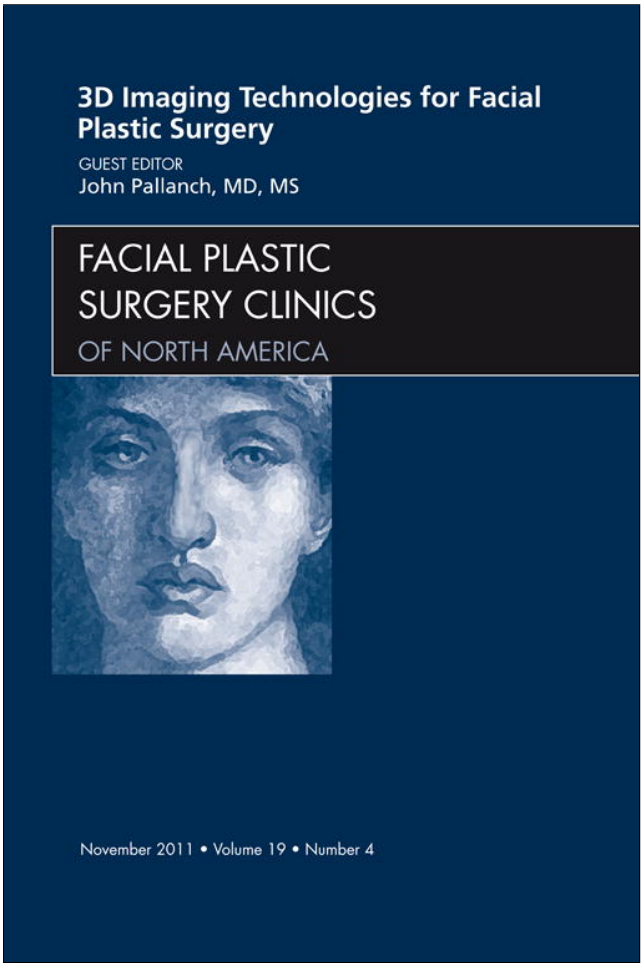
3D Imaging Technologies for Facial Plastic Surgery
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Teaching 3D Sculpting to Facial Plastic Surgeons

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KEYWORDS

• 3D • Three dimensional • 3D sculpting • Facial sculpting
• Image analysis • Preoperative planning
• Patient consultation

The human body is a 3-dimensional (3D) object; and any changes, whether from movement during facial expression or from surgery, occur in 3 dimensions. The importance of thinking in 3D when doing facial plastic surgery extends to[1] preoperative planning,[2] consideration of esthetics,[3] discussion with patients,[4] surgical simulation, and[5] manual dexterity in execution of the steps to attain the desired 3D goal.

Although ethnic differences exist in Turkey, we can describe the general structure of the Mediterranean nose as large and arched. The most common nasal surgery in this country currently is reduction rhinoplasty. Most patients requesting this surgery have a large nose associated with a nasolabial angle less than 90°, thick skin, and a deviated nose.

The interest in plastic surgery interventions has rapidly increased during the last 15 years and continues to rise. The interest in facial plastic surgery interventions is consistent with the general socioeconomic levels of society. The increased interest in rhinoplasty surgery began 25 years ago in the United States and was subsequently observed in European countries, including Turkey. Because of the increased interest in rhinoplasty, many otolaryngologists are keen to be taught rhinoplasty procedures and several courses and symposia continue to be organized to meet this need. These meetings are typically designed to improve theoretical knowledge in an engaging and educational manner. In accordance with the increased interest in rhinoplasty, the incidence of overcorrected noses has increased. This report is about 3D sculpting courses that the authors developed after realizing the need for education regarding planning the way to attain a suitable nose as an important element of plastic surgical interventions.

The authors have found clay to be an inexpensive, readily available medium that allows facial plastic surgeons to further explore the relationship between their 3D handwork and the 3D esthetic result. This article describes the authors' course and study, taking facial plastic surgeons through specific exercises to demonstrate the esthetic impact of 3D manipulations of the nose and face. The authors describe the course components, which include 3D assessment, exercises in manual dexterity, and improving imagination in sculpting facial and nasal features for the optimal esthetic result and match to a given facial shape. In addition, the authors discuss the overlap and relationship between a course in 3D sculpting in facial plastic surgery and current 3D tools for design and image analysis that are used now for facial plastic surgery. This has implications for the 5 previously mentioned areas incorporating 3D thinking in facial plastic surgery: planning, esthetics, discussion, simulation, and performance.

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TEACHING 3D SCULPTING TO FACIAL PLASTIC SURGEONS

Using clay, the authors produced and duplicated sample masks for these education courses (**Figs. 1** and **2**). The objectives of the course are

- Internalization of nose ratios
- Development of eye measurements
- 3D thinking
- 3D planning
- Improving manual dexterity and eye-hand coordination
- Improving imagination.

