DOI: 10.7860/JCDR/2017/31120.10959

Volumetric Analysis of the Jaws in Skeletal Class I and Class II Patients using CBCT and Derived Lateral Cephalograms

BATOL DARJAZINI NAHAS[1], MOHAMMAD Y HAJEER[2], MOWAFFAK A AJAJ[3], AGHIAD YASSIN ALSABBAGH[4]

ABSTRACT

Introduction: Cone Beam Computed Tomography (CBCT) imaging recently has become a very common diagnostic tool in the orthodontic literature. Recent research work has shown that CBCT imaging would give additional information regarding the volumetric assessment of the craniofacial structures. However, the previous published work has not considered the impact of the anterior-posterior skeletal classification and the vertical skeletal pattern on the volumetric assessment of the maxillary and mandibular bones.

Aim: To evaluate maxillary and mandibular volumes (MxV and MdV, respectively) in hyper-divergent skeletal Class II (CII) and normo-divergent skeletal Class I (CI) patients and to investigate any possible correlation between CBCT derived lateral cephalometric variables and the calculated volumes.

Materials and Methods: CBCT images of 60 patients (30 patients: CI, 30 patients: CII) were obtained and processed with Mimics® 17 software (Materialise, NV, Belgium). The three-dimensional models of both jaws were reconstructed and the related volumes were calculated using a novel approach. CBCT based cephalograms were also derived and linear and angular measurements of the craniofacial complex were obtained. Significance tests were based on t-tests (alpha set at 5%) and Pearson's correlation coefficients were calculated.

Results: No significant differences were detected between the two groups in the MxV (p=0.435) and the MdV (p=0.507). In the CI group, no or weak correlations were found between the volumetric measurements and the 2D variables. In the CII group, there was a strong correlation between both MxV and MdV and both the posterior facial height (r=0.60, 0.78 respectively) and the facial height index (r=0.62, 0.72 respectively). A negative moderate correlation was found between both MxV and MdV and the mandibular plane angle (r=-0.48, -0.44 respectively) and Bjork's sum (r=-0.48, -0.44 respectively).

Conclusion: There were no significant differences in the MxV and MdV between CI and CII skeletal patterns. Some cephalometric variables had moderate to strong correlation with the MxV and MdV in the CII group.

Keywords: Derived cephalograms, Hyper-divergent, Class II patients, Mandibular volume, Maxillary volume, Normo-divergent Class I patients

INTRODUCTION

Many studies have tried to assess the craniofacial morphological characteristics of patients with Class II malocclusion [1,2]. Treatment of Class II malocclusion poses a challenge in front of the orthodontists when correcting sagittal and vertical discrepancies [3]. Conventional Two-Dimensional (2D) cephalometric analysis involves the calculation of linear, angular measurements and area measurements as well as several ratios. However, 2D analysis does not provide any quantitative information of the maxillary and mandibular volume and size [4]. In contrast, 3D imaging allows the evaluation and analysis of "the anatomical truth" [5]. Computed tomography has been widely used at the end of the twentieth century for 3D maxillofacial imaging [6,7]. In the recent years, CBCT has evolved as an important method to collect 3D volumetric information in the orthodontic research. Few studies have tried to evaluate the volume of the maxilla and the mandible in the three main skeletal groups of malocclusion. However, the utilised samples in these studies have been relatively small [8,9]. The previous published work has not considered the impact of the anterior-posterior skeletal classification on the vertical skeletal patterns and the correlation analysis has only been focused on few cephalometric variables and their possible relationships with the mandibular volume without the evaluation of the maxillary volume in these analyses. Furthermore, the values given regarding the maxillary volume in the previous studies were not indicative of the real volume, as the maxilla was segmented anteroposteriorly without giving any attention to its complete anatomical shape.

Therefore, the study was carried out with an aim to evaluate any possible maxillary or mandibular volumetric difference between hyper-divergent skeletal CII and normo-divergent CI patients using CBCT images and to investigate any possible correlation between CBCT derived lateral cephalometric variables and the mandibular and maxillary volumes.

