Orthognathic virtual treatment planning for functional esthetic results

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Virtual three dimensional (3D) facial diagnosis and treatment planning has the potential to improve outcomes for orthognathic surgery patients. It is necessary to appreciate the inadequacies of traditional two dimensional treatment planning and how that may adversely affect the virtual 3D treatment planning process. Virtual 3D planning greatly improves the clinician's ability to diagnose and treat facial form and position problems that prevent the patient from accomplishing the three Functional Facial Keys (eating, breathing and communicating). It also enhances facial-skeletal orientation, maxillary and mandibular positioning, correction of asymmetries and occlusal plane management. This article presents a systematic approach to treat functional facial problems using virtual 3D treatment planning for consistent esthetic facial results. (Semin Orthod 2019; 25:230–247)

Introduction

We have been treatment planning facial esthetics three dimensionally (3D) for as long as we have been performing orthodontics and orthognathic surgery. When we discuss 3D treatment planning as a new method of approaching our orthognathic surgery patients we are referring to the capture and manipulation of 3D volumes and surfaces in a computer environment. The irony is that at any given moment while using most 3D software and computer imaging, we are only seeing in two dimensions (2D) through standard monitors. Therefore, an important question is "how has a 3D image capture and viewing software changed the practice of dentistry and-in particular-orthognathic surgery?"

Traditional

To answer the question, clinicians will use their education (academia, books, publications) and clinical experience (observing and treating patients). The problem with using traditional treatment approaches when planning in the virtual 3D environment is traditional diagnostic and treatment planning methods are frequently not applicable. Two dimensional measurements such as Frankfort Horizontal and Rickett's E-plane are absent realistic facial functionality and esthetics. Many of the studies evaluating skeletal, dental, and facial positions do so in a normative manner. To analyze 100−200 people who are considered "normal" and then apply those findings to an actual clinical patient is full of complicating factors. The patient that is being treated was not part of the cohort that was analyzed and the average findings of the studies may not represent the optimal result for any single individual. If we apply averages to our patients, we will, at best, have average results.

Functional

A better approach to 3D diagnosis and treatment planning and our patients is to ask better questions. What is the purpose of the face? If I change the position or shape of a particular structure of the face, how will it affect its purpose and the other structures that are adjacent. Esthetics is really just a measure of function. We are neurologically wired to be attracted to other humans

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who function appropriately. This is a protective mechanism for the species as we will not be inclined to share our genetic material with someone who is not functioning correctly. Stated simply, if the face works right, it looks right. The three Functional Facial Keys of the face define the purpose of the face which is to: (1) breathe, (2) eat and (3) communicate. When growth and development prevents the proper function of these three keys, the system will compensate in adaptive (mild form and position changes) or maladaptive ways (pain and tissue breakdown). So our goal in 3D facial planning is to provide an esthetic functional result by restoring natural forms and establishing proper positions for each part of the individual's face. This will then allow the facial system to accomplish all three Facial Functional Keys and thereby be esthetic.

Orientation

Orientation of the head is the most important step in facial treatment planning. If this step does not receive adequate attention, the orthodontic and surgical results will be compromised from the outset. It is surprising that surgeons spend very little time reviewing the orientation of the skull when using 3D virtual treatment planning services. Moorees quoting Schmidt from 1876 insisted "the horizontal positioning of the head is a physiologic concept, which we must find by observation of the living."[1]

The clinician needs to realize that head posture is dictated by the muscles of the head and neck. These muscles can respond dysfunctionally to growth disturbances or the compensations that arise from such growth problems. Interferences in the occlusion, a constricted airway and muscular pain can cause inappropriate posture and altered head position. For example, a patient who has a small airway will unconsciously open their airway by rolling their head forward over their shoulders to position their jaw down and forward, thereby opening the airway (Fig. 1). Since the occlusion, face and airway are being treated to correct these kinds of compensations,

Figure 1. The patient's head posture in the clinical photo represents her natural head position. She extends her neck and elevates her head to breathe more easily. The digital image shows the corrected sagittal plane orientation.

we expect posture to restore naturally after surgery. For this reason, we should treat to a corrected head position as opposed to a strict natural head position.[2]

3D viewing allows for head positioning (orientation) without muscular influence. Straight posture can be assigned as the patient is digitally made to look to the horizon. The corrected head position should not be determined by viewing each two dimensional plane of orientation statically. Using 3D software, the head can and should be moved through ranges of positions, along each planar axis, to reveal deviations from the desired corrected head posture.

Sagittal plane (profile view)

Traditional

Orientation of the face in the sagittal plane (profile) is traditionally performed by leveling Frankfort horizontal (Porion to Orbitale) to the horizon. There are no studies that articulate Frankfort horizontal parallel to the horizon as the natural sagittal plane posture for every individual. The literature reports deviations between plus or minus eight degrees relative to natural head position.[3] In our experience, leveling the head to Frankfort horizontal commonly causes an upward gaze as opposed to the natural and functional eyes forward head position (Fig. 2).

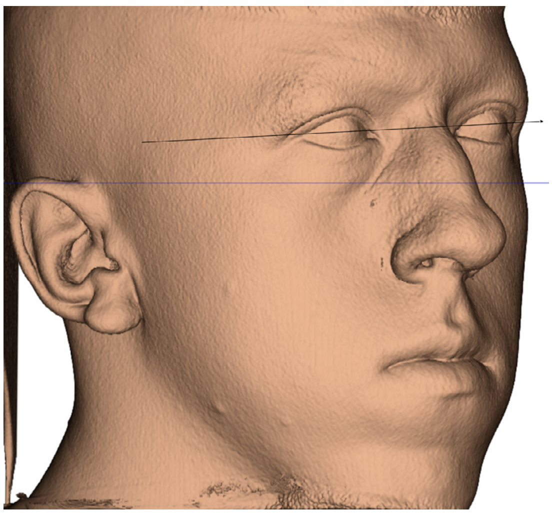

Figure 2. The patient's digital image has been leveled to Frankfort Horizontal (blue line) which results in the unnatural elevation of his gaze (black arrow). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The technique for setting the sagittal orientation using a *plumb line to the face* was described by Lundstrom and Lundstrom in 1992.[4] This approach is far superior to Frankfort horizontal for facial treatment planning. It requires the clinician to find the most naturally appearing sagittal head position without using any internal landmarks.

Functional

This technique can be misleading. There are enumerable points of view available to the clinician with the patient in the correct sagittal head position. The forward gaze "natural head position" may appear inappropriate in a 3/4 position compared to the profile (Fig. 3). Any disturbance in the frontal orientation will make the right and left profile/sagittal orientations different. The best technique is to set the eyes to the horizon in profile and then rotate the 3D object around the *x*-axis and observe if the forward gaze changes. If it lifts or falls, the frontal plane should be adjusted until the eyes maintain a correct forward gaze in all points of axial rotation.

Frontal plane (frontal view)

Traditional

Many techniques have been described for leveling the head in the frontal view, such as leveling the orbits, leveling the ears, leveling the globes, leveling the zygomatic arches, etc. All of these techniques are fraught with complicating factors as few humans have eyes, ears or jaws which are parallel to the floor (Fig. 4).