Internalization of Nose Ratios

The face is divided into 3 equal parts. These parts include 3 horizontal planes and a vertical division of the face with 5 vertical lines. To know these ratios in theory is not enough. Thus, the course starts with practice in measuring these ratios with a compass on a mud mask (**Fig. 3**), learning to equalize these portions by making appropriate changes, and observing the results. Such practice is beneficial in the internalization of nose ratios and giving an appreciation of the relationship between measurements and the 3D facial esthetic.

Fig. 1. Clay masks are made for the course participants.

3D measurements for anthropometric and esthetic purposes have raised great interest among artists and researchers who have designed useful methods to define and measure human facial features. The assessment of facial dimensions is of prime importance in medical fields for both diagnosis and treatment planning. Given that otorhinolaryngological, maxillofacial, and plastic reconstructive surgeons often require quantitative information regarding the relationships of hard and soft tissue, image processing algorithms using 3D image acquisition tools described at the end of this article may be applied to facial images to develop and improve anthropometric applications that reduce the time required for examination and improve measurement reliability. Additionally, the detection of clinically important distances and angles and the analysis and comparison of different forms can be enabled by such applications.

Three-Dimensional Thinking and Planning

Thinking and seeing in 3D is rarely included in classical medical training. Realizing the effects of the minor modifications of the tip of the nose on the profile appearance or on a three-quarter view may be described by some as 3D planning. However, to truly be 3D planning, it should take into consideration the view of patients during daily social interactions, not only from the front or side but also from all angles by evaluating the view from all perspectives. Many people describe their profiles (side views) as improving when they lift the tip of their nose with their fingertip, a process termed unidirectional evaluation. If a surgical process to achieve this lifting effect is performed, the profile lines may be improved; but this exact profile view is rarely achieved in daily life, which highlights the necessity of 3D planning. The surgeon, and others, will view patients in 3D after surgery not from a single direction.

In the case of facial plastic surgery, it is important to perform detailed surgical planning before surgery to ensure that the optimal and appropriate surgical methods are applied. Historically, esthetic surgical practice did not include 3D planning, but current advances in 3D technology are changing that.

Development of Eye Measurements

Eye measurement is a skill that can be developed through practice. Precise eye measurements are important to ensure equalization of the 3 horizontal facial areas. During the clay study, the participants first assess sizes, shapes, and angles with their eyes, followed by measurements with a compass.

Fig. 2. Each participant has his or her own mask to work on for each phase of the course.

The aim of this evaluation is to allow the participants to become accustomed to eye measurements, which will foster improvement in their accuracy.

As an example, we might describe the basic technique of placing a suture as beginning 2 mm outside the upper edge of the lip of the wound and exiting inside the wound 2 mm from the surface. This procedure is followed by entering 2 mm below the surface of the incision at the opposite lip of the wound and exiting 2 mm outside the upper edge of the lip of the wound. The suture is tightened by tying a knot. Good eye measurements, as well as excellent manual dexterity and hand-eye coordination, are all required to ensure that this procedure is performed correctly.

Fig. 3. The participants start with practice in measuring the ratios with a compass on a mud mask.

Improving Manual Dexterity

Fine-motor movements of the hands improve during the kindergarten period, and exercises are performed during preschool for this purpose. Some individuals increase their manual dexterity during their youth, whereas others do not have the opportunity to do so. Thus, if individuals who have graduated from medical school continue their otorhinolaryngology education and perform exercises that improve their manual dexterity, one can predict an improvement in the success of their operations. Exercises to both assess and improve manual dexterity include

- Cutting pictures from a newspaper without missing the borders: This exercise serves to identify those participants who are neater and faster. This practice can persuade participants who are unsuccessful to spend extra time practicing these exercises.
- A competition attempting to align 100 beads in the shortest time possible: At the end of this exercise, a bell curve is generated. Most of the group can complete this in an average or very short period of time. Some take longer to complete the exercise, and this group might be offered further exercises to improve manual dexterity.

- Suturing 4 sides of a 2 × 2-mm section of cartilage on gauze with 4 sutures: This exercise simulates difficulties encountered during suturing of a graft, including when cartilage graft placement is necessary during rhinoplasty. These difficulties include disruption of the graft when crossing the suture and tearing of the graft caused by excessive tightening of the suture. Those who are unsuccessful at the end of this exercise are frequently motivated to pursue additional training and to do exercises to improve their manual dexterity.

Improving the Imagination

When the clay masks are provided to participants, they are initially required to distribute the face into the appropriate proportions and design an ideal nose for these proportions. **Box 1** shows the tools that are used in the course (**Fig. 4**). The aim is then to perform changes that would not be possible to perform on patients. Most participants who become accustomed to training with clay frequently request clay masks to perform the exercise outside of the training period.

Fig. 4. Ceramic hand tools are used as the participants design the ideal nose.

Once this stage is complete, the aim is to perform changes to the mask that cannot be performed on patients and to create an ideal nose. This nose may be incongruous with the facial proportions. Participants in the training can observe directly whether the designed nose fits the face.