MATERIALS AND METHODS

This study was a cross-sectional study for descriptive and analytical purpose. Sample size calculation was done using Minitab® 16 (Minitab Inc., State College, PA, USA). Assuming that the smallest volumetric difference to be detected in the maxillary volume between the two groups was 2000 mm^3 and the standard deviation captured from a previous study was 2050 mm^3 [9], employing two sample t-test with a significance level of 5% and a power of 80%, 18 patients were required. Regarding the mandibular volume, the assumption of the smallest volumetric difference to be detected was 6000 mm^3 and the standard deviation in the same pervious study was 7500 mm^3 [9], therefore, employing the same assumptions as above in relation to the other parameters, the required number of individuals for each group was 26. Hence, we decided to include 30 patients in each group with a total number of 60 patients.

This research project was approved by the University of Damascus Local Research Ethics Committee (UDDS-2951PG) and was funded by the University of Damascus Postgraduate Research Budget (97687027788DEN). Disproportionate stratified random sampling with respect to skeletal malocclusion class was employed to create two groups of equal numbers. Our sampling frame was based on reviewing 678 records of patients who visited the Department of Orthodontics at University of Damascus Dental School, Damascus, Syria from February 2015 to March 2016.

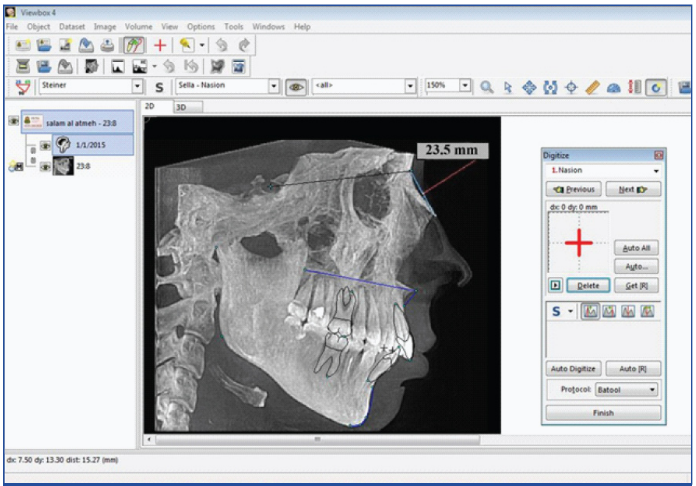
A total of 190 cases (66 CI patients, 124 CII patients) were found suitable to be included in the study after routine clinical and radiographic examination. From the 130 patients (56 CI patients and 74 hyper-divergent CII patients) who fulfilled the inclusion criteria and were willing to participate, 60 patients (14 males, 46 females; 30 in each group) were selected randomly and were included in the study. Random selection was based on a computer generated list of random numbers from the sampling frame.

The inclusion criteria were: No history of previous orthodontic treatment; complete permanent dentition present; no congenital disorders or systemic diseases. Patients in the CI group had the following cephalometric characteristics: 2°≤ANB≤4°, Y-axis angle= 65°±5°, Bjork's Sum=396°±6°, with class I molar relationship, whereas the hyper-divergent skeletal CII patients had the following characteristics: ANB<4°, Y-axis angle >70°, Bjork's Sum >402° and overjet ≥5 mm, class II molar relationship. CBCT imaging was performed using the SCANORA® 3D Device (Soredex, Tuusula, Finland), with 15 mA, 85 kV, 40 seconds exposure time and isotropic voxel size of 0.25×0.25×0.25 mm. All CBCT images were taken with their heads stabilised using ear rods that were placed in the external auditory meatus and the Frankfort plane parallel to the floor. Files were saved in Digital Imaging And Communications In Medicine (DICOM) format and the images were viewed through 3DOnDemand® programme (CyberMed, Finland). To measure craniomaxillofacial morphology, lateral cephalograms were derived from CBCT images. By using the 'Axial View', the sagittal plane was rotated and translated in order to pass through the centre of the first cervical vertebra and the anterior nasal spine in the Maximum Intensity Projection (MIP); [Table/Fig-1] according to the method proposed by Cattaneo PM et al., [10]. In order to visualise the inner structures of the cranium (eg., Sella) in the MIP cephalograms, the parietal bone had to be virtually excised from the CBCT data sets.

