Technical Note

Modified method of analysis for surgical correction of facial asymmetry

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ABSTRACT

Introduction: The aim of this article was to present a new method of analysis using a three dimensional (3D) model of an actual patient with facial asymmetry, for the assessment of her facial changes and the quantification of the deformity. This patient underwent orthodontic and surgical treatment to correct a severe facial asymmetry. **Materials and Methods:** The surgical procedure was complex and the case was challenging. The treatment procedure required an orthodontic approach followed by Le Fort I osteotomy, bilateral sagittal split osteotomy, septorhinoplasty and chin advancement. The imaging devices used in this paper is the 3dMDface system (Atlanta, GA) and the Kodak 9500 Cone Beam 3D system device (Atlanta, GA). 3D digital stereophotogrammetric cameras were used for image acquisition and a reverse modeling software package, the Rapidform 2006 Software (INUS Technology, Seoul, Korea) was applied for surface registration. The images were also combined and analyzed using the 3dMD vultus (Atlanta, GA) software and InVivoDental 5.2.3 (San Jose, CA). All data gathered from previously mentioned sources were adjusted to the patient's natural head position. **Results:** The 3D images of the patient were taken and analyzed in three time frames; before orthodontics and surgical treatment (T_1), at the end of orthodontic therapy and before surgery (T_2) and about 2 months after surgery (T_3). The patient showed significant improvement of her skeletal discrepancy between T_1 and T_3. In addition, there were some dentoalveolar changes between T_1 and T_2 as expected. The 3D analysis of surgical changes on the 3D models correlated very well to the actual surgical movements. **Conclusions:** The use of these 3D imaging tools offer a reliable accuracy to accessing and quantifying changes that occur after surgery. This study shows supportive evidence for the use of 3D imaging techniques.

Keywords: Facial asymmetry, surgery, three dimensional analyses

INTRODUCTION

Facial asymmetry is considered to be a common phenomenon and could be present even in twins with identical genes.[1] It is not clinically possible to find exactly similar parts on either side of the reference line, plane or distributed around a center or an axis. The percentage of variation or in the size, shape and correlation of dental, skeletal and soft-tissue facial structures between left and right halves of the face is important because it designates the severity of the asymmetry. In addition, there may be various congenital, environmental, functional or local factors that can result in a deviation.[2] These factors usually occur in the lower part of the face.[2] It is not always easy to discriminate when a natural asymmetry becomes abnormal and the etiology diagnosis may vary as well. A facial asymmetry may be the result of a mild skeletal discrepancy and may be managed by orthodontics alone, although the patient will need to be aware of some compromises required e.g., maxillary expansion and hybrid functional appliances in growing patients. In case of severe skeletal asymmetry, the problems become difficult or complicated to treat. The treatments may require a joint orthognathic approach and the timing of treatment always depends upon growth. The asymmetry may sometimes be limited to the overlying soft-tissues and may require augmentation or reduction of the soft-tissue involving bone grafts and implants. The functional etiology of asymmetries is also very important. Many treatment plans have been offered to correct a specific cause on a case by case basis and may include; (1) occlusal adjustments if there is a minor deviation or (2) orthodontic treatment combined with maxillary expansion if there is a need to correct a severe deviation. In cases of displacement of the mandible due to a habitual posture, there is an initial need for an occlusal splint for diagnosis and deprogramming.[2] All this existing evidence led investigators to designate innovative approaches for facial asymmetry diagnosis and treatment planning. Various methods for qualitative and quantitative evaluations of both hard and soft-tissue changes have been described.