STEPS OF THE COURSE

Study Phases on Large-Nosed Clay Masks

1. First, facial proportions are assimilated using sample clay masks derived from patients. An assessment of the horizontal and vertical components of the face is performed by measuring the face with a compass.
2. The deformed nose on the mask is then optimized to the known desirable proportions of the face (**Fig. 5**).
3. Interventions that will esthetically improve the face (apart from the nose) are performed, including chin advancement and raising the eyebrows.
4. The final goal is to design the ideal nose for this face (**Figs. 6** and **7**).

Box 1
Nasal study materials and instruments for surgeon training with clay

- Clay and water
- Ceramic hand tools
- Sponge
- Brush
- Compass

Studies on Sculptures Without a Nose

This study is more difficult to perform and is regarded as the second phase. In phase 1, the participants begin with a nose on the clay mask that is typically deformed. In this instance, it is easy to observe and correct the defect. Adding a nose to a noseless sculpture (**Fig. 8**) during the second phase is more difficult, but it is an important skill to master for 3D planning and training.

At this stage, the determination of the nasofrontal angle is ensured by directing the participants. The next goal is to create the dorsum and to decide the level of nasal projection. Once this is completed, the nostrils and columella are created. The basal view of the nose is frequently the most difficult section for the participants.

BENEFITS OF 3D SCULPTING

For a long time, automobile designers have created automobile prototypes, sometimes in full size, in clay to appreciate the true esthetic effect of a given design. Furthermore, designers have made smaller clay models and scanned this model using a 3D optical or laser scanning system to put the model into a computer-aided design (CAD) program for further design work (reverse engineering). Designers have used special 3D viewing devices to appraise their designs, but nothing as truly simulates the esthetic impact to a viewer as seeing it as an actual 3D object. Just as multiple photographic views would give patients more information than a single view, the ability to move

Fig. 5. The deformed clay nose is optimized to the known desirable dimensions of the face.

an image in 3D looking at the esthetic effect of any changes from different angles gives an even greater appreciation of changes that can occur with surgery. Stereophotogrammetry (see the section at the end of this article) now allows facial plastic surgeons to capture the 3D image of their patients and to analyze the esthetics of the nose and face while viewing it in 3D from an infinite number of perspectives. Further enhancement of 3D appreciation is gained by viewing an actual 3D object. Studying facial relationships and esthetics with clay sculpting is like the automobile designers creating a full-size prototype in clay.

The exercises in sculpting for Facial Plastic Surgeon's Course have implications that carry over directly to facial plastic surgery. Besides the obvious value of exercises in 3D assessments of dimension and esthetics, there is the less-obvious

Fig. 6. The participants design an ideal nose of the appropriate proportions for their mask.

Fig. 7. The participants in phase 1 are designing the ideal nose for the face on their mask.

role of insight regarding preoperative planning and communication with patients.

Planning for facial plastic surgery includes

- Deciding the surgical procedure to be performed and determining the most appropriate method whereby the surgeon can achieve this outcome
- Explaining the result-oriented planning to patients
- Discussing the expected or desired outcome of the operation with patients
- Reaching a clear conclusion about the objective of the surgery
- Achieving an understanding of the surgeon's and the patients' points of view using 1 or

Fig. 8. In phase 2, a nose is added to a noseless sculpture. This exercise is more difficult.

more tools for communication: These tools include verbal description while pointing to certain features on patients, drawings, photographs, or digital images in 2-dimensional (2D) or 3D renderings to demonstrate elements of the process that would be difficult to describe without such media.

Preoperative Planning and Communication With Patients

Surgical procedures done in the setting of tumor or trauma to cure disease and repair damaged anatomic structures differs from elective facial plastic surgical procedures in that there may not be as detailed a discussion about the details of the surgical approach before surgery because of the imperative nature of the surgery, particularly when medical treatment proves insufficient. The primary objective in a surgery for a malignant parotid tumor is total resection with ample surgical margins, and the secondary aim is to repair the skin defect or fill the empty cavity of the tumor. Three-dimensional tools can aid appreciably in reconstruction after tumor removal (eg, contour defects attributable to parotidectomy[1] or in mandibuloplasty). However, in these cases, the hope of patients is to have some return toward their previous appearance, whereas in elective facial plastic procedures, patients hope for a change to something better than what they had. In this case, the surgery targets the same region, but the primary objective of the surgery is for an improved new appearance. In elective plastic surgical procedures, the patients have planned carefully and considered their choice to proceed. For this reason, expectations may be higher, and the results obtained may not fit with the patients' intended outcome, which emphasizes the importance of communication regarding planning and possible outcomes of surgery.

The next step beyond using 3D tools at a console to communicate preoperatively with patients and to do 3D preoperative planning is to work with a true 3D model of the patients' face or nose.

Clay studies for surgery planning before the operation

1. It is not always possible for patients to describe the changes they require without visual aids. Conducting a clay study with patients allows the translation of a 3D idea into a tangible objective. This process can be considered as the next stage of 3D image processing.
2. A clay study conducted before the operation is useful for patients to recognize, in a tangible way, any visible nasal pathologies that should be addressed, in addition to esthetic issues. This study is particularly important when patients with prominently asymmetric faces realize this asymmetry following surgery and are unhappy on careful examination, having not realized that the asymmetry existed previously.
3. A clay study makes it possible to show the patients any severe nasal pathologic condition and demonstrate that the nose shape requested by patients may not be possible.
4. The preoperative clay study should be conducted 24 hours in advance of surgery, and changes in the procedure, once confirmed by patients, should be minimized during this period.