Functional

The clinician needs to decide the facial level for each patient. This can be difficult as our eyes are influenced by the symmetry and/or the asymmetry of adjacent structures. Uneven eyes, for example, might cause us to view canted maxillary canines as level if they match the pupillary cant. We are capable, however, of interpreting all sensory input from a patient's face and determining the correct level for the entire complex shape that is the face. The clinician should use all

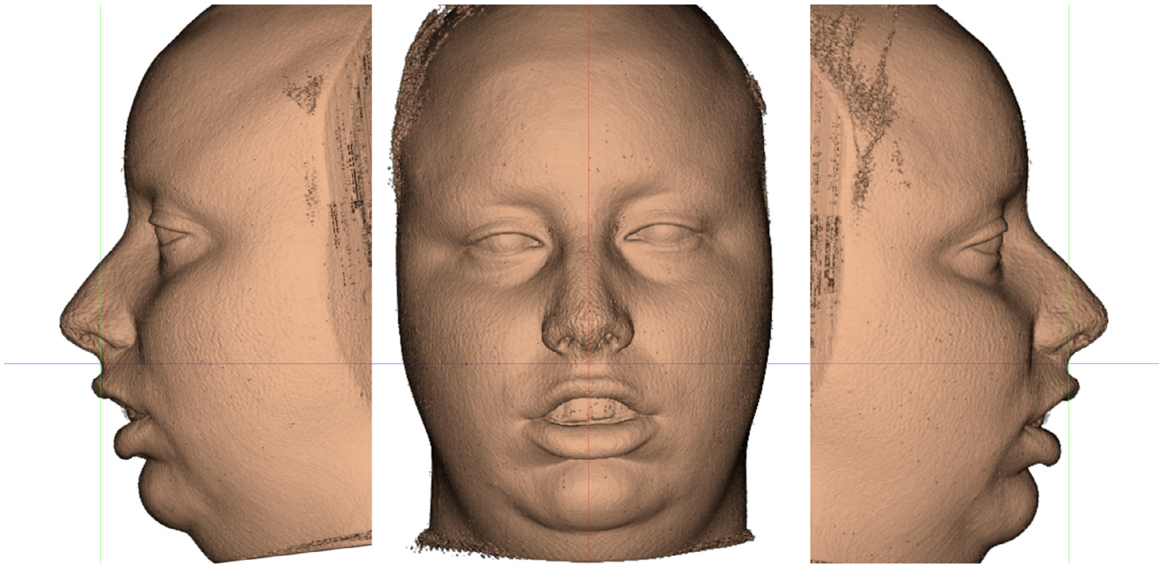

Figure 3. The center image shows the head canted down on the right side. In the right profile image, the sagittal plane orientation looks appropriate whereas the left profile orientation appears head down.

available structures of the face to decide the proper frontal plane orientation. Here are important observations. Are the eyes level? If not, how far off? Is there a cant to the maxillary canines? If so how much? Are the ears level? If not, how far off are they? Do the pupils look level? If not, how far off are they? Once all possible measurements are noted, the face is then positioned to fulfill as many, if not all of the individual measurements.

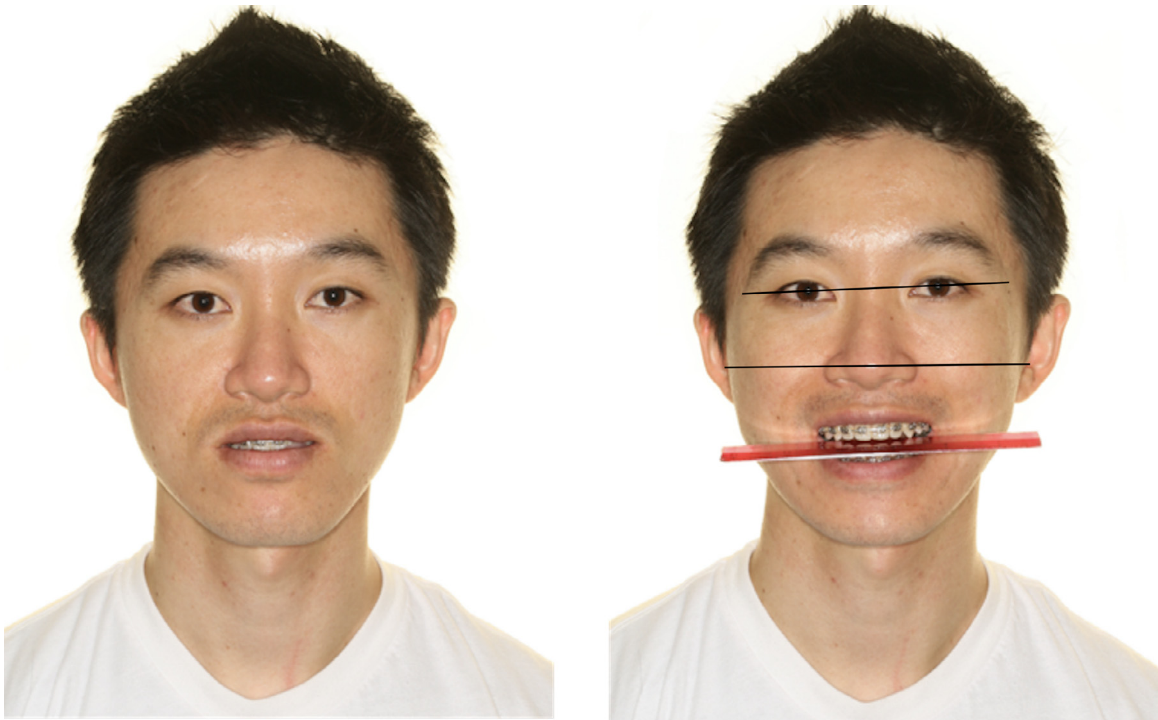

Figure 4. Frontal plane orientation is influenced by multiple measurements. In these images the eyes, ears and canines are observed to be on three different planes, possibly complicating orientation.

Axial plane

Traditional

This orientation has often been taken for granted when looking at a patient's two dimensional radiograph. We assume we are viewing perpendicularly to their facial frontal plane. Radiographically, the frontal plane is defined by the position of the film plate relative to *x*-ray beams as they pass through the face. The assumption is that the patient is positioned looking forward, but it is not necessarily true in a cephalostat or other head positioning device. Any axial deviation of a two dimensional image creates errors in a frontal and a profile measurement and the positioning error is not very evident when examining the radiograph.

Functional

Axial orientation is complicated by the fact that a face does not grow in a straight forward direction. Because the cranial sutures can fuse at different times, the face may deviate in many directions as develops. The best technique is to measure and observe multiple locations to best project the face in a most forward position. Relying solely on bisecting the foramen magnum is rarely correct by itself. Combining the observations of the foramen magnum, the position of the mid palatal suture, the outline of the frontal bones and the forward projection of the lateral orbital rims will improve the accuracy of the axial orientation (Fig. 5).

The midline

Traditional

Traditional methods for defining the facial midline include: the philtrum, the tip of the nose and the midline of the distance between the inner canthi, the zygomas or the pupils. All of these methods can be influenced by scar tissue, septal deviation, nasal bone asymmetry (from growth or rapid palatal expansion), orbital dystopia and other issues. A negative influence to defining the facial midline is a mandibular deviation. A significant mandibular deviation will distort the tissues of the mid face in the direction of the deviation. If the mandibular asymmetry is corrected, the upper lip and face will move in the direction of the correction and change the origin of the incorrectly diagnosed midline.