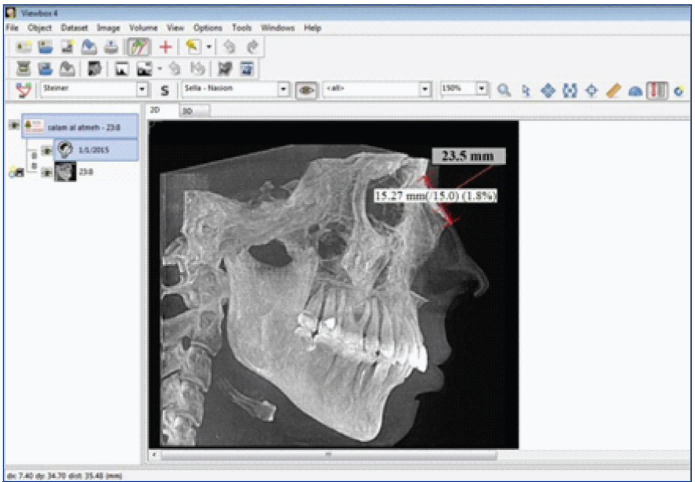
A 2D traditional analysis from CBCT derived cephalograms: The CBCT derived cephalograms were imported into Viewbox V4.0 (dHAL Software, Kifissia, Greece) for tracing [Table/Fig-2]. The length of the nasal bone from Nasion to Rhinion (lowest and midpoint of inter-nasal suture) was used as a measure to calculate the magnification ratio [Table/Fig-3]. All the cephalometric analysis was conducted by one researcher (BDN). The definitions of the linear and angular cephalometric measurements are given in previous published work [11,12].

A 3D volumetric analysis from CBCT data: In order to calculate the MxV and MdV, the DICOM files were imported into Mimics™ 17 program (Materialise, NV, Belgium). The reference lines to the volume of the maxillary bone were located at its anatomical sutures with the neighbouring bones and the whole maxilla was measured without the inclusion of tooth crowns. The mandibular volume was measured without tooth crowns and with the inclusion of the condyles. The cranium was visualised in the recommended range of bone density (range of grey scale from -1024 to 1650) then a preliminary mask was made using an adaptive threshold. The boundaries of the maxillary and mandibular bone and the tooth crowns were selected in all three planes of space from all the other structures using the Lasso tool [Table/Fig-4]. Then, a new mask was created using the 'separate' tool in order to construct a 3D object that included only the maxillary bone. The volumetric measurement was carried through the Mimics™ automatic function [Table/Fig-5]. The same steps were applied to separate and measure the mandibular volume. [Table/Fig-6] shows the reconstructed maxillary and mandibular bones in each group.

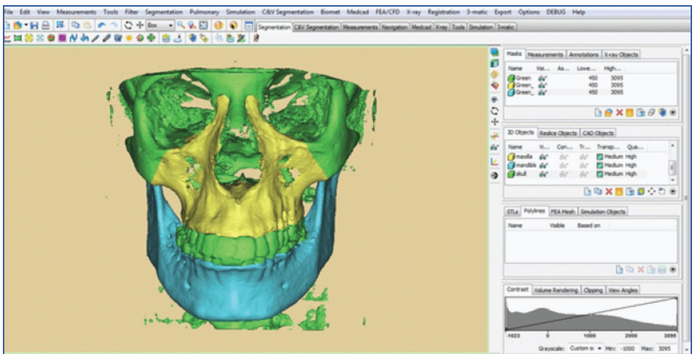
[Table/Fig-1]: The selection procedure in the coronal and axial views to derive the lateral cephalograms on 3DOnDemand® programme.