Although manipulating clay during a discussion with patients may not be practical for many surgeons, one can imagine an extension of the 3D software user interface to accomplish an actual tactile 3D model–based discussion. Facial plastic surgeons can already discuss changes on preoperative digital images using touch screens or light pens. Some surgeons are now doing this using 3D images and a 3D display. The next step is to have a facial model with a surface that can be manipulated and that will be given the 3D shape of a given patient from the 3D images acquired by stereophotogrammetry or similar capture techniques. Then the surgeon, using his or her hands or instruments similar to the ones used in the authors' course, could demonstrate to themselves away from patients, or even in mutual discussion with patients, the effect of various subtle manipulations of the 3D model.

The technology for such a user interface for a simulator/patient communication device is already tangible. One only needs a modifiable 3D surface that could serve as both a 3D printout but also allow a 3D input device sending the computer the surface spatial alterations occurring on the 3D object. It is already possible to use stereophotogrammetry to capture the external 3D dimensions of any face and print a matching 3D object. From this a mold can be made to create clay models for the authors' course. This practice would allow various kinds of noses to be modified by surgeons to immediately appreciate what each type of manipulation can accomplish. It would also allow 3D printing of a model of patients that the surgeon could use to communicate about their mutual desired surgical goals.

The most important thing, however, is the appreciation of the consequence of 3D changes on the esthetic of the patients' nose and face. The 3D manipulations done by the surgeons in the authors' course bring together the surgeon's 3D vision, sense of touch, feel for what is attractive, appreciation of what is possible, and immediate awareness of the result rendered by any 3D manipulation. This appreciation is accomplished with a depth that is one step beyond even 3D design changes done with 3D glasses or in a 3D design hood because of the additional feedback element of touch, a sense so integral to a surgeon's work.

RELATING 3D SCULPTING TO COMPUTER-BASED 3D IMAGING AND COMPUTER-BASED 3D MODELING

Facial model reconstruction and surgical simulation are increasingly important to today's facial plastic surgeons. Precise presurgical planning can help surgeons reduce the potential risks in facial plastic surgery. Koch and colleagues[2] proposed algorithms for both presurgical planning and postsurgical evaluation using surgery realistically simulated with finite element methods. Lee and colleagues[3] developed a physically based model to generate facial expression. At the time, this approach was computationally expensive and, therefore, not readily available for real-time surgical simulation.

The authors have found clay to be an inexpensive, readily available medium that allows facial plastic surgeons to further explore the relationship between their 3D handwork and the 3D esthetic result. This article describes the authors' course and study taking facial plastic surgeons through specific exercises to demonstrate the esthetic impact of 3D manipulations of the nose and face.

The authors noted the possibility of using the patients' 3D images to print or render a 3D moldable model of the patients' face, thus, enhancing the ability to conceptualize and visualize planned surgical modifications for any given patient. New technologies of CAD and computer-aided manufacturing that can be used in facial plastic surgery and to premanufacture facial reconstructive elements or prostheses have increased rapidly in the last decade.[4]

COMPUTER-BASED 3D IMAGING AND COMPUTER-BASED 3D MODELING

Current advances in 3D imaging technology now offer powerful options for planning and simulation that can be used by the facial plastic surgeon. Using data from a normal side, modeling (more reverse engineering) can be done in mirror image in 3D to fashion sizing templates or reconstructive plates or implants for patients with head and neck tumors that will be resected.

These 3D tools are essential for the practical implementation of 3D anthropometrics. In particular, it is possible to obtain information on the 3D facial features of a person. Not only does this allow 3D rendering as the authors have discussed previously but it allows study in 3D of the anthropometrics that are appreciated as attractive.

For many years, Farkas[5] applied the direct anthropometry technique for studying facial morphology.[5] This approach has been applied to study facial growth and to compare patients' phenotype with the norms of the population. Anthropometrics is an objective tool for assessing the facial form and detecting changes over time, diagnosing genetic or acquired deformities, planning and evaluating interventions for surgery, studying normal and pathologic growth, and verifying the outcome of treatments. Anthropometry has the advantages of being inexpensive, simple to be applied, and noninvasive. Limitations of this approach include the need for patient cooperation and longer time for data acquisition and capturing.[6]

Cephalometric radiographs have been widely applied in the study of hard-tissue morphology, prediction of changes related to the growth, and quantitative assessment of references data.[7,8] It is also an important tool for the diagnosis of craniofacial abnormalities and planning of treatment modalities.[9] Errors in analysis caused by magnification, superimposition of structures, limited experience, and difficulty in landmark determination are common in this method.[10]