At present, the usage of 2D cephalometry radiographs and photographs has been extensively applied and are considered the gold standard. These techniques are inexpensive and fast to acquire.[3] On the other hand, three dimensional (3D) systems have been successfully introduced in the era of digital imaging with promising results. Several 3D techniques such as traditional computed tomography, cone beam computed tomography (CBCT), magnetic resonance imaging, laser surface scanning and stereophotogrammetry are now available.[4,5] In addition, the development of new software packages to capture the 3D facial forms and their accurate analysis have led to much improved understanding of facial disproportions during routine treatment follow-up. New 3D analysis tools facilitate the calculation of anthropometric measurements and predictions of successful correction of facial asymmetry and understanding of post-treatment relapse. Finally, 3D imaging also allows for precise monitoring of the surgical procedures, through the assessment of both the changes of the texture of the face and skeletal structure of the head and teeth. In this paper, we present a series of 3D methods to evaluate anatomic hard tissues structures in correlation with soft-tissues that are being displaced by surgery. We also apply a mandibular asymmetry analysis to diagnose the level of asymmetry and the level of progress after surgery.

MATERIALS AND METHODS

A 44-year-old White female who had undergone both orthodontic treatment and maxillofacial surgery to correct a severe facial asymmetry is described. The orthodontic treatment was initiated for this patient to achieve the appropriate relationship of dental arches and to allow for a Le Fort I and bilateral sagittal split osteotomies (BSSO) to be undertaken. All essential diagnostic modalities were obtained at the start and included basic dentoalveolar and maxillofacial examination measurements, dental casts with face bow transfers and intraoral and extraoral photographs of the patient [Figure 1].

The intraoral and extraoral examination showed that there was a cant of both the maxillary and mandibular plane. The deviation of the chin point was to the patient's right side. Moreover, there was deviated nasal septal deformity, maxillary hypoplasia and mandibular retrognathia. In the dental arches, a Class III subdivision was present on the left side and Class I subdivision on the right. The mandible dental arch form was asymmetric and moderate dental crowding was present. Her upper dental midline was coincident with the midsagittal plane of her face, but the lower dental midline was to the right of the reference plane.

Figure 1: Diagnostic intraoral and extraoral photos of the patient before orthodontics and surgical treatment

3D diagnostic methods

Assessment of soft-tissue is difficult to achieve due to muscular motion, breathing and head posture. These factors were minimized by establishing a consistent posture protocol. Natural head position (NHP) was adapted to this study and adjustments to this posture were done if necessary because this position of the individual has been shown to be clinically reproducible.[6] NHP is considered to be the most natural physiologic and anatomic orientation of the head.[7] In order to achieve this, in this study the patient sat on a self-adjustable stool and was asked to look into a mirror with standard horizontal and vertical lines simulating a cross on it.

3D data acquisition

The 3dMD face stereophotogrammetry system was used in this study for soft-tissue acquisition. The 3dMD device consisted of six digital high resolution cameras with a reported manufacturing accuracy of 0.1 mm. The light pattern was projected onto the patient's face and the cameras captured a variable of different angled photos at the same time so that any motion artifacts would be avoided.[4] Data were processed on a computer workstation by a processor and the outcomes coordinates of the surface registration were generated and saved as tsb file format.[6] The Kodak 9500 Cone Beam 3D system device (Atlanta, GA) was used for hard tissue acquisition and a series of two dimensional (2D) projections were obtained. Data from the projections were reconstructed using sophisticated algorithms and the process resulted in the axial, coronal and sagittal planes of the patient's face. The device allows radiation dose control through variable mA and kV settings. The estimated radiation dose of CBCT devices is between about 60 and 120 mSV.[8]

Software packages used

In this paper, three types of software packages were used. The first one was the Rapidform 2006 (RF6) software (INUS Technology, Seoul, Korea). This commercial implementation technique offers clinicians the potential to create the solid model by automatically converting point clouds into surface facet reconstructions and transfer this information of the patient to computer aided design (CAD), providing subsequently the "CAD model" directly from scan data.[9] It is especially useful under the surface to surface topology. The shell deviation map from T_3 follow-up was then indicated and compared with the baseline T_1. The differences are presented in Figure 2. The referring reverse modeling technology also includes a variety of options to accomplish further function. In order to achieve the development of the virtual textured model, four phases had to occur in the software procedure. These were triangulation, segmentation, solid modeling and model translation. Other studies have previously described the process in detail.[10]

The 2nd software package used was the 3dMD vultus software (Atlanta, GA). This technology created the CBCT models of the three time frames (T_1, T_2, T_3) directly from the corresponding CBCT scans. Moreover, this software affords with the possibility of obtaining three-dimensional (x, y, z) coordinates of both soft- and hard-tissue landmarks and fusing these two facial forms together. After loading the software image file (*tsb) and CBCT dicom files into the software, we used 13 soft-tissue landmarks [Figure 3, Table 1] and 18 hard-tissue landmarks [Figure 4, Table 2]. The nasion was used as the reference point (0,0,0) in both templates.