Functional

Grybauskus et al. described a technique referred to as "forced symmetry" where CBCT's are taken

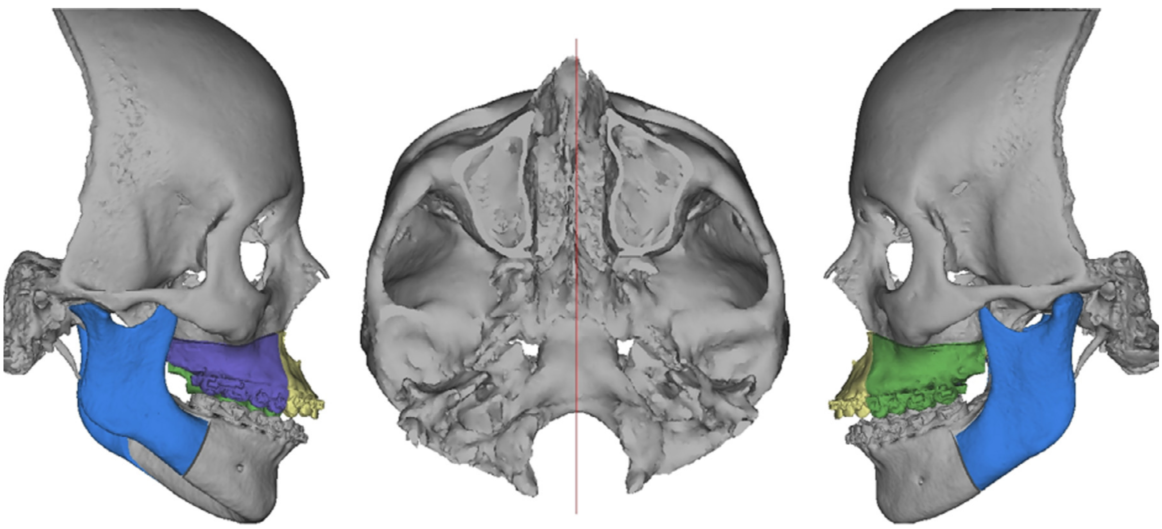

Figure 5. During axial plane orientation, the midsagittal plane can be observed to bisect the foramen magnum and the midpalatal suture, though this is not always the case. This patient also shows even lateral orbital rim projection but has an uneven frontal bone with the right brow projecting forward more than the left.

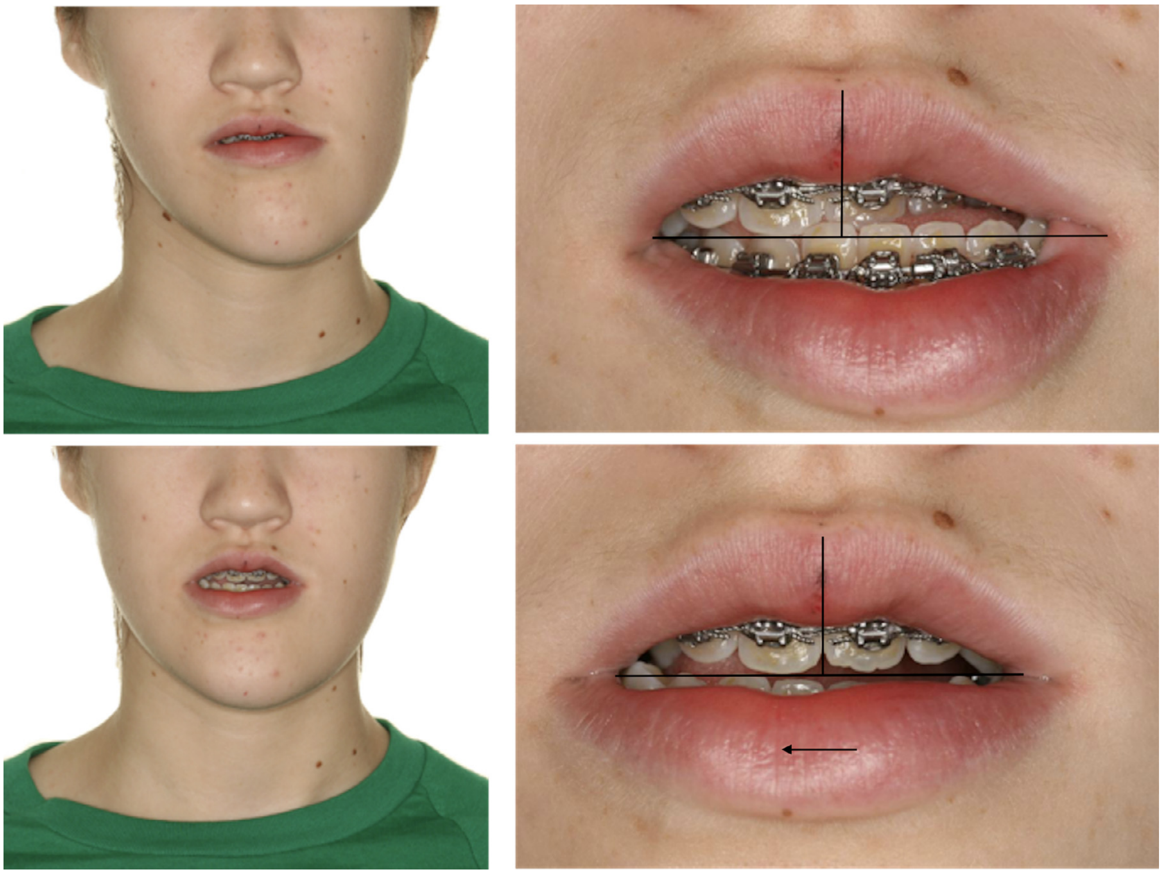

Figure 6. The patient places her mandible to right, more coincident with the facial midline which reveals a significant correction of her upper philtrum. Relying on the philtrum in this patient, without centering the mandible, would have resulted in a significant positioning error.

in the natural head position and then with the mandible "forced" into the facial midline position.[5] A simple approach during the clinical exam is to ask the patient to hold their mandible close to the facial midline and observe the upper lip and nose for changes (Fig. 6).

The clinician must establish a hierarchy of trust in regarding those references he/she will use to choose the facial midline. The mid sagittal plane is then chosen and checked against the other planes of orientation. It is important to realize that each change in an orientation plane affects the other two planes. When one plane is adjusted the other two are changed and might require re-orientation. 3D facial orientation is a complex process that cannot be relegated to a single-measurement-fits-all approach. The more data considered during the orientation process, the more likely the final head orientation will be correct.

Final occlusion

After orientation, the next step in virtual orthognathic treatment planning is placing the patient's dentition together into a finished occlusion. There are numerous issues to address during this step such as establishing esthetic anterior tooth inclinations and angulations, decompensating posterior molars and establishing esthetic and functional tooth forms. Optimized tooth interdigitation promotes a stable surgical result with functional uncompressed temporomandibular joints. Arch form symmetry and a level occlusal plane (OP) help to insure correct positioning of the underlying bones. Orthodontically uncorrected dental cants should be noted but not corrected in the virtual environment. Such a correction would lead to an asymmetric skeletal-facial result. Overbite and overjet should be appropriate anteriorly

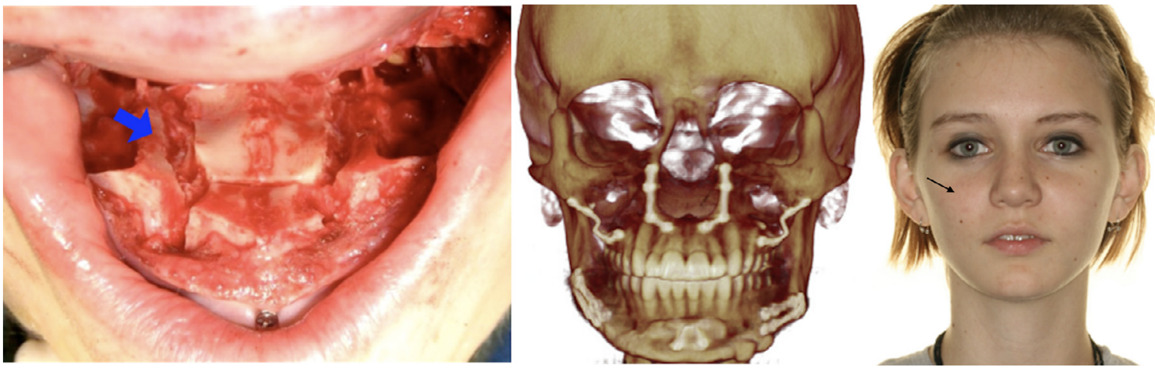

Figure 7. Flowering of the maxilla is caused by the skeletal correction of orthodontic torque problems. In this patient, the right maxillary posterior segment was set up with excessive buccal crown torque. As her teeth were brought into occlusion, the nasal base and lateral sinus wall rolled lateral. The bony projection can be seen in her face.

and posterior with the occlusal contacts verticalized. This approach prevents "flowering" of the maxillary segments during multi-segment surgery which can cause asymmetric mid-face projections (Fig. 7). The final occlusal is either accomplished on stone dental casts, scanned and merged into the virtual plan or it is set in the digital environment. Once the final occlusal position is established, the maxillomandibular complex (MMC) can be addressed. We leave the maxillary central incisors in the zero/neutral position vertically and anterioposteriorly with the patient's dentition in final occlusion at the outset of treatment planning.