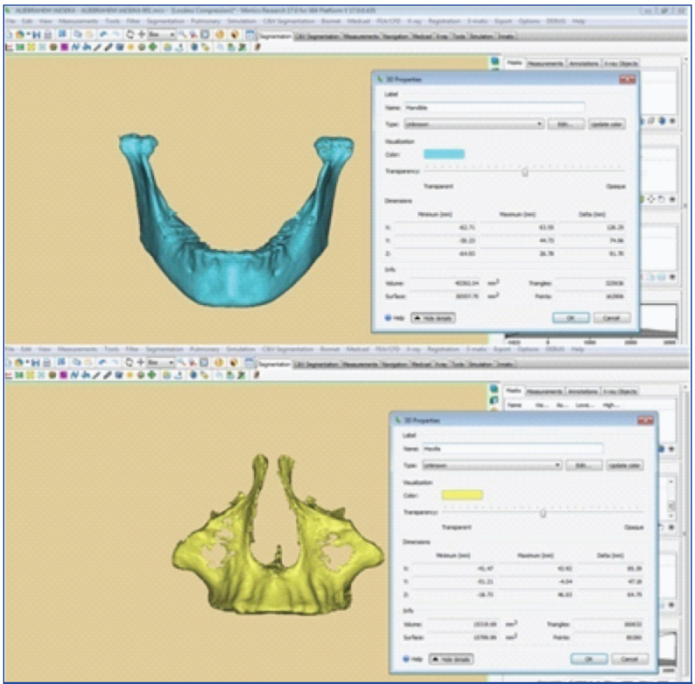
[Table/Fig-2]: The digitization of the derived lateral cephalometric image using View-box software.

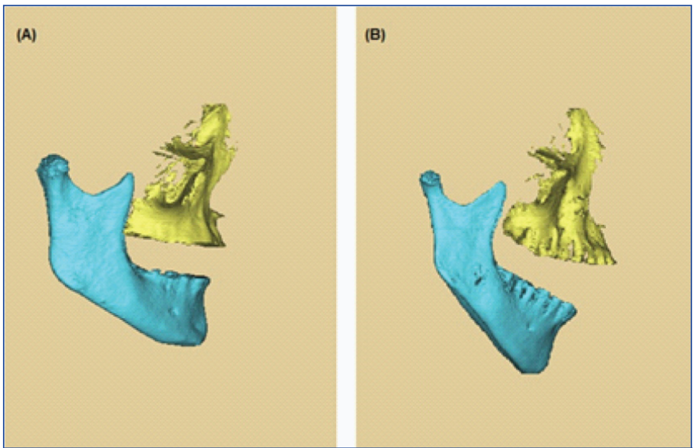


[Table/Fig-3]: The measurement of the nasal bone height in order to calculate the magnification ratio.



[Table/Fig-4]: The boundaries set for segmenting the maxilla (in yellow) and the mandible (in blue) and the parts to be removed (in green).


[Table/Fig-5]: The reconstructed mandibular and maxillary bones and their volumetric measurements.



[Table/Fig-6]: The reconstructed mandibular and maxillary bones in (a) Normo-divergent CI group; (b) Hyper-divergent CII group.

STATISTICAL ANALYSIS

A two sample t-test was employed to detect any possible significant difference between the CI normo-divergent group and CII hyper-divergent group regarding the volumetric analysis and the cephalometric variables whereas Pearson's correlation coefficients were calculated to detect any possible relationship between the 2D variables and the volumetric measurements. To investigate the reliability of the employed procedure, the cephalometric analysis and the MxV and the MdV of 10 randomly selected patients were measured twice with a time interval of two weeks. Intraclass Correlation Coefficients (ICCs) were used to determine the intraobserver reliability, whereas paired t-test was employed to detect any significant difference between the two assessment times.

The significance level of 5% was adjusted according to Bonferroni correction due to multiple testing and any p-value of paired t tests less than 0.01 was considered statistically significant.

RESULTS

Regarding the assessment of method reliability, there were no significant differences between the two assessment times for all variables (i.e., no systematic error), and the reliability analysis confirmed an excellent agreement between the two readings in the 2D and 3D analyses [Table/Fig-7,8].