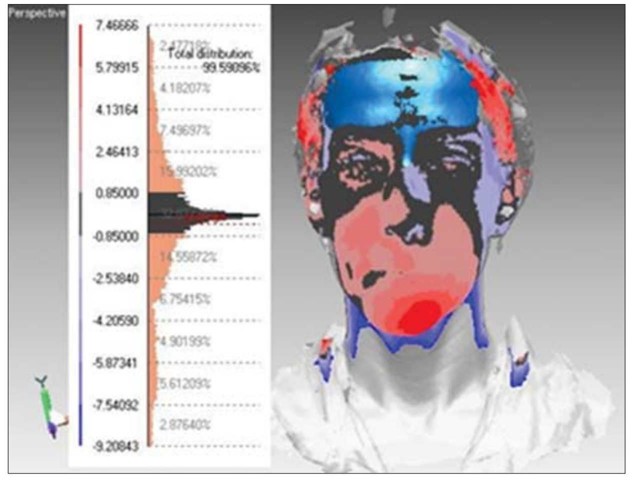

Figure 2: A shell deviation colored map indicating the changes in soft tissue morphology between time plans T_1 and T_3

Table 1: Soft tissue landmarks template Rapidform 2006

Abbreviation	Landmark
G'	Glabella
N'	Nasion
Or'	Orbitale
Prn	Pronasale
Sn	Subnasale
Sbal	Subalare
Ls	Labiale superious
Li	Labiale inferious
Ch	Cheilon
Pog	Pogonion

Table 2: Hard tissue landmarks template using 3dMD vultus software

Abbreviation	Landmark
N	Nasion
S	Sella
Or	Orbitale
ANS	Anterior nasal spine
PNS	Posterior nasal spine
Point A	Subspinale
Point B	Supramentale
Pog	Pogonion
GP	Genial point
Go	Gonion
Co	Condylion
RP	Ramus point

The third software package used was InVivoDental 5.2.3 software by applying a 3D novel analysis on the patient to measure mandibular asymmetry on the right and left side. A new co-ordinate system was set for the MS, horizontal plane (HP) and frontal plane (FP). 21 evaluation criteria were set, 8 vectors and 13 angles. The analysis was performed on (T_1) before orthodontic and surgical treatment, (T_2) at the end of orthodontic therapy and before surgery and (T_3) about 2 months after surgery. The mandible was divided into four parts by selecting the following landmarks: Condylion R, Gonion R, Menton, Gonion L and Condylion L. Mesiobuccal cusp of the right upper 1st molar and mesiobuccal cusp of the left upper 1st molar were selected on the occlusal plane to measure the severity of the cant [Table 3]. The angles between each mandibular vector and the three different planes were acquired in order to compare each line from a 3D aspect. The angle between the Menton and MS plane was calculated to measure Menton deviation.

RESULTS

The patient underwent orthodontics, Le Fort I osteotomy, BSSO, septorhinoplasty and chin advancement. This combined treatment approach allowed the patient to have normal breathing and to obtain an ideal occlusion whilst restoring facial asymmetry to achieve both an esthetic and functional result.

The analysis of hard and soft-tissue changes in the patient was performed in three time frames; (1) T_1 which is the baseline and considered to be the initial time plan, before orthodontics and surgical treatment, (2) T_2 evaluates the situation at the end of orthodontic therapy and before surgery and (3) T_3 corresponds to the treatment outcomes, about 2 months after surgery. The data for T_1, T_2, and T_3 were gathered by using 3dMDface system and Kodak 9500. All scans for the three time plans were processed and analyzed each of these three times using Rapidform 2006 and 3dMD vultus (Atlanta, GA) and InVivoDental 5.2.3 (San Jose, CA) software.

