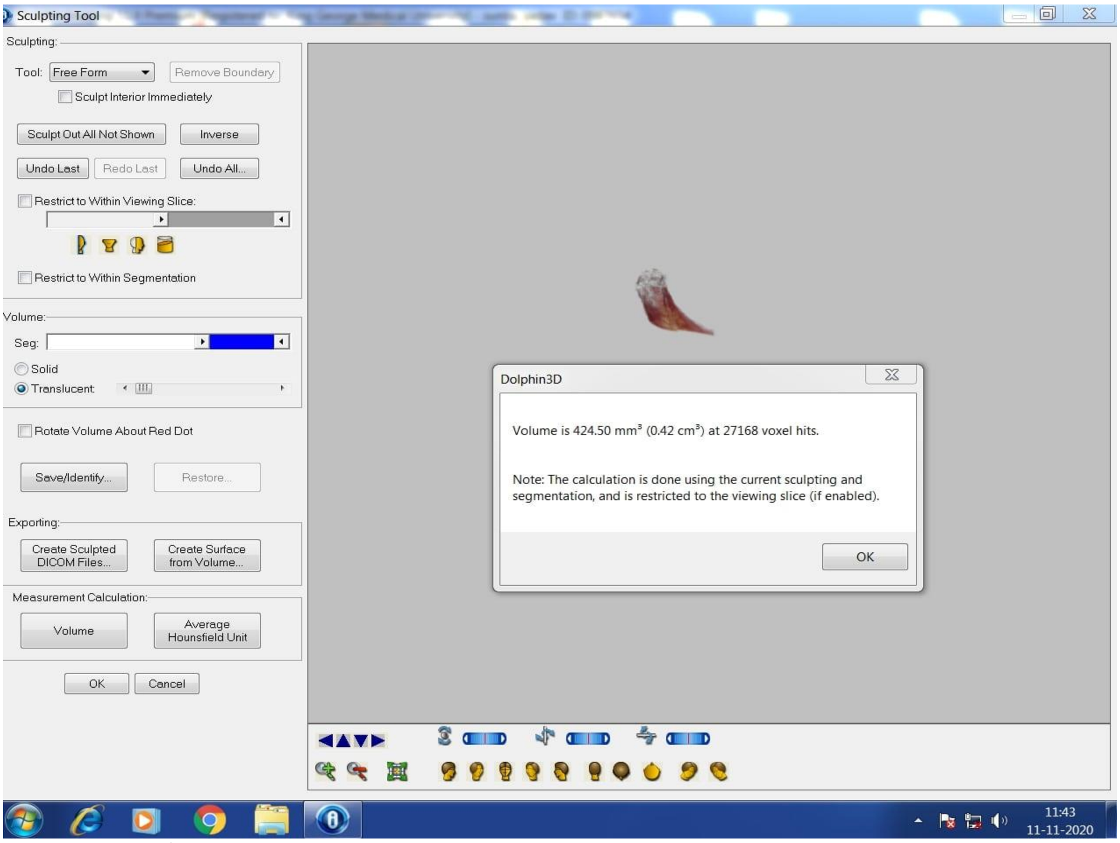

Fig 2c: Showing volume of mandibular condyle in class I, Class II and class III malocclusions respectively measured with Dolphin imaging software V11.9