Photogrammetric digital imaging is a noninvasive, inexpensive, and commonly used method to investigate preoperative and postoperative changes and provides a permanent record of patients.[11] The recent spread and development of digital 2D imaging has made it an essential and routine part of medical practice.[12] Digital imaging has many advantages, such as the immediate display of the image and simplicity in manipulation. Furthermore, data can be stored or managed in a digital format that makes measurements applicable.[11] This approach has been used to acquire facial norms of populations, detect interethnic variations, and in the diagnosis of dysmorphic children.[13]

Three-dimensional imaging methods include 3D cephalometry, morphoanalysis, moire topography, computed tomography (CT)-assisted 3D imaging, 3D ultrasonography, 3D laser scanning, and stereophotogrammetry. Advances in technology have now allowed 3D imaging, such as CT.[14,15] Some of these technologies require expensive equipment and the ability to determine soft-tissue features is limited.[16,17] Moreover, concerns have been raised about the use of radiation for facial studies.[18] For these reasons, 3D surface imaging techniques, such as laser scanning and stereophotogrammetry, have been developed to capture the soft-tissue facial structures.[19–21] Three-dimensional surface imaging has become more common in computer animation and movies, but its application in medicine is more recent. Among the earliest systems of measuring the spatial relationships, Ras and colleagues[22] presented 3D imaging as a new method for quantifying facial morphology and detecting changes in facial growth. The rapid development in computer technology opens new perspectives to improve 3D imaging.

After data acquisition, several steps are needed to create 3D surface images.[23,24] The first step includes the production of geometric mode of visualization or wireframe, which is made up of a series of x, y, and z landmark coordinates. Mathematical algorithms are used to connect the points with each other and express the 3D model in triangles or polygons. In the second step, color information is added to the wireframe, which consists of a layer of pixels called texture mapping. A further step is to add shading and lighting, which brings more reality to the 3D object obtained. The final step is called rendering, in which the computer converts the anatomic data into a lifelike 3D object viewed on the computer screen. Improvement in computer-vision tools makes it possible to perform all measurements in 3D, and subsequently, statistical shape analysis can be applied.[25,26]

Laser Scanning

This technology depends on projecting a known pattern of laser light onto the object of interest and then using geometric principles to create a 3D model of the object.[27] Many studies test the accuracy and precision of laser scanner measurements versus those obtained using digital calipers.[28,29] The results showed that the accuracy of laser scanner was less than 2 mm in the plaster model with a precision of 0.8 to 1.0 mm on the human face. Laser scanning gives a noninvasive, accurate, and reproducible tool for medical applications.[14] However, this technology does have its shortcoming, such as a long scan time (making it difficult to apply for children)[30] and the inability of the laser scanner to capture soft-tissue texture, which results in difficulties in the identification of landmarks. Moreover, patients' eyes must also be closed for protection and the head must be kept in a fixed position.[16]

Stereophotogrammetry

Stereo photography has been in existence for many years. As with laser scanning, it also relies on the method of triangulation. The basic principle of stereophotogrammetry is the use of 2 or more cameras configured as a stereo pair to capture simultaneous images of the subject.[31] The cameras are placed apart from each other and the patients' face is enclosed by a calibration frame or placed in a space in which a calibration object was previously imaged.[32] The cameras focal lengths, their exact position to each other and to the object, are calculated during the calibration procedures.[32] After that, a 3D facial image can be captured and displayed on the monitors so that landmarks can be selected either manually or by using image-processing algorithms.[15] The acquired 3D coordinates are used to calculate distances between points allowing subsequent 3D reconstruction of the entire face.[33] Many 3D stereophotogrammetric commercial systems are available in the markets. One system that was developed at Glasgow University Dental School[34] consists of 2 camera stations, each with a pair of monochrome cameras to capture the stereo image and a color digital camera to capture the skin texture. The face illumination depends on random projected light or on natural lighting.[31] Picture capture takes 50 ms and a computer program constructs a 3D image from the data transferred from each camera station. The system has been validated and its accuracy was reported to be within 0.5 mm.[19] This system has been tested in the facial morphology of patients who are orthognathic to detect the magnitude of surgical change, along with the possible postsurgical relapse.[15] Another stereophotogrammetric system is called 3dMD FACE (3dMD; Atlanta, GA, USA). It uses multiple cameras to capture facial images (1 color and 2 infrared) with random light projected on the object's surface.[31] The capture time is 1.5 to 2.0 ms, which creates less distortion and is more useful for data capture for children.[26,35] The 3dMD system can also accommodate additional cameras with no reduction in capture speed.[26] The 3dMD systems can overlap the random light pattern to allow a full 360° view of patients to be digitally captured in a single acquisition. The picture accuracy is within 1 mm, with a resolution of up to 40,000 polygons per square inch, and the texture image is in 24-bit color. Distances, angles, and volumetric data can subsequently be calculated using the computer software, in addition to facial shape, texture, and skin tone in 3 dimensions. The 3dMD FACE system is also capable of capturing more than 22 frames per second, making the technology's real-time mode an option for speech or motion analysis requirements.