Asymmetry correction

Identifying and treating dental and skeletal asymmetries is where digital imaging and virtual orthognathic surgery planning has made the most impact in improving accuracy and esthetic results.

Traditional

While centering the midlines with analog articulator based model surgery was straight forward, identifying and treating maxillomandibular asymmetries was quite difficult. The soft tissue mask often impeded proper identification of bony asymmetries and the correct measurement of posterior rotations (yaw) and shape distortions. Treating them on the model block or the articulator was equally as difficult. It was often impossible to know how much yaw correction at the dental level would actually correct osseous maxillary and mandibular asymmetries.

Functional

Visualizing the bone and teeth together and tracking their positions in space is very accurate in the virtual 3D environment. It is also possible to assess shape distortions in the mandibular bone and maxillary alveolus. With the teeth together, the maxillary and mandibular midlines are centered to the mid sagittal plane. Lateral distance from the midline is measured at various points moving posteriorly from canines to molars, chin to mandibular angles and nasal base to zygomatic arches. Confounding information can occur when relying on point measurement distances to the midline. If, for example, a structural rotation occurs and the points being measured fall out of the same frontal plane, their distances will not be equal from the mid sagittal plane although the bones may be symmetrically placed in the axial plane. For this reason, it is better to judge the projection of the shapes or outline of the dental arches, the maxilla and the mandible in the axial plane. Looking at the outline of the mandible relative to the outline of the maxilla in the axial plane will reveal rotational asymmetry (Fig. 8). Viewing the projected outlines of bones relative to the soft tissues of the upper face, assures that the dentition and bones finish in a pleasing and symmetrical position (Fig. 9).

When dental arches are not symmetric to the basal bones, the clinician needs to (1) choose which deviation needs to be corrected based on

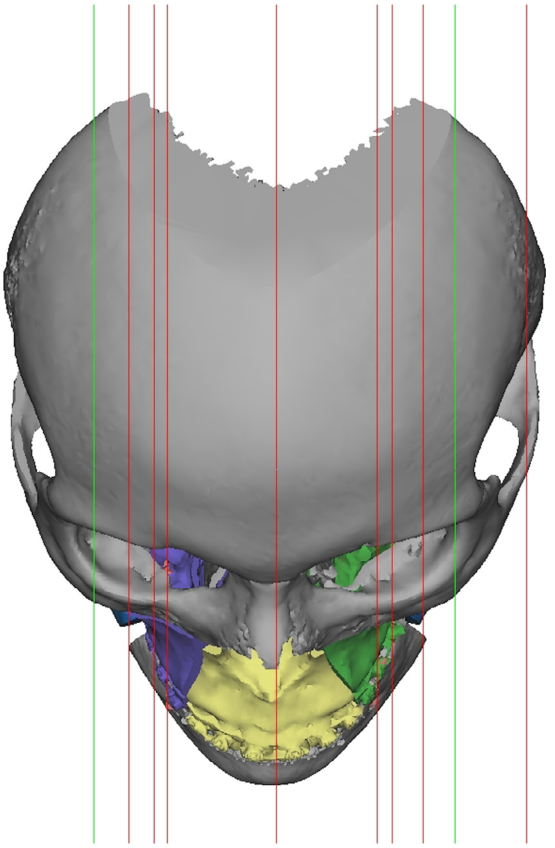

Figure 8. In this view, the outline of the high mid-face, the maxilla, the maxillary alveolus and the mandible can be compared. The shapes and outlines of all these structures should align with each other. This is a more accurate approach to asymmetry correction than relying on linear measurements to the midsagittal plane.

the visibility of the asymmetry, (2) request from the orthodontist that the arches be made more coincident with the basal bones prior to surgery or (3) consider contour grafting for improved symmetry.

Also, any correction in the axial plane will change the relative vertical position of any angled object, in particular the mandibular inferior border. What might look like an osseous cant at one axial position may disappear or worsen with any rotational correction of the jaws in the axial plane.

Maxillary AP position

Traditional

Most cephalometric analyses are referenced to the cranial base. Due to the variability of the cranial base and its disconnect from the actual face, these analyses are inadequate assessments of esthetic or functional upper incisor positions. The Steiner analysis, like many others, is derived from the observation of "normal" patients. What made the patients normal for inclusion into these studies was likely a normal occlusion, not necessarily correct function or esthetics.[6]

Doctors G. William Arnett and Larry Andrews developed facial cephalometric analyses which improved the diagnosis of the face as the points described were actually on the face or directly supporting the face. Dr. Will Andrews described the maxillary central incisor position relative to the forehead in Caucasian women with "good facial profiles."[7] Dr. Arnett's analysis of "beautiful" subjects recommend the maxillary central incisor tip be 8–10 mm behind the true vertical line.[8] Comparing Dr. Will Andrews' article on incisor position and Dr. Arnett's reported values for incisor position, the prescribed maxillary incisor position for both analyses are nearly identical. While neither article discusses the functional relevance of the "normal" position of the maxillary incisor, the fact that "good facial profiles" and "beautiful" subjects were chosen includes the bias towards functionally esthetic faces. This approach is much better than their cranial base analysis predecessors.

Functional

The four main functional goals of maxillary advancement are:

1. to maximize airway size
2. to support upper lip projection and function
3. to maximize mandibular advancement
4. to fill the buccal corridors.

The maxilla often needs to be advanced to overcome the common finding of maxillary anteroposterior growth deficiency. The anterior repositioning of the maxilla forward and consequently repositioning the mandible, is dependent on maximizing upper lip support without compromising lip function. Advancement of the maxilla functionally provides an expanded airway in all dimensions.[9] In addition, as the greatest transverse projection of the maxillary arch is advanced into the commissures, the buccal corridors are filled with the posterior teeth. This is an