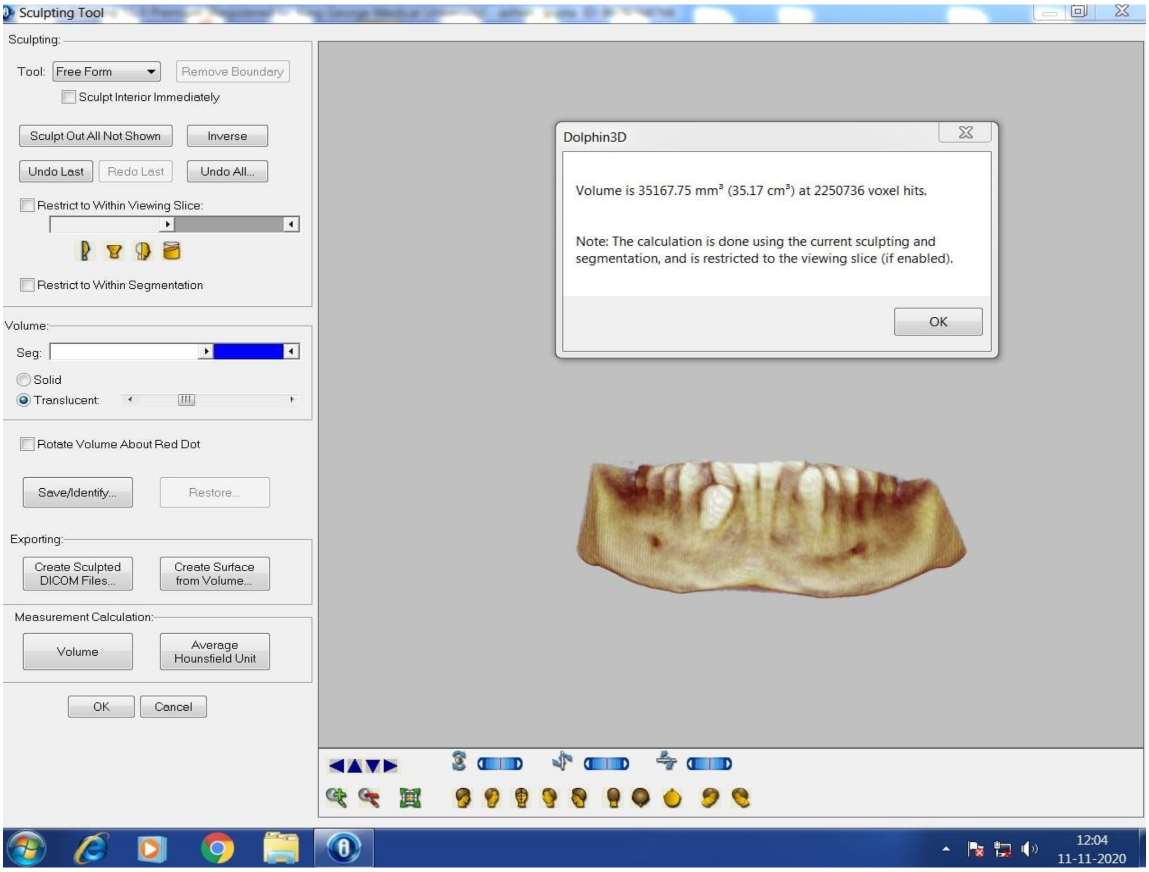

Fig 3a: Showing volume of body of mandible class I, Class II and class III malocclusions respectively measured with Dolphin imaging software V11.9