This system has been applied in studies of facial morphology[36] and assessment of facial anomalies.[37,38] In comparison with laser scanning, stereophotogrammetry eliminated the need for direct contact and reduced the need for patients' cooperation because of the high speed of data acquisition.[19] Moreover, the patients' image can be repeated without any harmful effects on the participant.[35] When using a laser scanning system, to achieve good acquisition, the person has to cooperate by staying motionless throughout the scanning (15 s) because even small movements could produce errors in the resultant point cloud. A special device (cephalostat) must be used to hold the head still during 3D acquisition. The equipment developed for the photogrammetric acquisition is simple: 3 or 4 digital cameras and photogrammetric software are enough to obtain the 3D information. With the photogrammetric technique, data processing is slower but the information acquisition (the time spent to take photographs) is very fast (1/5000 s, the flashing time). Stereophotogrammetry has been reported to be accurate and reliable for landmark digitization[39,40] and distance acquisition.[26,35] Moreover, although less information about facial shape is obtained using photogrammetry (less points), the points where 3D information is acquired are equally spaced and, after estimation of their spatial localization, need no further processing. Previous studies have shown that the photogrammetric method is very promising for the digital reconstruction of 3D shapes of human faces. Indeed, photogrammetry seems to offer the best compromise regarding all parameters used to evaluate systems of digitization of human faces: a realistic reproduction of the shape, short processing times of the model, simplicity and low cost, noninvasive equipment, and accuracy.

Facial variations among ethnic groups and populations have been studied using direct anthropometry or by 2D imaging.[41] With the development of the 3D technologies, additional methods in facial evaluation can be applied, such as statistical shape analysis.[38] Another application for 3D imaging is the assessment of differences between genders. Three-dimensional surface imaging can evaluate growth changes by studying the variation in sequential captures of faces superimposed on one another.[31] This method of facial assessment offers an excellent opportunity for the possibility of greater accuracy than 2D cephalometric studies.[10,12]

Facial morphology plays an important role in the diagnosis and treatment planning for many dysmorphic syndromes.[42,43] Classical anthropometry and 2D approaches have been applied in the study of craniofacial anomalies[5,13]; but technical approaches, including 3D surface imaging, are now available for further differentiation of facial distortions.[44] Stereophotogrammetry was used to compare craniofacial morphology of unaffected relatives of individuals with nonsyndromic clefts and matched controls.[38] Three-dimensional imaging technologies were also used to compare postsurgical nasal changes after orthognathic surgery.[37] Other studies were conducted to evaluate the treatment outcome of facial augmentation in upper-lip reconstructive surgery,[45] assess the 3D facial soft-tissue response to transverse palatal expansion,[46] or to localize and quantify differences in facial soft-tissue morphology in patients with obstructive sleep apnea.[47] Samson Lee and Wayne F. Larrabee (unpublished data, 2006) were able to demonstrate quantitative changes by generating a histogram of color-based differences taken from 3D images of preoperative and postoperative patients undergoing a facelift procedure. Decreases in jowl volume, neck volume, and neck surface area were calculated, as well as relative changes to the nasolabial fold. Current research focuses on changes as a result of nasal surgery and looks at possible new cephalometric measurements that may not be easily calculated from regular 2D photographs. In the literature, 3D analysis of facial esthetics has involved cadaveric study, such as that of Nemoto and colleagues,[48] who studied cadaveric forehead skin attachments to the underlying galea to determine planes of dissection for facial rejuvenation. Smith and colleagues[49] used histologic sections from a cadaver to recreate a 3D image using computer-modeling software.

Three-dimensional technology has improved in the last decade and is rapidly becoming mainstream. Recently, surgeons have been using 3D image viewing to aid in presurgical planning and discussion. The surgeon has the possibility of making modifications virtually using the presurgical anatomy of the nose. This practice allows the option of correcting the anatomy by taking into account the potential pursuit of facial symmetry. Three-dimensional tools may also be used for an immediate provisional adhesive prosthesis that can be delivered to patients in a few days after surgical resection to restore an acceptable esthetic appearance.

Stereophotogrammetric systems can now provide 3D surface imaging. This capability allows comparing the pretreatment and posttreatment facial status of the patient, ensures monitoring of postsurgery results of various postures and various facial expressions during the treatment process, and allows follow-up of the effectiveness of the treatment. These systems are used in facial plastic surgery and orthognathic surgery cases for selecting and planning possible therapies and operations, evaluating and simulating the treatment visually, and for following up with comparison of presurgical and postsurgical changes. In many studies, such as cleft lip and palate, airway studies, orthodontic treatment, and speech therapy, diagnostic and treatment planning can be made by combining the anatomic and biomechanical characteristics of patients with the surface tone characteristics captured by stereophotogrammetry.

Available software (compatible with Mimics, SimPlant OMS, SimPlant Ortho) allows combining (registering) the surface data with CT/cone beam CT images and digital medical model studies and even the corresponding tissue biomechanical characteristics (see the article in this publication by Mazza and Barbarino), which allows enhanced 3D diagnostic and treatment planning technology.

Technical capabilities of stereophotogrammetric systems are detailed in other articles. These capabilities include surface data corrections when combined with cone beam CT surface data, documentation of natural head movements and facial expressions of the patient, and enabling the surgeon to perform digital surface angle and distance as well as volume measurements.