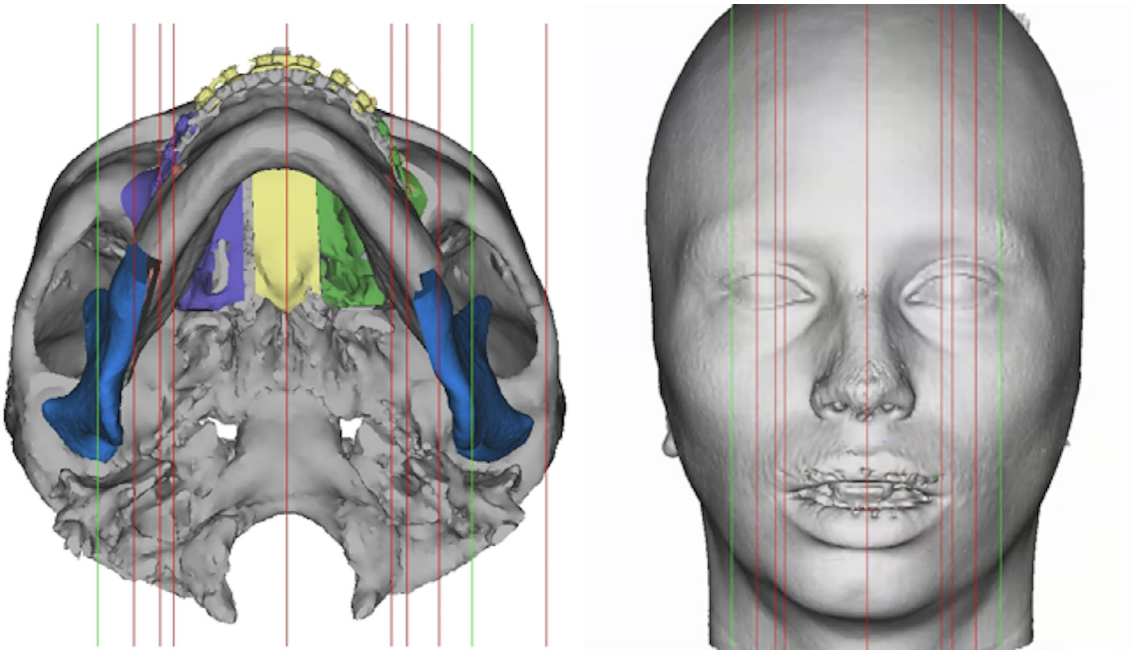

Figure 9. The outlines can be assessed from the worm view as well. The outlines of the jaws and teeth can also be projected onto the facial soft tissues to ensure they are symmetrically underneath the soft tissue structures.

esthetic benefit to the patient's smile. Often, correction of the buccal corridors is thought to be a purely transverse problem.

Upper lip support requirements are measured clinically. Various instruments can be used to assess how much hard tissue support is required to achieve maximum lip projection. We recommend using a dental mirror (2 mm) held behind the relaxed upper lip. The mirror is then advanced until the lip projection is esthetic (Fig. 10). Utility wax or a stereolithographically printed jig can serve this purpose (Figs. 11 and 12). The goal is to measure how much projection is needed to evert the vermillion and support esthetic upper lip projection. There are two confounding factors when performing this clinical measurement, however. First, if the mandible is significantly retruded, it will hold the soft tissues of the mid face in a retracted position placing posterior tension on the upper lip. To overcome this, have the patient position their mandible forward to the approximate post-surgical AP position. This will allow the mid face soft tissue to relax forward and often reveals the need for

Figure 10. A 2 mm thick dental mirror is used to measure the patient's need for maxillary advancement. The mirror is place at the location of the central incisors intended most anterior projected surface.

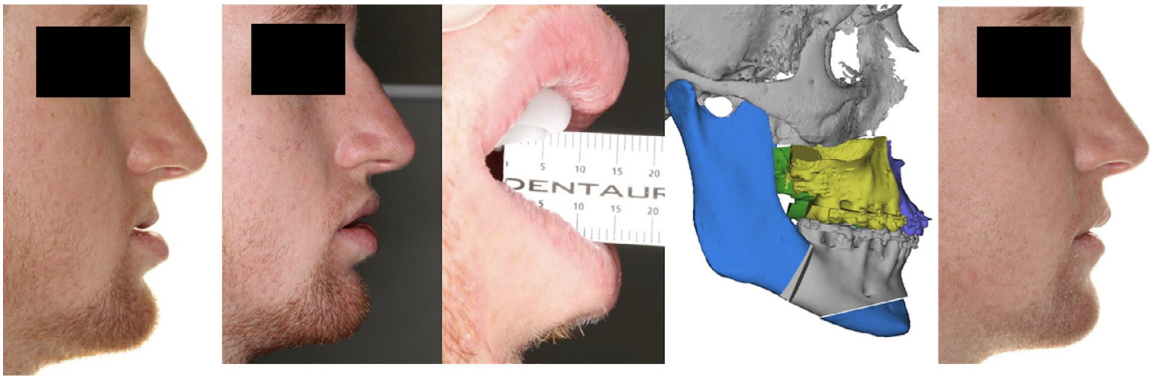

Figure 11. Utility wax can be used to sculpt the proposed dentoalveolar anteroposterior advancements. In this patient the was represents a 9 mm advancement at the facial surface of the maxillary incisor. The virtual plan is seen and the resultant lip support post operatively.

Figure 12. A stereolithographic model based on the proposed movements of the upper jaw was adapted to the surfaces of the patient's teeth and alveolar bone. The change in the upper lip was minor and so the decision was made to advance the upper jaw further than planned.

greater maxillary advancement. Second, the most anterior hard tissue projection point that will support the lip must be identified. Nature designed the maxillary incisor with its height of contour in the cervical third as measured upright. If the incisor is angulated as it is in the alveolar bone, the crown is "torqued" forward changing the central incisors' most anteriorly projected surface to the incisal third (approximately 3 mm above the incisor tip). This means that if the central incisor is placed with 3 mm of tooth show at rest, the lip will rest supported by the height of contour, esthetically projected forward and everted at the level of the vermilion. Therefore, the clinician needs to measure the actual lip support where the greatest AP projection of the dentoalveolar complex will be (Fig. 13). If this support point it is not going to be at the vermillion position of the lip as a result of surgery, the surgeon should consider changing the treatment plan and/or referring the patient for restorative and/or orthodontic solutions before surgery.

Upper lip function is dependent on the position of the teeth and the bones of the anterior maxilla. Drs. Raffaini and Cocconi describe the nasolabial unit (NLU) as the relationship of the central incisors most anteriorly projected surface relative to the anterior nasal spine (ANS).[10] They describe that the most esthetic AP position for the most anterior facial surface of the central incisor as resting in a vertical line, parallel to the true vertical line, as it passes through the ANS (Fig. 14). They do not describe why this position is esthetic. The functional reason for this esthetic position is that the insertion points for the orbicularis oris muscle are immediately underneath the ANS (Fig. 15). The lips need to move over the anterior teeth passively to provide lip closure. If the teeth are too far anterior or too far posterior relative to the muscular insertions, lip function will be compromised. The orthodontist controls this position by changing anterior tooth inclinations and bodily positions while the surgeon controls the position by altering the occlusal plane of the maxilla.

Figure 13. In the image on the right, the red and green dots represent the most anteriorly projected surface of the central incisors. Since his incisor exposure is 4 mm, these points line up perfectly with the upper lip vermillion border. This support esthetically projects and everts the upper lip. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

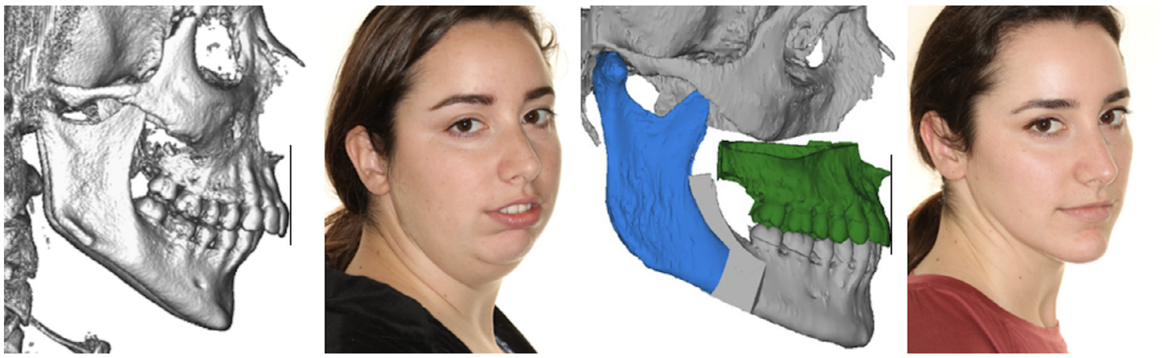

Figure 14. The nasolabial unit is defined by the black line which is parallel to the true vertical line and rests on the most anteriorly projected surface of the maxillary incisor. In the preoperative position, the surface is labial to the ANS due to poor inclinations and the maxillary occlusal plane. Postoperatively, the ANS is in line with the facial surface of the incisor and the appearance and function of the upper lip are improved.