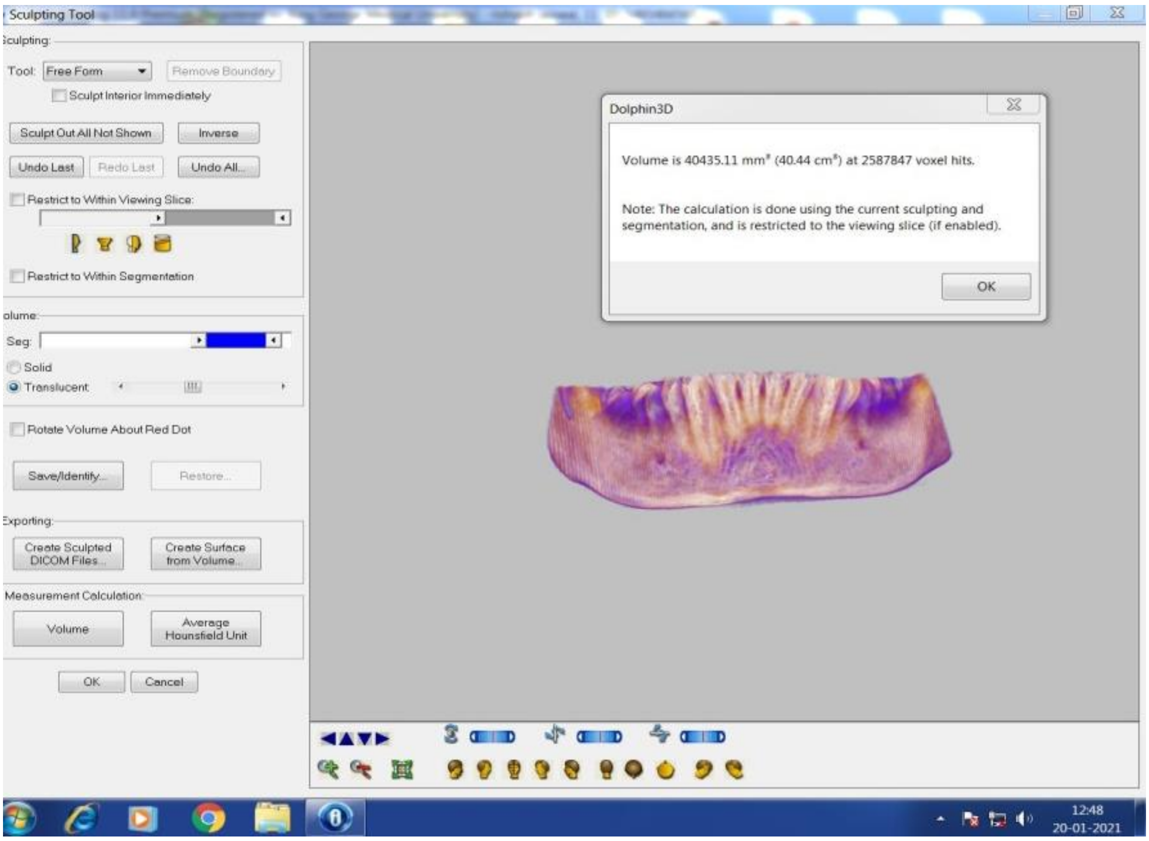

Fig 3b: Showing volume of body of mandible class I, Class II and class III malocclusions respectively measured with Dolphin imaging software V11.9