SUMMARY

The 3D manipulations done by the surgeons in the authors' course allow the appreciation of the consequence of 3D changes on the esthetic of the patients' nose and face. This appreciation incorporates the surgeon's sense of touch, which is an integral element in surgery.

Presurgical planning with 3D tools, like any preoperative planning, can help surgeons reduce risk and improve the course and outcome of surgery. These tools also offer new means of optimizing preoperative communication with patients.

The authors' course includes facial measurements. Various current 3D techniques for measuring surface facial morphology are reported. The 3D imaging system that will be most widely adapted will be one that is accurate and reliable in capturing, archiving, and storing data and will do so in a cost-effective way.

REFERENCES

1. Lin SJ, Patel N, O'Shaughnessy K, et al. A new three-dimensional imaging device in facial aesthetic and reconstructive surgery. Otolaryngol Head Neck Surg 2008;139:313–5.
2. Koch RM, Gross MH, Carls FR, et al. Simulating facial surgery using finite element models. In ACM SIGGRAPH'96. Annu Conf Proc 1996;421–8.
3. Lee Y, Terzopoulos D, Waters K. Realistic face modeling for animation. In ACM SIGGRAPH'95. Annu Conf Proc 1995;55–62.
4. Ciocca L, Bacci G, Mingucci R, et al. CAD-CAM construction of a provisional nasal prosthesis after ablative tumour surgery of the nose: a pilot case report. Eur J Cancer Care 2009;19:97–101.
5. Farkas LG. Examination, photogrammetry of the face, craniofacial anthropometry in clinical genetics. In: Farkas LG, editor. Anthropometry of the head and face. New York: Raven Press Ltd; 1994. p. 22, 80, 104, 192.
6. Guyot L, Dubuc M, Richard O, et al. Comparison between direct clinical and digital photogrammetric measurements in patients with 22q11 microdeletion. Int J Oral Maxillofac Surg 2003;32(3):246–52.
7. Thilander B, Persson M, Adolfsson U. Roentgen-cephalometric standards for a Swedish population. A longitudinal study between the ages of 5 and 31 years. Eur J Orthod 2005;27(4):370–89.
8. Inada E, Saitoh I, Hayasaki H, et al. Cross-sectional growth changes in skeletal and soft tissue cephalometric landmarks of children. Cranio 2008;26(3):170–81.
9. Uysal T, Yagci A, Basciftci FA, et al. Standards of soft tissue Arnett analysis for surgical planning in Turkish adults. Eur J Orthod 2009;31(4):449–56.
10. Sayinsu K, Isik F, Trakyali G, et al. An evaluation of the errors in cephalometric measurements on scanned cephalometric images and conventional tracings. Eur J Orthod 2007;29(1):105–8.
11. Ettorre G, Weber M, Schaaf H, et al. Standards for digital photography in cranio-maxillo-facial surgery - part I: basic views and guidelines. J Craniomaxillofac Surg 2006;34(2):65–73.
12. Paredes V, Gandia JL, Cibrián R. Digital diagnosis records in orthodontics. An overview. Med Oral Patol Oral Cir Bucal 2006;11(1):E88–93.
13. Boehringer S, Vollmar T, Tasse C, et al. Syndrome identification based on 2D analysis software. Eur J Hum Genet 2006;14(10):1082–9.
14. Hajeer MY, Ayoub AF, Millett DT, et al. Three-dimensional imaging in orthognathic surgery: the clinical application of a new method. Int J Adult Orthodon Orthognath Surg 2002;17(4):318–30.
15. Hajeer MY, Millett DT, Ayoub AF, et al. Applications of 3D imaging in orthodontics: part I. J Orthod 2004;31(1):62–70.
16. Honrado CP, Larrabee WF Jr. Update in three dimensional imaging in facial plastic surgery. Curr Opin Otolaryngol Head Neck Surg 2004;12(4):327–31.
17. Ayoub AF, Xiao Y, Khambay B, et al. Towards building a photo-realistic virtual human face for craniomaxillofacial diagnosis and treatment planning. Int J Oral Maxillofac Surg 2007;36(5):423–8.