Occlusal plane

When the dentition represents the final occlusion, cants and midlines have been corrected and the maxillary advancement is achieved, the occlusal planes (OP) of the maxillomandibular complex (MMC) can be addressed.

Traditional

When stainless steel wire was the only method for skeletal fixation in orthognathic surgery, it was understandable that counter clockwise rotation (CCWR) of the MMC was considered unstable and unreliable. The advent of rigid fixation has addressed most of those concerns. Concerns over CCWR of the OP still exist but ample research provides that such movements are stable.[11] CCWR is the normal pathway of growth of the maxilla and mandible. Patients with maxillomandibular growth restriction will likely be observed to have a steep occlusal plane and bimaxillary AP restriction. Yet, the most common approach to the high angle class II patient with anterior open bite is the maxillary posterior impaction with autorotation and large genioplasty. That treatment plan results

Figure 15. The red circles represent the place where the orbicularis oris muscles insert. For the upper lip to function properly, the incisors cannot be too far in front of these attachments without inducing strain, which leads to dysfunction and esthetic decline. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

in excessive nasal projection with its resultant alar base widening, unesthetic lip support with flattening of the lip and unsightly projection of the chin. The esthetic and functional demands for each patient should support the surgeon providing the appropriate treatment plan based on the patient's individual growth restriction.

Functional

The adjustment of the MMC in sagittal rotation (adjusting the occlusal plane) has effects on numerous functional and esthetic aspects of the face in multiple dimensions. Manipulation of the occlusal plane controls:

1. chin projection
2. nasal base projection
3. posterior teeth show on smiling
4. squareness or taper to the jaw line in frontal and sagittal views.

The esthetic benefits of occlusal plane manipulation in the sagittal plane are well known. In dolichofacial patients, CCWR with advancement helps to minimize the projection of the bones behind the nose preventing unsightly nasal widening and flattening of the upper lip. It also maximizes chin projection without needing a large genioplasty thereby maintaining the natural contour and shape of the chin. In brachyfacial patients, clockwise rotation of the MMC results in the opposite movements with greater projection of the nasal base and relative retrusion of the chin below the mandibular incisors; common esthetic defects in the brachyfacial patient (Fig. 16).

Control of the occlusal plane of the MMC helps define the projection of the body of the mandible as seen in frontal and lateral views. As the body of the mandible moves vertically, the surgeon can square or taper the appearance of the jaw depending on the rotation of the OP, CCWR or CWR, respectively. This is important when considering the goals of the patient to appear more feminine (taper) or more masculine (square).

Manipulation of the OP also helps to place the premolars and molars within the smile arc. The posterior premolar/molar exposure or gumminess can be measured and applied to the needs of the patient in managing the sagittal rotation of

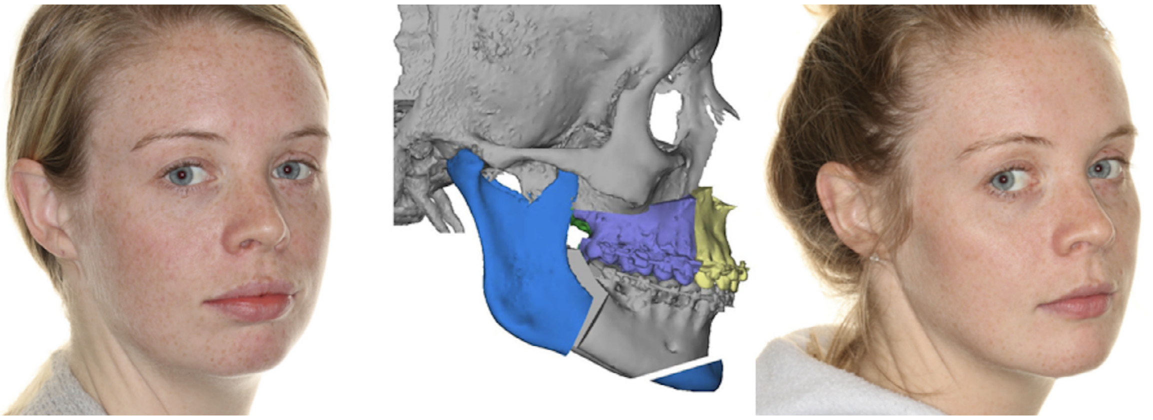

Figure 16. This patient is brachyfacial, with poor nasal base support and a deep soft tissue b point secondary to a short anterior face height and a counterclockwise positioned mandible. The treatment plan rotated the mandible clockwise to provide nasal base fullness, while the genioplasty helped lengthen the lower face height without causing interlabial gap.

the MMC. The smile arc range is usually between 92 and 95° of maxillary OP angle to the TVL.

If maxillary CCWR violates the NLU by positioning the ANS behind the maxillary incisor, the smile will become hyperactive. If CWR violates the NLU by positioning the ANS forward of the incisor, the upper lip will flatten or worse become convex in its profile form. These errors have unesthetic outcomes for the patient's nasal complex.

Cocconi and Raffaini also describe the labiomental unit (LMU). The LMU defines the most esthetic position for Pogonion. Pogonion should lie in the vertical plane (parallel to the TVL) that passes through the most anterior facial surface of the mandibular incisor (Fig. 17). This position allows for the lower lip to be projected adequately in the AP without disturbing its closure via the orbicularis oris and the mentalis muscles. In addition, an esthetic chin requires a hard tissue B-point positioned 4–5 mm behind the LMU vertical plane in order to have adequate definition at the labiomental angle. If alteration of the OP does not fulfill all of the above requirements for the LMU and B-point depth, then a sliding genioplasty should be performed.

Advancing or retracting the chin will allow the final adjustments necessary to align Pogonion with the mandibular incisor and maintain sufficient depth at B-point. When altering the OP, it is important to satisfy all aspects discussed above in order to achieve an esthetic and functional face.

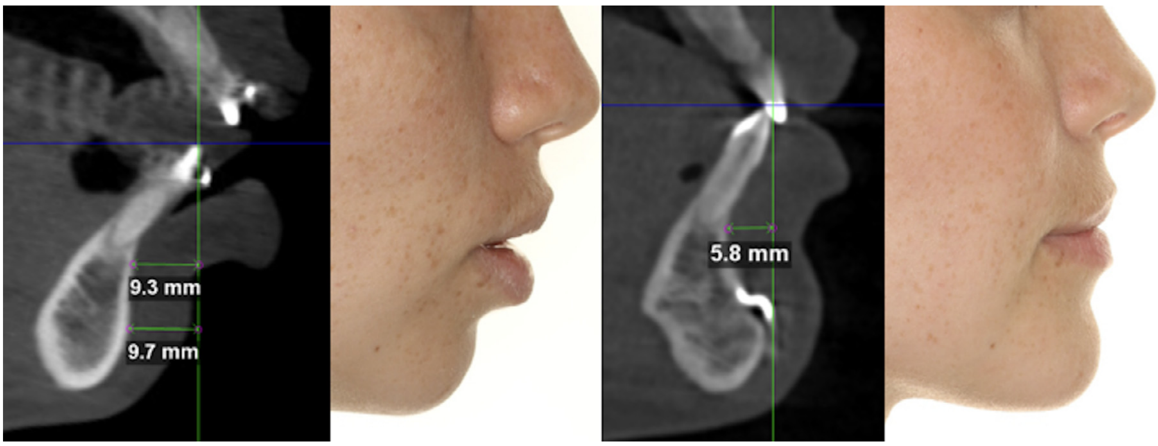

Figure 17. Correction of the labiomental unit improves the appearance of the lower lip and chin as it normalizes lower lip function. The orbicularis oris muscle and the mentalis muscle are able to function with minimal effort which appears esthetic.