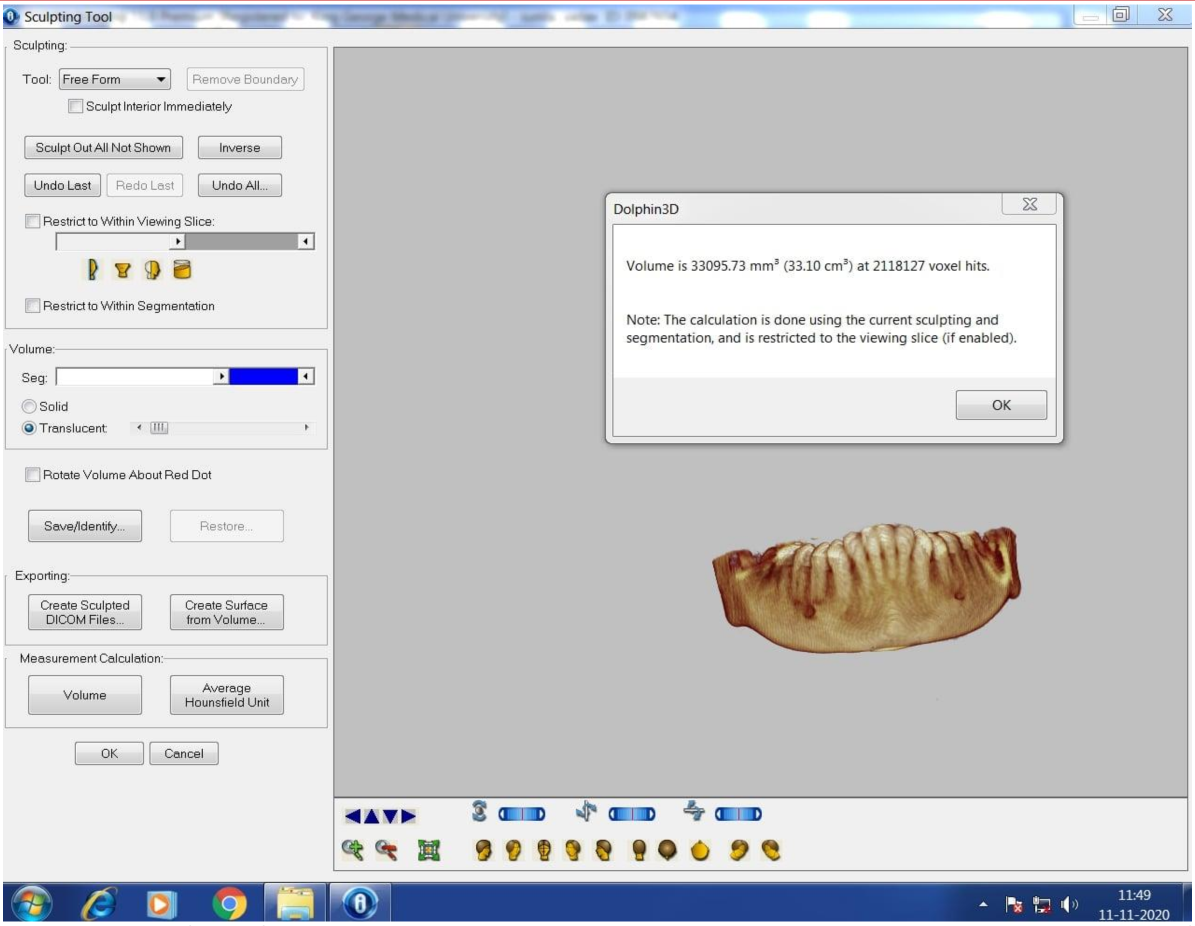

Fig 3c: Showing volume of body of mandible class I, Class II and class III malocclusions respectively measured with Dolphin imaging software V11.9