The skeletal CI group consisted of 30 patients (23 females and seven males) with a mean age of 22.66. A total of 26 of these patients had Class I molar relationship, whereas and four patients had Class II molar relationship. The skeletal Class II division 1 group consisted of 30 patients (23 females and seven males) with a mean age of 20.9. All patients in this group had Class II dental relationships. Descriptive statistics of the cephalometric variables of these patients are given in [Table/Fig-9] along with the results of significance tests between the two groups. Descriptive statistics of the MxV and MdV as well as

Variables	ICC[a]	Mean	Std. Deviation	p-value[b]
Magnification	0.999	0.00	0.55	0.978
Overjet	0.988	0.10	0.26	0.266
Overbite	0.971	-0.08	0.55	0.662
U1-SN	0.979	0.00	1.75	1.000
LI-GoMe	0.922	-0.12	2.29	0.872
SNA	0.990	0.23	0.56	0.231
SNB	0.996	0.31	0.34	0.020
ANB	0.908	-0.08	0.37	0.512
SN-GoMe	0.977	-0.29	0.85	0.309
Y-Axis	0.989	-0.13	0.48	0.419
MM	0.992	-0.69	0.78	0.021
NaMe	0.999	0.08	0.21	0.269
S-Go	0.996	0.44	0.72	0.088
S-Ar	0.999	0.12	0.19	0.081
Go1	0.998	-0.19	0.48	0.248
Go2	0.988	0.20	0.52	0.263
LAFH/LPFH	0.884	0.04	0.06	0.104
LAFH	0.999	-0.04	0.20	0.545
NSAr	0.975	-0.89	1.44	0.083
ArGoMe	.996	0.01	0.89	0.972
SArGo	.983	0.58	1.27	0.183
Bjorks sum	0.977	-0.29	0.85	0.309
SN	0.999	0.02	0.31	0.847
ArGo	0.991	0.27	0.72	0.271
GoMe	0.998	-0.31	0.58	0.126
FHI	0.978	0.48	0.97	0.155

[Table/Fig-7]: Assessment of the intraobserver reliability and error of the method for 2D variables.
ICC[a]: Intraclass Correlation Coefficients; p-value[b]: comparison between two repetitions using paired t-tests, p<0.05 indicates statistical significance.
"p<0.01 was considered significant according to Bonferroni correction of the significance level due to multiple testing."

Variables	ICC[a]	Mean	Std. Deviation	p-value[b]
MxV	0.967	-62.73	1148.85	0.867
MdV	0.987	368.13	1497.54	0.457

[Table/Fig-8]: Assessment of the intraobserver reliability and error of the method for volumetric measurements.
ICC[a]: Intraclass Correlation Coefficients. p-value[b]: comparison between two repetitions using paired t-tests with alpha set at 5%.

the mandibular/maxillary volumetric ratios are shown in [Table/Fig-10]. There were no statistical significant differences in the maxillary or mandibular volumes between the two groups (p=0.435 and p=0.507, respectively). Values of Pearson's correlation coefficients between the 2D variables and the volumetric measurements are shown in [Table/Fig-11]. In the CI group, no or weak correlations were found between the volumetric measurements and the 2D variables. In Class II Division 1 group, there was a strong correlation between both MxV and MdV and these variables: posterior facial height (S-Go), the Facial Height Index (FHI). There was a strong positive correlation between Ar-Go and the MdV, whereas a moderate correlation was found between the MxV and S-Ar. On the other hand, a negative moderate correlation was found between

Variables	Mean±SD Group I	Mean±SD Group II	Mean Difference	p-value
OJ	3.407±1.776	5.907±1.476	-2.500	<0.001***
OB	1.848±2.156	1.191±2.2	0.658	0.251
U1-SN	100.38±5.16	99.83±6.56	0.55	0.721
LI-MdP	88.01±8.19	86.64±6.99	1.37	0.489
SNA	80.647±3.274	80.26±3.367	0.387	0.654
SNB	77.52±3.137	72.74±2.839	4.780	<0.001***
ANB	3.133±1.122	7.293±1.465	-4.160	<0.001***
SN-GoMe	35.897±3.289	43.829±3.97	-7.932	<0.001***
Y-axis	69.892±1.868	75.414±2.745	-5.521	<0.001***
MM	27.653±3.846	34.867±5.41	-7.21	<0.001***
NaMe	109.77±4.78	111.1±5.57	-1.32	0.328
S-Go	69.45±5.58	63.706±4.814	5.74	<0.001***
S-Ar	31.046±2.739	28.6±3.299	2.446	<0.001***
Go1	50.87±4.525	50.253±3.907	0.62	0.574**
Go2	74.877±3.567	80.707±3.417	-5.830	<0.001***
LAFH/LPFH	1.6069±0.1624	1.7138±0.1329	-0.10	0.008**
ANS-Men	62.289±3.349	66.767±4.432	-4.48	<0.001***
N-S-Ar	126.01±5.66	129.43±5.24	-3.42	0.020*
Ar-Go-Me	125.76±5.93	131.83±5.66	-6.07	<0.001***
S-Ar-Go	144.13±6.63	142.52±7.75	1.62	0.389
Bjork	395.9±3.29	403.83±3.97	-7.932	<0.001***
S-N	63.666±3.174	61.101±3.878	2.565	0.008**
Ar-Go	41.794±4.394	39.351±2.869	2.444	0.015*
Go-Me	66.841±4.472	61.641±3.796	5.20	<0.001***
FHI	63.213±3.577	57.824±3.24	5.389	<0.001***