Within RF6, a shell deviation map was created in order to access the differences in whole-face soft-tissue morphology between two scans. These two scans were merged together and corresponded for the baseline final facial shell (T_1) and the time frame about 2 months after surgery (T_2). The surface of the cranial base was used for registration. A reproducibility error of 0.85 mm was shown to apply well in these two superimposed scans as is shown in Figure 2, because the clinical difference, meaning the amount of overlap between the two faces, was then seen to be 90%, which is considered to be reliable and reproducible finding.[6]

Pre-alignment of images were done in order to improve the previous stage. The initial facial alignment used five points on the face; the outer and inner canthus of the right and left eye and the nasal tip.

The average image was afterward color coded to highlight the deficiency. Black colored areas indicate regions on the face that didn't change after surgery when the composite faces aligned with tolerance level 0.8 mm.

The color map showed the changes made of red purple and black. The scale on the left of the image enables measurement of the surface distances between T_1 and T_3 time frames, and direction of displacement of a specific region as well. It is expressed in millimeters. For this case report, it was from the color maps that the greatest change was seen in the mandible. The regions with an inward displacement from baseline were indicated with the color purple and regions with an outward displacement were indicated with red. A significant improvement in the lower face is highlighted. The mandible rotated significantly to the left and the chin point advanced on the right side. The maxilla was positioned superiorly on the left, inferiorly on the right and mildly rotated to the left. The red color is seen all over the zygomatic area on the right side indicating that the Le Fort I procedure had produced a significant change on that side. In addition, the purple color on the left side indicated about a 3 mm bone removal from there. Because of the nasal reconstruction rhinoplasty we can see the negative change on the left and the positive on the right side respectively, reflecting

Figure 3: Three dimensional soft-tissue landmarking examples using 3dMD vultus software

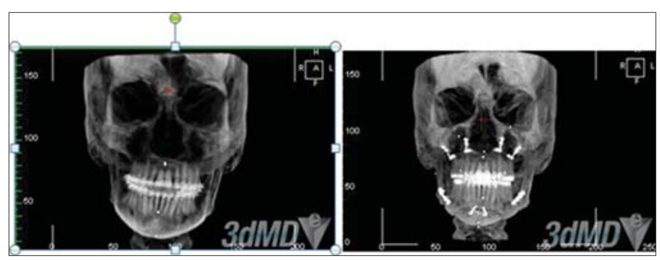

Figure 4: Three dimensional hard tissue landmarking examples using 3dMD vultus software

Table 3: Hard tissue landmarks template using InVivoDental 5.2.3 software

Vector	Landmark 1	Landmark 2
RLR	CA Condylion R	CA Gonion R
BMR	CA Gonion R	M_e
BML	CA Gonion L	M_e
RLL	CA Condylion L	CA Gonion L
Vertical position of the right upper 1st molar	Mesiobuccal cusp of the right upper 1st molar	Frankfort horizontal plane
Horizontal position of the right upper 1st molar	Mesiobuccal cusp of the right upper 1st molar	Mid-sagittal plane
Vertical position of the left upper 1st molar	Mesiobuccal cusp of the left upper 1st molar	Frankfort horizontal plane
Horizontal position of the left upper 1st molar	Mesiobuccal cusp of the left upper 1st molar	Mid-sagittal plane

RLR = Ramus length right side, BMR = Body of the mandible right side, BML = Body of the mandible left side, RLL = Ramus length left side the correction of the contour of the nose. The pogonion soft-tissue point was transferred by 4 mm. The same hard tissue point has changed too. Furthermore, the NMf distance between right and left side has been almost equivalent showing the symmetry correction of the mandible and the 3 mm deviation from an ideal face proportion. The surgical instructions confirm the accuracy of our results. Finally, the comparison between T_1 and T_2 outcome shows the dentoalveolar changes that occurred because of initial orthodontic treatment. The intraoral and extraoral photographs of the patient about 2 months after surgery (T_3) are shown in Figure 5.