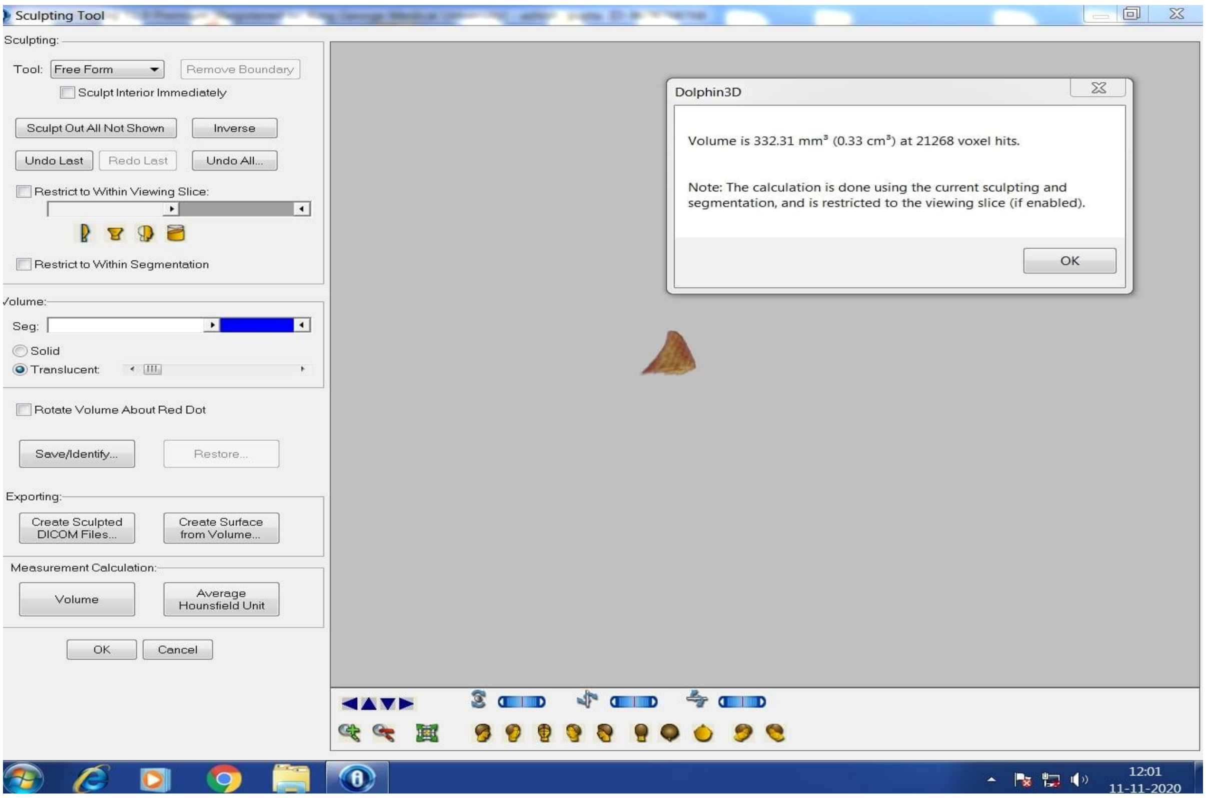

Fig 4a: Showing volume of Coronoid process in class I, Class II and class III malocclusions respectively measured with Dolphin imaging software V11.9