[Table/Fig-9]: Means and Standard Deviations (SD) of the cephalometric analysis for CBCT derived cephalograms.
Employing two sample t-tests
*p<0.05;**p<0.01;***p<0.001

Variables	Mean±SD	Mean±SD	Range		p-value*	Significance
	Class I group	Class II group	Class I group	Class II group		
MxV	18409± 3633	19165± 3810	12133 to 26338	11180 to 26605	0.435	NS
MdV	40115± 8037	41432± 7227	28869 to 59508	26138 to 62449	0.507	NS
MdV/ MxV	2.1988± 0.2953	2.1871± 0.2553	1.674 to 2.8956	1.8202 to 2.9432	0.871	NS

[Table/Fig-10]: Descriptive statistics for the MxV and MdV and the mandibular/maxillary ratios as well as the results of the significance tests.
*Two sample t-tests were employed, p<0.05 indicates statistical significance
MxV: Maxillary Bone Volume; MdV: Mandibular Bone Volume; Mdv/MxV: Mandibular Bone Volume/Maxillary Bone Volume ratio, NS: Non Significant difference

both MxV and MdV and SN-GoMe and Bjork's sum. Also, a negative moderate association between the MdV and Ar-Go-Me was noted.

DISCUSSION

The technique of extracting the upper jaw in the current study is different from other previously published work [8,9]. To our knowledge, this is the first study to evaluate the volume of the maxillary bone with its complete anatomical components and extensions. Furthermore, two previous studies evaluated the association between a limited number of traditional cephalometric variables (i.e., seven variables only) and the MdV [13,14], whereas the current study investigated the possible associations between 25 derived cephalometric variables and the MxV and the MdV.

To separate the maxilla and the mandible, the threshold in all slices was set to clarify the boundary between soft tissues and the cortical bone. The outer circumference of the cortical bone was traced, as performed in previous studies [13,14]. However, dental crowns were removed from the 3D objects because they were judged to be affected by artefacts such as metallic restorations or crowns [8,9,13,14]. The mandible was extracted as reported by previous studies [8,9,13,14].

There was no statisticaly significant difference for in the MdV between the two groups (p>0.05). In previous studies which were all conducted on one race, i.e., the Japanese race, there was no significant difference in MdV between CI and CII groups [8,9,14]. An earlier pilot study showed no significant difference in the MdV between the hypo-divergent Class II and hyper-divergent Class II subjects [9]. However, a recent study by Nakawaki T et al., showed a larger MdV in hypo-divergent subjects compared with hyper-divergent subjects [14].

Previous studies did not evaluate the possibility of any association between mandibular backward rotation and an increased volume of the lower part of the face. This may be attributed to small sample size of these studies [8,9] or the ignorance of the antero-posterior skeletal component in their analysis [13,14]. The current study was designed to answer this question and we found no statistically significant differences between the two groups.

It seems that the increase in the facial length in hyper-divergent Class II Division 1 patients is due to the elongation of the bone in different areas but the total volume of the mandible did not change. This confirms that alterations may occur during growth as a result of any pathological factor (eg., mouth breathing, digit sucking) and these are accompanied with adjustments in the direction of growth (i.e., posterior rotation) and not in growth quantities (i.e., apposition of new bone). Therefore, this type of patients may suffer from thinning of the bone at some specific areas of the jaw. This finding suggests that additional research work should be done to identify areas where bone thinning had happened and care should be taken by oral-maxillofacial surgeon when an orthognathic surgery is planned for a patient with such craniofacial type (eg., long face syndrome).