Anterior vertical positioning of MMC

Traditional

This position is determined by the clinician's measurement of incisor exposure at rest. The predominance of articles and case reports recommend a 3–4 mm of central incisor exposure at rest. There are also other legacy measurements which compare the proportions of the facial thirds. These measurements are based on averages and have no real functional connection to the face.

Functional

The most important functional action of the face is passive lip seal. Patients need to have their lips touch passively in order to accomplish the three Functional Facial Keys of eating, speaking and breathing. Interlabial gap is the most important measurement when considering treating the anterior vertical. If the patient can't close their lips to swallow, eat breathe and/or speak, the system will compensate in dysfunctional ways with lip elongation, mentalis ptosis, forward head posture, mouth breathing and temporomandibular joint compression.

The three hard tissue measurements that control anterior vertical are maxillary vertical incisor position, overbite and chin height. If the lips are of normal length and the maxillary and mandibular incisors have normal crown heights, the goal for maxillary incisor exposure at rest should be 3–4 mm and overbite should be 2–3 mm. If satisfying these two parameters does not close the interalabial gap to zero at first tooth contact, then the problem is in the length of the chin measured from lower incisor tip to hard tissue Menton. The clinical, functional measurement that helps to reveal excessive chin height is mandibular incisor exposure. The mandibular incisors should not be visible behind the lower lip. If they are, there has either been passive anterior eruption of the anterior teeth or an elongation of the chin itself through inappropriate muscle pull. As a result, the chin will need to be shortened in order to achieve lip seal at rest and esthetically hide the lower incisors behind the lower lip (Fig. 18).

Final check

Like all aspects of virtual treatment planning, it is important to review planned movements and final measurements. Every linear movement affects in some way movements and shapes in

Figure 18. The interlabial gap is excessive secondary to the long incisor to Menton distance. The lower incisor show reveals the need for chin shortening. The jaws were advanced and counterclockwise rotated but the genioplasty was the key to closing the lips and covering the lower teeth at rest.

other planes of space. Assuring that all movements are as planned and the outlines of the jaws are appropriate, is required for an accurate, stable and esthetic result.

Bringing the surgery to the OR

Once the final occlusion and final jaw positions are assured, the upper jaw is reset to its preoperative position and the mandible is rotated open to clear tooth interferences. Because we perform mandible first orthognathic surgery, an intermediate splint is fabricated to position the mandible against the stable upper jaw position. Mandible first surgery avoids the absolute need to achieve proper joint positioning during preoperative records. If the joints are not seated when initial records are obtained and the joints seat at surgery, the whole treatment plan will be flawed when seating the mandibular condyles (Fig. 19).

Accurate transfer of the model surgery to the patient in the operating room depends on precise management of the mandibular condyles by the surgeon. Preventing displacement, torque or compression of the condyle during the fixation process is integral to achieving an accurate result. If the joints are not held in the correct position or are rotated or displaced severely, the intended movements of the 3D virtual plan will not be achieved. Checking the repeatability of the planned mandibular position prior to beginning with maxillary surgery is required.

3D post-operative analysis

A benefit of 3D digital imaging and treatment planning is the ability of the orthodontist and the oral and maxillofacial surgeon to check the accuracy of their results. Never before has there existed such a definitive means of detecting variance from the orthognathic surgery plan. Overlaying the CBCT at the cranium allows comparisons of the preoperative position to the post-operative position and the measurement of actual intraoperative movements (Fig. 20(a)–(c)). This has improved the results in our office as we have been forced to discover new

Figure 19. This patient appears to have had a frame shift during orthognathic surgery. The causes are usually (1) improper joint seating at the records appointment followed by maxillary first surgery or (2) improper seating of the joints during fixation of the mandible and maxilla. The virtual orientation and plan might have been perfect for this patient, but if either of these errors occurred, the plan would not have been achieved.

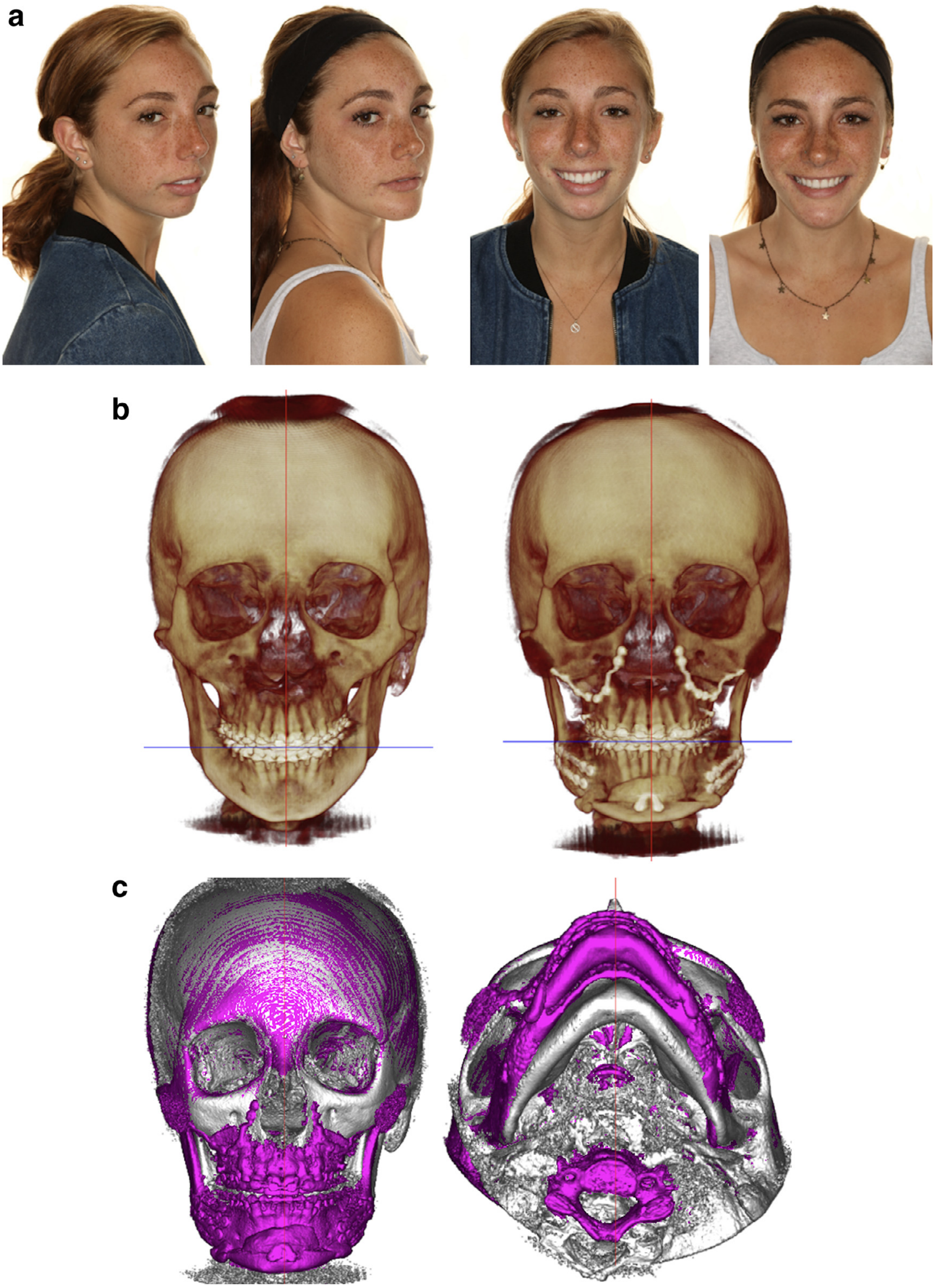

Figure 20. (a) – (c). Each surgery performed in our office is analyzed in virtual 3D. The accuracy of the surgery is compared by overlaying the preoperative cone beam CT with the postoperative cone beam CT through cranial surface registration. Any deviations from the virtual plan can be measured and seen in great detail. Every effort is made to understand why deviations occur so they are not repeated.