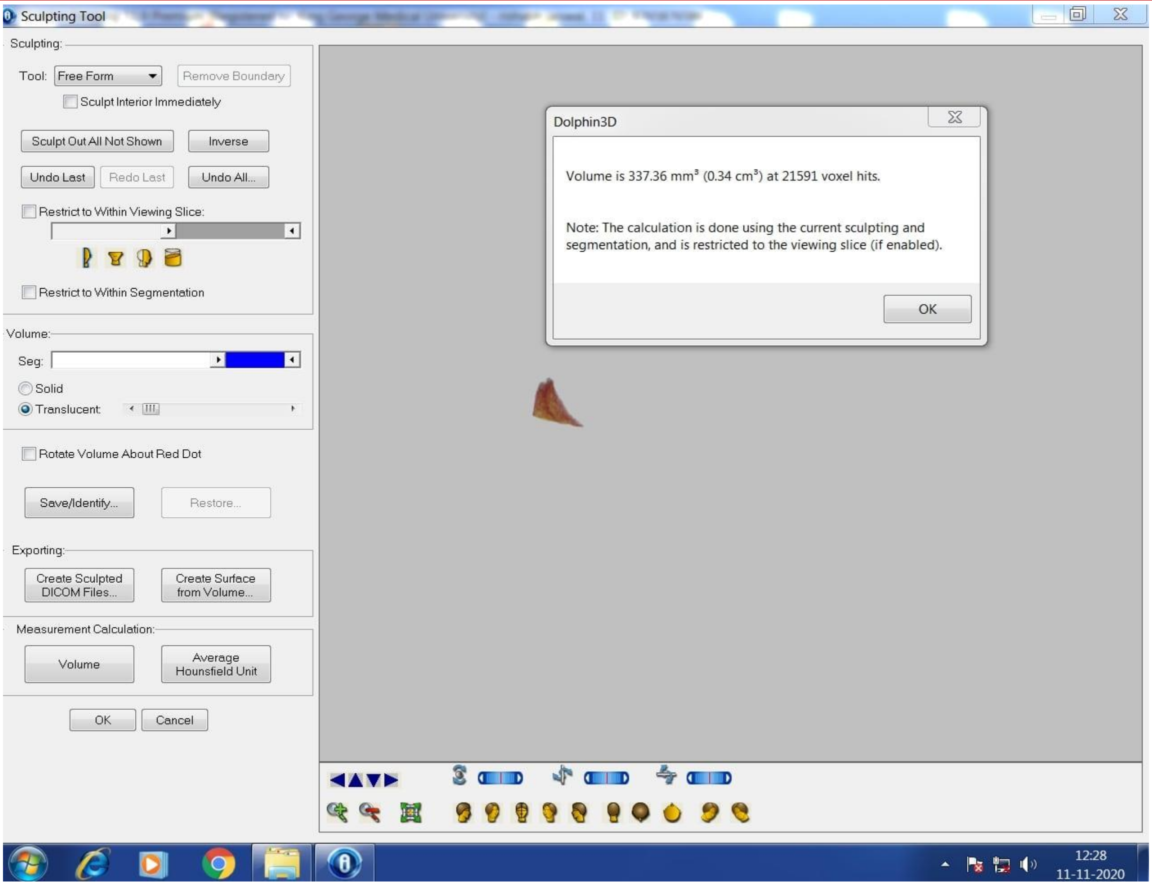

Fig 4b: Showing volume of Coronoid process in class I, Class II and class III malocclusions respectively measured with Dolphin imaging software V11.9