There was no statistical significant difference for the MxV between the two groups (p>0.05). This result was consistent with the results of two previous studies [8,9] despite the differences between the current study and these two papers regarding the method of calculating the MxV. This result could be explained by the thinning of the maxillary bone in specific areas in conjunction with elongation at other areas but with no increase in the overall bone volume in class II hyperdivergent patients.

It has been shown that muscular function and activity has an influence on the growth of the craniofacial components of the skull as well as the dental arch dimensions [15]. An increased masticatory function had a positive effect on the growth and the morphology of the facial sutures as well as sutural bone apposition [15,16]. An increased transverse growth of the maxilla can also be observed as well [15]. In addition, masticatory muscles are attached to the lower jaw and increase in their function is expected to cause more development of the angular, coronid and condylar processes [15]. Therefore, it is reasonable to say that an increase in muscular force would lead to increased volumes of the jaws.

The correlation analysis in the Class II group revealed strong correlation between the posterior facial height (S-Go) and the Facial Height Index (FHI) with the volumes of the mandible and the maxilla. Previous studies have shown that masticatory muscle force was positively correlated with the posterior facial height and the facial height index [17]. Therefore, any increase in the posterior facial height would increase bone apposition and this may explain the expected increase in the volume of the lower jaw. In a similar way, MxV is expected to increase with the increased masticatory muscle force.

The height of the ramus (Ar-Go) was strongly correlated with the MdV which was similarly found by Hashiba C in a study conducted on dry skulls [18]. It has been shown that the

Variables		OJ	OB	U1-SN	L1-MdP	SNA	SNB	ANB	SN-GoMe	Y-axis	MM	NaMe		S-Go
Class I	Max	0.10	0.21*	-0.13	-0.22*	-0.03	-0.12	0.23*	-0.24*	0.26*	-0.21*	0.26*		0.27*
	p-values	0.583	0.261	0.468	0.232	0.838	0.511	0.211	0.189	0.193	0.251	0.165		0.146
	Mand	-0.02	0.03	-0.02	-0.38*	0.06	-0.04	0.30*	-0.35*	0.13	-0.27*	0.13		0.29*
	p-values	0.886	0.875	0.894	0.035	0.749	0.814	0.097	0.056	0.508	0.144	0.492		0.115
Class II	Max	0.13	0.14	0.00	-0.12	0.12	0.28*	-0.11	-0.48**	-0.15	-0.20*	0.39*		0.60***
	p-values	0.496	0.456	0.961	0.501	0.512	0.128	0.561	0.008	0.422	0.279	0.030		0.001
	Mand	-0.00	0.01	0.07	-0.26*	0.01	0.26*	-0.21*	-0.44**	-0.03	-0.21*	0.24*		0.78***
	p-values	0.990	0.958	0.701	0.17	0.94	0.172	0.275	0.02	0.85	0.253	0.219		0.000
Variables		S-Ar	Go1	Go2	LAFH/LPFH	ANS-Men	N-S-Ar	Ar-Go-Me	S-Ar-Go	Bjork	S-N	Ar-Go	Go-Me	FHI
Class I	Max	0.27*	-0.04	-0.22*	-0.13	0.13	*0.24	-0.29*	-0.24*	*0.24-	*0.27	0.26*	0.38*	0.17
	p-values	0.148	0.798	0.232	0.48	0.488	0.189	0.118	0.201	0.189	0.155	0.153	0.03	0.357
	Mand	0.18	0.01	-0.37*	-0.19	0.04	0.31*	-0.21*	-0.25*	-0.35*	0.27*	0.32*	0.15	0.309
	p-values	0.341	0.956	0.043	0.321	0.829	0.085	0.251	0.176	0.056	0.165	0.08	0.42	0.096
Class II	Max	0.56**	-0.14	-0.33*	-0.25*	0.25*	0.07	-0.33*	-0.06	-0.48**	0.19	0.20*	0.23*	0.62***
	p-values	0.001	0.445	0.082	0.181	0.167	0.693	0.073	0.749	0.008	0.301	0.302	0.21	0.001
	Mand	0.39*	-0.16	-0.22*	-0.24*	0.30*	0.13	-0.41**	-0.11	-0.44**	0.18	0.61***	0.38*	0.72***
	p-values	0.038	0.395	0.25	0.219	0.105	0.494	0.027	0.54	0.02	0.34	0.001	0.03	<0.001