3dMD vultus (Atlanta, GA) was used to evaluate the progress of the treatment in the three time frames (T_1, T_2, T_3). Results were classified into two categories: 1- expected to stay stable and 2- expected to change immediately after surgery and 2 months later.

The highest difference in the soft tissue between T_1 and T_3 was detected in Nasion-Pogonion 4.72 mm which was expected to change after surgery. On the other hand, the least amount of change between T_1 and T_3 was in Nasion-Orbitale left 0.06 mm, which was expected to stay stable [Table 4].

The highest difference in hard tissue measurement between T_1 and T_3 was detected in Nasion-Point B 5.98 mm which was expected to change after surgery. On the other hand, the least amount of change between T_1 and T_3 was in Orbitale left 0.03, which was expected to stay stable. Our expected results matched the data from using 3dMD vultus software (Atlanta, GA) [Table 5].

The 3D novel analysis using InVivoDental 5.2.3 (San Jose, CA) software was applied to measure the level of mandibular asymmetry was to the three time frames, to diagnose the level of asymmetry in the initial records and help determine the level of progress after the surgery. Vectors magnitude differences in the mandible were calculated after plotting all the landmarks [Table 6].

The difference in magnitude between the total length of the body of the mandible and the ramus comparing right side and left side varies from 7.15 in the initial (T_1), 7.24 after the orthodontic

Table 4: Soft tissue measurements

Reference point	N′	N′	N′
G′	13.8	**13.08**	**13.74**
Or′_R	46.48	**46.31**	**46.29**
Or′_L	45.21	**45.83**	**45.15**
Prn	57.2	**57.37**	*55.92*
Sn	65.49	**65.93**	*63.65*
Sbal_R	62.17	**62.61**	*61.85*
Sbal_L	63.12	**63,64**	*61.99*
Ls	79.87	*80.75*	*80.21*
Sto	83.16	*84.15*	*84.11*
Li	88.59	*89.53*	*88.97*
Ch_R	85.82	*86.4*	*87.56*
Ch_L	88.18	*88.2*	*89.32*
Pog′	113.01	**113.78**	*117.73*
Time frame	T_1	T_2	T_3

Bold: Expect to stay stable, Italics: Expect to change

Figure 5: Intraoral and extraoral photos of the patient about 2 months after surgery

treatment (T_2) and 1.32, 2 months after surgery (T_3). The highest level of asymmetry was recorded in the initial record (T_1) in the body of the mandible. The left side was 6.62 mm larger than the right side. The lowest level of asymmetry between right and left was recorded in the initial record of the ramus length. The left side was 0.3 mm larger than the right side. There was 8.98 mm decrease on the level of asymmetry in the body of the mandible on the right side when comparing the initial records with the final records [Table 6 and Figure 6].

Further measurements were taken to determine the severity of the cant. Vectors magnitude differences in the occlusal plane were calculated. The highest length difference was recorded in the vertical position of the upper 1st molar in the after surgery records (T_3). An increase of 2.38 was noted on the vertical position of the right upper 1st molar after surgery. As a result, the occlusal can't, which was present in the initial record was highly reduced [Table 7 and Figure 7].

Angle between each vector and the three different planes were measured. The difference in the angulation between each plane and each vector comparing right side and left side varies from 0.36° to 8.29° in the different time frames. The highest angulation was recorded between the ramus length and the MS plane in the initial records (T_1). The left side was 8.29° larger than the right side. The lowest angulation was recorded between the ramus length and the FP at (T_2). The right side was 0.36° larger than the left side. There was 1.71° decrease in the angle between the body of the mandible on the right side and the Frankfort HP after surgery in comparison with the initial records. That means after surgery there was an overall decrease in the angular asymmetry of the mandible, but still the right side was slightly more medial inferior and posterior than the left side [Table 6 and Figure 6].