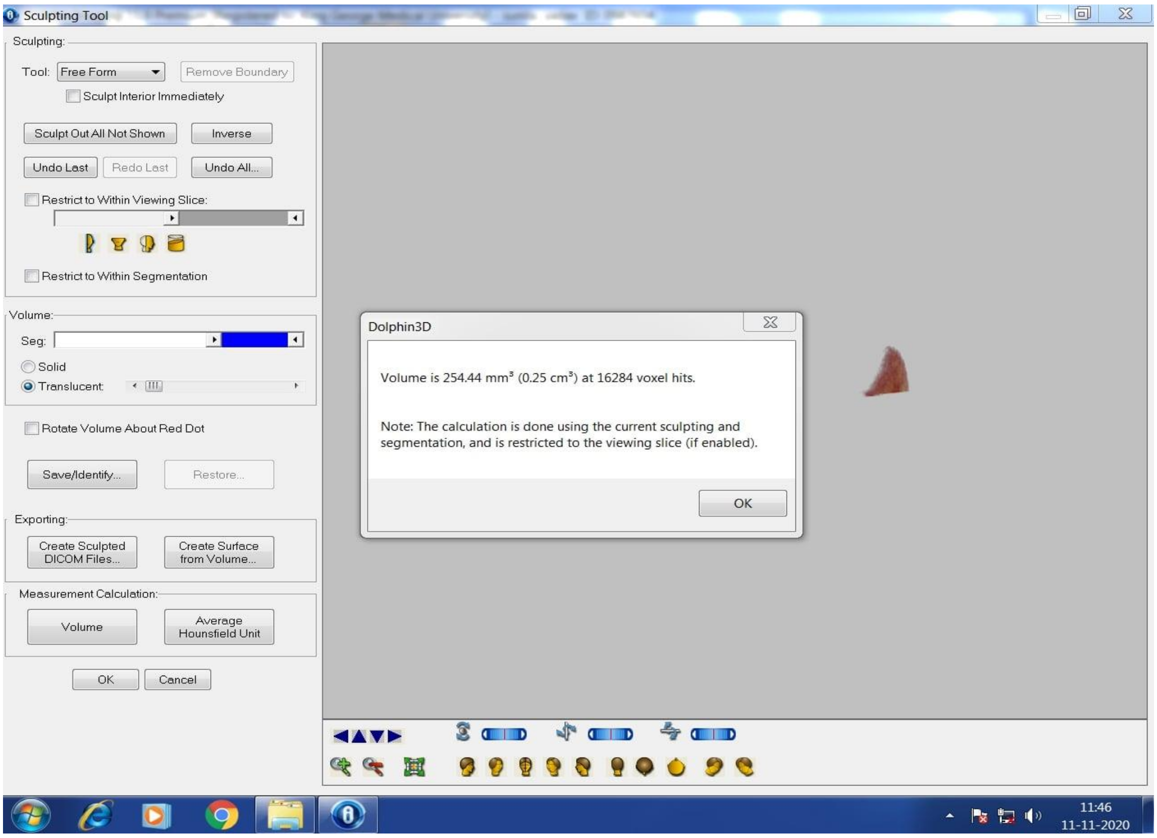

Fig 4c: Showing volume of Coronoid process in class I, Class II and class III malocclusions respectively measured with Dolphin imaging software V11.9

DISCUSSION

Naitoh, Aimiya, Hirukawa and Ariji working with in vitro models found that trabecular bone volume per total tissue volume as found on CBCT correlated closely with values measured with computed tomography (range 0.83-0.93) [9]. Unlike Hounsfield Units in which CT images are obtained, values obtained on CBCT imaging are not absolute. Using 25 dry skulls marked with ten fiducial markers, Gribel, Frazao *et al*., compared direct measurements with both cephalometric and CBCT measurements proved conclusively that two-dimensional norms of cephalometry cannot be used for three dimensional measurements because of the variation in accuracy of measures in the two exams [10]. Fourie, Damstra, Garrits and Ren marked 21 standard linear measurements on 7 cadaver heads and compared the physical linear measurements to those obtained from three different scanning systems one of which was CBCT and found out that three dimensional imaging systems were of adequate accuracy and reliability for both research work and clinical uses [11]. El-Beialy, Fayed *et al*., studied accuracy and reliability of 3D CBCT measurements differed with the orientation of head of subject. Using stainless steel wires fixed to a dry skull at different places, imaging was done in ideal centred position and then in 5 different positions. They found a very high concordance between direct physical measurements with CBCT measurements and that neither accuracy nor reliability was affected by changing orientation of skull. Interestingly, they also suggested that both upper-lip and chin rests were unnecessary if stable head position can be ensured otherwise during imaging in CBCT [12]. Since then multiple studies have shown that CBCT imaging can be used accurately and reliably to perform volumetric measurements of condyle of mandible even in the presence of soft tissue [13-15].

Remzi, Akgun *et al*., obtained and evaluated biometric data with 3D digital imaging and real bone measurements for ten rabbits with no bone deformities and proved that tomographic imaging measurements of bone were both accurate and reliable for bone tissue and could be substituted for traditional digital calliper [16].

Alam Ganji *et al*., retrospectively studied 800 CBCT scans of patients above 18 years of age and observed statistically significant gender difference in both anteroposterior and mediolateral width of right and left mandibular condyles. However they pointed out that condylar morphometry can only be a weak predictor for gender with accuracy noted to be 57.2% for males and 53.3% for females [17].

Bayram Kayipmaz *et al*., used five dry mandibles with 9 condylar heads to study volume estimation on CBCT imaging with water displacement technique being the gold standard of measurement. The volume of condyle was noted to vary between 1.4040 to 1.4350 cm^3. On CBCT image for condylar volume observed to be 1.4731 cm^3 on water displacement. For condylar head with physical volume 2.8907 cm^3, CBCT imaging volume varied between 2.6210 cm^3 and 2.7490 cm^3. Overall there was highly significant intra-observer agreement in measurements and no significant difference between physical measurements and those done with 3D imaging [18].