[Table/Fig-11]: Values of Pearson's correlation coefficients between the 2D variables and the volumetric measurements.
(+) positive correlation; (-) Negative correlation. * r=0.2-0.39: weak correlation; ** r=0.4-0.59: moderate correlation; *** r=0.6-0.79: strong correlation.

masseter muscle thickness was positively correlated with the mandibular ramus height [19]. It seems that an increase in the masseter muscle function is accompanied with an increase in the ramus height, which would result in more bone apposition and this in turn leads to an increase in MdV.

MxV and MdV showed a moderate negative correlation with the mandibular plane angle as well as with the sum of Bjork. Previous published work has shown negative correlation between the masticatory muscle force and both the mandibular plane angle [17] and Bjork's sum [20]. It has been shown that increased intermaxillary divergence and backward rotation pattern of the growth is accompanied with decreased masticatory muscular function [17,20], which may result in decreased thicknesses at certain regions of the lower jaw leading to diminished overall volume.

The posterior cranial base length (S-Ar) showed a moderate positive correlation with the volumes of the maxilla. Again, going back to the available literature, it has been shown that a strong correlation exists between the cranial base length and the length of the maxilla [21]. When the maxillary length increases (a variable which was not evaluated in the current study), it is expected that the anterior posterior bone mass will increase leading to an increased volume of the upper jaw. This may explain the current finding.

From the clinical point of view, bone augmentation in surgical orthodontics is usually indicated when a bone deficiency is encountered or when there is a need to improve soft tissue appearance in certain areas of the face. Despite the insignificant volumetric differences observed in the current work between the skeletal groups, future research work would give more information about those specific regions of the maxillofacial complex requiring volumetric enhancement and therefore, the surgical decision of bone augmentation would be placed on a stronger scientific ground.

There is a need to explore the differences between hypo and hyper-divergent skeletal Class II patients as well as those in the skeletal Class I category. The differences between skeletal Class I and Class III patients should be also evaluated. A comprehensive analysis of different regions in each jaw should be performed in future research work to give more insight about the actual mechanisms beyond the vertical changes that occur to the craniofacial complex and to make use of the great power that is embedded in CBCT-based 3D modelling.

CONCLUSION

There were no significant differences in the volumes of both jaws between Class I and Class II skeletal patterns. Also, no or weak correlations were found in the Class I group between the volumetric measurements and the 2D variables. However, there was a strong correlation in the Class II group between both MxV and MdV and the posterior facial height as well as the facial height index. There was a strong positive correlation between the length of the ramus and the mandibular volume, and a negative moderate correlation between maxillary/mandibular volumes and mandibular plane angle as well as Bjork's sum in the Class II group.

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PARTICULARS OF CONTRIBUTORS:
1. MSc Student, Department of Orthodontics, University of Damascus Dental School, Damascus, Syrian Arab Republic, Syria.
2. Associate Professor, Department of Orthodontics, University of Damascus Dental School, Damascus, Syrian Arab Republic, Syria.
3. Associate Professor, Department of Orthodontics, University of Damascus Dental School, Damascus, Syrian Arab Republic, Syria.
4. MSc Student, Department of Periodontology, University of Damascus Dental School, Damascus, Syrian Arab Republic, Syria.

NAME, ADDRESS, E-MAIL ID OF THE CORRESPONDING AUTHOR:
Dr. Mohammad Y Hajeer,
Associate Professor, Department of Orthodontics, University of Damascus Dental School, Mazzeh,
Damascus-9309 MAZZ, Syrian Arab Republic, Syria.
E-mail: myhajeer@gmail.com

FINANCIAL OR OTHER COMPETING INTERESTS: As declared above.

Date of Submission: **Jun 25, 2017**
Date of Peer Review: **Jul 17, 2017**
Date of Acceptance: **Aug 19, 2017**
Date of Publishing: **Dec 01, 2017**