18. Bourne CO, Kerr WJ, Ayoub AF. Development of a three-dimensional imaging system for analysis of facial change. Clin Orthod Res 2001;4(2):105–11.
19. Ayoub A, Garrahy A, Hood C, et al. Validation of a vision-based, three-dimensional facial imaging system. Cleft Palate Craniofac J 2003;40(5):523–9.
20. Holberg C, Schwenzer K, Mahaini L, et al. Accuracy of facial plaster casts. Angle Orthod 2006;76(4):605–11.
21. De Menezes M, Rosati R, Allievi C, et al. A photographic system for the three-dimensional study of facial morphology. Angle Orthod 2009;79(6):1070–7.
22. Ras F, Habets LL, van Ginkel FC, et al. Quantification of facial morphology using stereophotogrammetry–demonstration of a new concept. J Dent 1996; 24(5):369–74.
23. Seeram E. 3-D imaging: basic concepts for radiologic technologists. Radiol Technol 1997;69(2): 127–44 [quiz: 145–8].
24. Riphagen JM, van Neck JW, van Adrichem LN. 3D surface imaging in medicine: a review of working principles and implications for imaging the unsedated child. J Craniofac Surg 2008;19(2):517–24.
25. Moss JP. The use of three-dimensional imaging in orthodontics. Eur J Orthod 2006;28(5):416–25.
26. Weinberg SM, Naidoo S, Govier DP, et al. Anthropometric precision and accuracy of digital three-dimensional photogrammetry: comparing the Genex and 3dMD imaging systems with one another and with direct anthropometry. J Craniofac Surg 2006;17(3):477–83.
27. Majid Z, Chong AK, Setan H. Important considerations for craniofacial mapping using laser scanners. Photogramm Rec 2007;22(120):290–308.
28. Kau CH, Richmond S, Zhurov AI, et al. Reliability of measuring facial morphology with a 3-dimensional laser scanning system. Am J Orthod Dentofacial Orthop 2005;128(4):424–30.
29. Gwilliam JR, Cunningham SJ, Hutton T. Reproducibility of soft tissue landmarks on three dimensional facial scans. Eur J Orthod 2006;28(5):408–15.
30. Bozic M, Kau CH, Richmond S, et al. Facial morphology of Slovenian and Welsh white populations using 3-dimensional imaging. Angle Orthod 2009;79(4):640–5.
31. Kau CH, Richmond S, Incrapera A, et al. Three-dimensional surface acquisition systems for the study of facial morphology and their application to maxillofacial surgery. Int J Med Robot 2007;3(2):97–110.
32. Majid Z, Chong AK, Ahmad A, et al. Photogrammetry and 3D laser scanning as spatial data capture techniques for a national craniofacial database. Photogramm Rec 2005;20(109):48–68.
33. Littlefield TR, Kelly KM, Cherney JC, et al. Development of a new three dimensional cranial imaging system. J Craniofac Surg 2004;15(1):175–81.
34. Siebert JP, Marshall SJ. Human body 3D imaging by speckle texture projection photogrammetry. Sensor Rev 2000;20(3):218–26.
35. Wong JY, Oh AK, Ohta E, et al. Validity and reliability of craniofacial anthropometric measurement of 3D digital photogrammetric images. Cleft Palate Craniofac J 2008;45(3):232–9.
36. Seager DC, Kau CH, English JD, et al. Facial morphologies of an adult Egyptian population and an adult Houstonian white population compared using 3d imaging. Angle Orthod 2009;79(5):991–9.
37. Singh GD, Levy-Bercowski D, Yanez MA, et al. Three-dimensional facial morphology following surgical repair of unilateral cleft lip and palate in patients after nasoalveolar molding. Orthod Craniofac Res 2007;10(3):161–6.
38. Weinberg SM, Neiswanger K, Richtsmeier JT, et al. Three-dimensional morphometric analysis of craniofacial shape in the unaffected relatives of individuals with nonsyndromic orofacial clefts: a possible marker for genetic susceptibility. Am J Med Genet A 2008; 146(4):409–20.
39. Lee JY, Han Q, Trotman CA. Three-dimensional facial imaging: accuracy and considerations for clinical applications in orthodontics. Angle Orthod 2004;74(5):587–93.
40. Khambay B, Nairn N, Bell A, et al. Validation and reproducibility of a high-resolution three-dimensional facial imaging system. Br J Oral Maxillofac Surg 2008;46(1):27–32.
41. Ngeow WC, Aljunid ST. Craniofacial anthropometric norms of Malays. Singapore Med J 2009;50(5): 525–8.
42. Grobbelaar R, Douglas TS. Stereo image matching for facial feature measurement to aid in fetal alcohol syndrome screening. Med Eng Phys 2007;29(4): 459–64.
43. Hammond P. The use of 3D face shape modeling in dysmorphology. Arch Dis Child 2007;92(12):1120–6.
44. Hammond P, Hutton TJ, Allanson JE, et al. Discriminating power of localized three-dimensional facial morphology. Am J Hum Genet 2005;77(6):999–1010.
45. Downie J, Mao Z, Rachel Lo TW, et al. A double-blind, clinical evaluation of facial augmentation treatments: a comparison of PRI 1, PRI 2, Zyplast and Perlane. J Plast Reconstr Aesthet Surg 2009; 62(12):1636–43.
46. Ramieri GA, Nasi A, Dell'acqua A, et al. Facial soft tissue changes after transverse palatal distraction in adult patients. Int J Oral Maxillofac Surg 2008; 37(9):810–8.
47. Banabilh SM, Suzina AH, Dinsuhaimi S, et al. Craniofacial obesity in patients with obstructive sleep apnea. Sleep Breath 2009;13(1):19–24.
48. Nemoto M, Uchinuma E, Yamashina S. Three-dimensional analysis of forehead wrinkles. Aesthetic Plast Surg 2002;26:10–6.
49. Smith D, Aston S, Cutting C, et al. Designing a virtual reality model for aesthetic surgery. Plast Reconstr Surg 2005;116:893–7.