Using CBCT, Gouldart Munoz *et al*., studied and compared the condylar volume between patients with transverse asymmetry of face and class III facial deformity (10 patients in each group). Among the subjects with unilateral condylar hyperplasia, mandibular condyle with hyperplasia showed mean volume of $1.97 \pm 0.52 cm^3$ (range 1.49 cm^3 to 3.06cm^3) and counterpart condylar head volume was noted to lie within the range of 0.80 cm^3 to 1.44 cm^3 with a mean volume of $1.16 \pm 0.17 cm^3$. This difference was statistically significant ($p<0.05$). The second group of patients who had class III deformity showed symmetrical condylar volumes on both sides with no significant difference between right and left mandibular condyle measurements($p=0.06$). On comparing mandibular condylar heads in all study subjects, non-hyperplastic condyles showed significantly lower volume than hyperplastic counterparts as well as lower than left side condylar heads in Class III group ($p<0.05$). Right condylar heads, right and left Class III condylar heads, non-hyperplastic condyles and between hyperplastic condyles and class III left and right condyles showed no statistically significant differences ($p>0.05$). In this study, effective mandibular length in unilateral hyperplastic condyle group was calculated to be 117.30 ± 11.70mm with mean value for females being 118.5mm and for males 116.75mm. In the group with class III deformity effective mandibular length was 120.25 ± 11.22mm with measurement in females being 115.1mm and males being 129.25mm. This difference between the groups was found to be statistically not significant ($p=0.57$) [19].

In 2018, Saifi, Ali-Farid *et al*., reported their comparative study of 700 mandibular condyles. Mean volume for right mandibular condyle was reported as 2.443 cm^3 and 2.278 cm^3 for left counterpart with the difference between the two volumes found to be statistically significant ($p<0.01$). The team also reported that among study subjects, females had a significantly smaller condylar volume than males ($p<0.01$ for both right and left condyles). No significant correlation was noted regarding volume and age ($p=0.939$) for right condylar head and ($p=0.798$) for left condylar head [20]. Using CBCT images of 87 patients aged between 17 and 53 years, Lentzen, Reikert *et al*., performed volumetric measurements on 174 mandibular condyles. The volume of right condylar head varied from 2.379 cm^3 to 0.121 cm^3 with a mean value of 1.378 ± 0.447 cm^3. For left mandibular condyle, mean volume was calculated to be 1.435±0.474 cm^3 with extreme values in study sample being 3.264 cm^3 and 0.109 cm^3. On bi-variate analysis, the inter-subject difference between the volume of the left and right mandibular condyles was found to be highly significant ($p<0.01$). Female subjects were noted to have a significantly smaller volume of mandibular condyle than male subjects with $p<0.05$ for left side and $p<0.01$ for right side [21]. Nota Caruso *et al*., used 3D CBCT images of 94 patients (46 females and 48 males) to study 188 temporomandibular joints. Condylar volume was with respect to puberty (11-16 years), late adolescence (17-21years) and young adulthood (22-26 years). The investigators found no significant difference between the right and left condylar volumes and surfaces ($p>0.05$). Gender based difference in mean condylar volume however turned out to be statistically significant ($p<0.05$) with female subjects having a mean condylar volume of 2250.4 ± 350.4 mm^3 and male subjects with value 2650.4 ± 350.2 mm [3, 22]. Salli and Ozturkmen evaluated CBCT images of 690 condyle from 345 patients (165 females and 180 males). The mean right condylar volume in their study was 1678.8mm^3 and for left counterpart it was calculated to be 1661.3mm^3. They reported significant differences between the volumes of mandibular condyle for different sex whereas none when differences in condylar volumes were calculated based on age, laterality and posterior occlusal support [23].

CONCLUSION

This study is first of its kind which determined the volume of mandibular condyle, coronoid process and body of mandible in all classes of orthodontic malocclusions. Among the malocclusions studied, the volumes of all 3 variables were maximum in Class I malocclusion. Mean coronoid volume and volume of body of mandible was noted to be higher in males than females while mean condylar volume was higher in females. 3D CBCT morphometry shows that volumetric variations in mandible are related to age and type of occlusion. Mandible bone volume also shows sexual dimorphism. On the basis of these volumes the age and sex of patients can be predicted.

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