Angle between Menton and the MS plane was measured to calculate the chin point deviation [Table 8]. The highest Menton angulation was 4.97 in the initial records. The lowest Menton

Table 5: Hard tissue measurements

Reference point	*N*	*N*	*N*
S	68.8	**68.62**	**68.06**
Or_R	41.35	**41.46**	**41.74**
Or_L	39.57	**39.35**	**39.6**
ANS	58.08	**58.37**	*55.35*
PNS	70.25	**70.68**	*67.06*
Point A	63.31	*59.26*	*59.29*
Point B	101.99	*96.95*	*96.01*
Pog	116.56	*116.16*	*110.74*
Go_R	119.18	**119.52**	*115.52*
Go_L	119.9	**119.67**	*118.71*
Co_R	96.07	**96.1**	*92.81*
Co_L	93.35	**93.24**	*91.53*
RP_R	107.53	**107.95**	*109.22*
RP_L	105.67	**105.07**	*109.46*
Mf_R	106.18	**106.55**	*103.66*
Mf_L	111.62	**111.58**	*106.5*
Time frame	T_1	T_2	T_3

Bold: Expect to stay stable, Italics: Expect to change

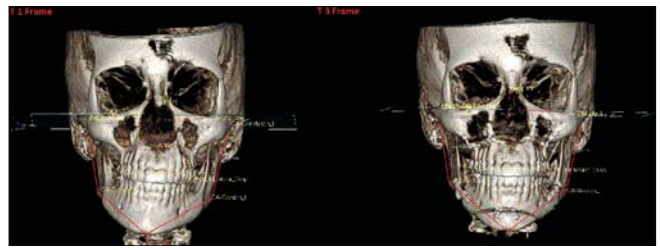

Figure 6: Mandibular vectors and the angulation between the body of the mandible on the right side and the mid-sagittal plane using InVivoDental 5.2.3 (San Jose, CA) software (Left side: Frame 1, right side: Frame 3)

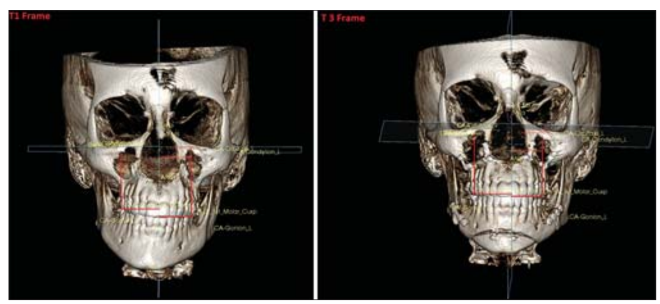

Figure 7: Vertical and horizontal position of the right and left 1st molar which represents the occlusal cant using InVivoDental 5.2.3 (San Jose, CA) software (Left side: Frame 1, right side: Frame 3)

Table 6: Vector and angular measurement for the initial, progress, and after surgery records respectively

T1	MS	FHP	FP	T2	MS	FHP	FP	T3	MS	FHP	FP
RLR 56.16	6.53	77.84	10.15	RLR 54.06	6.76	79.34	8.18	RLR 55.94	5.95	79.05	7.33
RLL 56.69	14.82	74.35	5.72	RLL 58.31	11.09	77.31	7.82	RLL 57.80	8.75	79.29	6.86
BMR 81.15	25.49	24.35	53.39	BMR 85.19	25.95	24.09	53.37	BMR 90.13	24.81	22.64	54.24
BML 87.77	32.40	21.52	49.63	BML 88.18	31.83	20.47	51.28	BML 89.59	31.86	22.07	49.63

RLR = Ramus length right side, RLL = Ramus length left side, BMR = Body of the mandible right side BML = Body of the mandible left side, FP = Frontal plane, MS = Mid-sagittal, FHP = Frankfort Horizontal Plane