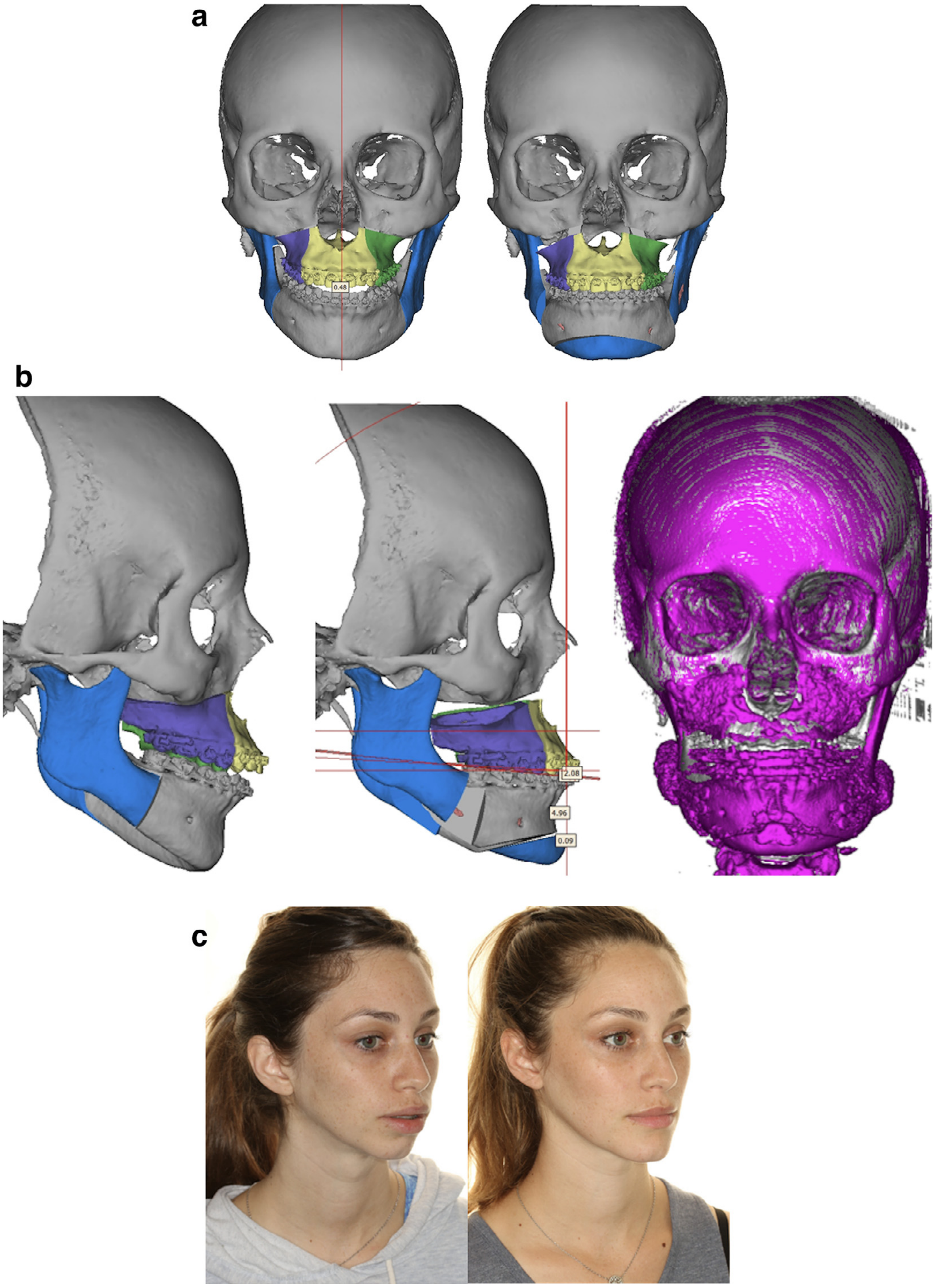

Figure 21. (a) – (c) A final patient. In the frontal treatment planning views, the midlines, cants and vertical changes can be seen. The shortening of her anterior face is a significant key to the final esthetic result as the lips can now close passively. The profile planning views show the mandibular inferior border corrections, the leveling of the chin and a significant counterclockwise rotation of the MMC. Contour grafts were used for (1) mandibular angle length discrepancies and (2) to overcome the excessively posterior ANS. Grafts were place under the right mandibular angle and at around the nasal base to correct the NLU (pink and white image). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

surgical techniques in order to overcome previously unobserved inaccuracies in our surgeries.

Conclusion

Gregory Bateson, the father of Systems Theory, said "It is impossible, in principle, to explain any pattern by invoking a single quantity."[12] This statement is perfect advice pertaining to orthognathic 3D virtual planning. We cannot rely on any single measurement for orientation, diagnosis or treatment planning the face. Success is achieved through concentrating our focus on the patterns and the relationships between things. Proper patterns combine together to provide effortless function in breathing, speaking and eating (the three Functional Facial Keys) which will protect the system from breakdown. A facial system working harmoniously is functional and esthetic (Fig. 21(a)−(d)).

References

1. Moorees C, Kean M. Natural head position, a basic consideration in the interpretation of cephalometric radiographs. *Am J Phys Anthropol*. 1958;16:213–234.
2. Lundstrom A. Intercranial reference lines versus the true horizontal as a basis for cephalometric analysis. *Eur J Orthod*. 1991;13:167–168.
3. Zebeib A, Naini F. Variability of the inclination of anatomic horizontal reference planes of the craniofacial complex in relation to the true horizontal in orthognathic patients. *Am J Orthod Dentofac Orthop*. 2014;146(6):740–747.
4. Lundström F, Lundström A. Natural head position as a basis for cephalometric analysis. *Am J Orthod Dentofac Orthop*. 1992;101(3):244–247.
5. Grybauskas S, Saiki C, Cintra O, Razukevicius D. A "forced symmetry" surgical planning protocol for the treatment of posterior facial asymmetries. *Eur J Clin Orthod*. 2016;4:53–59.
6. Steiner C. The use of cephalometric as an aid to planning and assessing orthodontic treatment. *Am J Orthod*. 1960;46(10):721–735.
7. Andrews W. AP relationship of the maxillary central incisors to the forehead in adult white females. *Angle Orthod*. 2008;78(4):662–669.
8. Arnett GW, Jelic JS, Kim J, et al. Soft tissue cephalometric analysis: diagnosis and treatment planning of dent-facial deformity. *Am J Orthod Dentofac Orthop*. 1999;116:239–253.
9. Almuzian M, Almukhtar A, Xiangyang J, et al. Effects of Le Fort 1 osteotomy on the nasopharyngeal airway—6 month follow up. *J Oral Maxillofac Surg*. 2016;74(2):380–391.
10. Cocconi R, Raffaini M, Amat P. De l'orthodontie à la chirurgie ortho-faciale. entretien avec renato cocconi et mirco raffaini. *Orthod Francaise*. 2016;87:247–271.
11. Al-Moraissi E, Wolford L. Is counterclockwise rotation of the maxillomandibular complex stable compared with clockwise rotation in the correction of dent-facial deformities? A systematic review and meta-analysis. *J Oral Maxillofac Surg*. 2016;74(10):2066. e1-2066.e12.
12. Bateson G. *Mind and Nature: A Necessary Unity*. New York, NY: E.P. Dutton; 1979.