Table 7: Horizontal and vertical vectors of the occlusal plane

Position of the 1st molar	Horizontal position of the right upper 1st molar	Horizontal position of the left upper 1st molar	Vertical position of the right upper 1st molar	Vertical position of the left upper 1st molar
T_1	26.67	22.65	43.99	48.68
T_2	26.77	23.03	44.84	48.78
T_3	26.80	22.28	46.37	46.30

Table 8: Menton deviation

Landmark/Time frame	Menton (T_1)	Menton (T_2)	Menton (T_3)
Mid-sagittal plane	4.97	4.83	1.83

angulation was 1.83 in the after surgery records. A noticeable decrease in the Menton deviation was noted after the surgery by 3.14°. The Menton is deviated to the right side [Table 8 and Figure 8].

After surgery, the patient had more favorable readings that represent less mandibular asymmetry.

Clinical application

Several attempts have been made to accurately analyze and measure hard tissue and the more complex dynamic soft-tissue changes of an individual. Investigators, when attempting to assess soft-tissue simulation are now concentrated on identifying the 3D coordinate values for specific selected landmarks and recording the actual growth or treatment changes by linear measurements. This systematic process is possible with the support of several reliable software packages and under those conditions; it will offer reliable reproducibility to the procedure resulting to accurate outcomes. Some examples of commercial CAD packages are SolidWorks (Amory, MS), Pro/Engineer Wildfire (Needham, MA, USA) and computer aided three dimensional interactive applications (Pembroke Pines, FL). There are also some non-CAD packages like Geomagic (Morrisville, NC) that are intended to support reverse engineering as Rapidform can do.[10] However, these offer limited capabilities for shape engineering and there is an intensive need for elaboration.[10] Kuang-Hua Chang has used 3D scanning software and hardware to determine the best available technology including Rapidform 2006 Software.[10] The first attempt of the contributors was to come through with surface modeling and at their second attempt they concentrated in parametric solid building.[10] The geometric error in average and standard deviation between the solid model and the mesh polygon were 0.021 and 0.049 respectively when using the Accuracy Analyzer of Rapidform.[10] This process has the potential to tolerate imperfect and incomplete scan database and nevertheless to still give excellent CAD-model results.

The 3dMD vultus software and vultus InVivoDental 5.2.3 (San Jose, CA) are considered a fast, accurate, non-invasive tool that enables further development of a new approach in craniofacial dysmorphology studies. 3D volumetric and cross sectional visualization of the patient can be achieved with multiple options for the patient's condition assessment. Skeletal and 3D surface measurement (distance/angle), 3-dimensional airway analysis from CBCT data, surgical, dental and orthodontic treatment planning, pre- and post-surgery superimposition and quantitative evaluation of surface and volumetric changes or establishment of database for normative populations are only some examples of what this technology enables investigators to achieve.

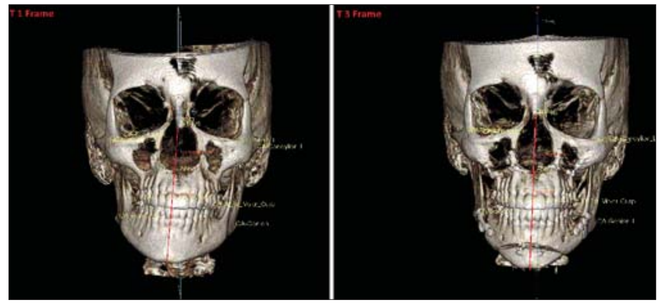

Figure 8: Menton deviation in relation to the mid-sagittal plane using InVivoDental 5.2.3 (San Jose, CA) software (Leftside: Frame 1, right: Frame)

CONCLUSION

These techniques indicated in this study have shown to offer a reliable accuracy to quantifying craniofacial changes after surgery and to evaluate even close deviations between two different time frames. Furthermore, the three images derived from this software can be obtained without the need to additionally radiate the patient. These new methods of analysis that has been described in this case report has helped to develop a great potential in the approach to future management and treatment of the patient in complicated cases that include surgery. As a result of using this technology, clinicians are being able to evaluate the treatment outcomes and precisely locate a possible relapse.

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