The Evolution of Photography and Three-Dimensional Imaging in Plastic Surgery

Jason M. Weissler, M.D.
Carrie S. Stern, M.D.
Jillian E. Schreiber, B.A.
Bardia Amirlak, M.D.
Oren M. Tepper, M.D.

New Brunswick, N.J.; Bronx, N.Y.; and Dallas, Texas

Summary: Throughout history, the technological advancements of conventional clinical photography in plastic surgery have not only refined the methods available to the plastic surgeon, but have invigorated the profession through technology. The technology of the once traditional two-dimensional photograph has since been revolutionized and refashioned to incorporate novel applications, which have since become the standard in clinical photography. Contrary to traditional standardized two-dimensional photographs, three-dimensional photography provides the surgeon with an invaluable volumetric and morphologic analysis by demonstrating true surface dimensions both preoperatively and postoperatively. Clinical photography has served as one of the fundamental objective means by which plastic surgeons review outcomes; however, the newer three-dimensional technology has been primarily used to enhance the preoperative consultation with surgical simulations. The authors intend to familiarize readers with the notion that three-dimensional photography extends well beyond its marketing application during surgical consultation. For the cosmetic surgeon, as the application of three-dimensional photography continues to mature in facial plastic surgery, it will continue to bypass the dated conventional photographic methods plastic surgeons once relied on. This article reviews a paradigm shift and provides a historical review of the fascinating evolution of photography in plastic surgery by highlighting the clinical utility of three-dimensional photography as an adjunct to plastic and reconstructive surgery practices. As three-dimensional photographic technology continues to evolve, its application in facial plastic surgery will provide an opportunity for a new objective standard in plastic surgery. (*Plast. Reconstr. Surg.* 139: 761, 2017.)

Since its inception, photography has served artists, journalists, and doctors in their respective professions to help capture moments in time. Plastic surgeons are no exception to this, having long depended on traditional two-dimensional photographs for patient assessment, surgical planning, and postoperative follow-up. For decades, clinical photography has had a wide range of applications in plastic surgery and has helped facilitate preoperative and postoperative patient counseling. Clinical photography not only plays an important role in documentation, but provides information that may be difficult to accurately document with words and measurements alone.

Furthermore, plastic surgeons strive to analyze surgical outcomes, and photography serves as one of the fundamental tools by which we can objectively measure outcomes. Two-dimensional photographs are quickly obtained and can be archived for further analysis without causing any inconvenience to the patient when reexamination is needed.

Over recent years, three-dimensional photography has been gaining popularity in plastic surgery and is used routinely in academic and private offices. In contrast to traditional two-dimensional photography, three-dimensional imaging

From the Rutgers Robert Wood Johnson University Hospital; Montefiore Medical Center, Albert Einstein College of Medicine; and the University of Texas Southwestern Medical Center.
Received for publication May 27, 2016; accepted August 22, 2016.

DOI: 10.1097/PRS.0000000000003146

Disclosure: *Dr. Tepper is a consultant for Stryker CMF and a shareholder in 3D Systems and MirrorMe3D. Dr. Stern is a founder of MirrorMe3D. The remaining authors have no financial disclosures to report.*

provides true surface anatomy. Additional valuable data include variables such as volumetric analyses and geometric parameters, including depth and surface topographic distance measurements. Despite the clinical utility of three-dimensional photography, this technology has been used primarily to enhance the preoperative consultation with surgical simulations. However, the value of three-dimensional imaging extends well beyond the marketing application, and we believe that in the near future three-dimensional imaging will become a more valuable part of the strategies used in plastic surgery. The purpose of this article is to review the evolution of clinical photography in plastic surgery and to elucidate the recent advances of three-dimensional photography in plastic surgery.

HISTORY OF TWO-DIMENSIONAL PHOTOGRAPHY

Photography originated as early as the sixteenth century, when Leonardo da Vinci sketched a prototype of a box-shaped structure capable of capturing a still image. As experimentation with photographic exposure emerged, a once novel theory ultimately manifested as proven concept.

Centuries after da Vinci's camera prototype, Louis Daguerre, a French inventor, pioneered the next photographic revolution, as he made pivotal contributions to photography, unveiling the daguerreotype in 1839.[1,2] After learning of Daguerre's invention, William Talbot introduced a novel photographic process by incorporating silver iodide, a technique known as talbotype (calotype). This idea would later be refined over the course of history, notably by the father of film and the Eastman-Kodak company, George Eastman.[1,3]

Two-Dimensional Photography and Plastic Surgery

The progressive use of clinical photography in plastic surgery has been governed by the technological advancements throughout history. In the late nineteenth century, Janos Balassa, a Hungarian surgeon, published some of the first photographs of reconstructive surgery patients in his book, *New Operative Methods of Nose Reconstruction*.[4]

Throughout the nineteenth century, the use of clinical photography in plastic surgery was not particularly common. For instance, a review of McDowell's 1977 book *The Source Book of Plastic Surgery* reveals some of the earliest clinical photographs extracted from the classic articles in plastic surgery[5] (Fig. 1). In addition, the French facial reconstructive surgeon Victor Veau, who devoted his career to cleft lip and palate patients, took photographs at every stage of his patients' treatment, ultimately compiling a collection of 1200 photographs and 8000 sketches.[4]

In the mid-1900s, fadeless color photodocumentation was introduced to plastic surgery by Percy Hennell, a clinical photographer who worked alongside two of the most influential plastic surgeons of the century, Harold Gillies and Archibald McIndoe. Hennell contributed over 500 photographs of burn reconstruction patients to Gillies' and Millard's 1957 book *The Principles and Art of Plastic Surgery*[6] (Fig. 2).

As plastic surgery transformed into a more visually oriented and geometric-dependent science, measurement of surgical success shifted from a highly subjective analysis based on surgeon opinion and patient satisfaction to a more objective measure, using calipers and measuring tape, and ultimately to two-dimensional photography. The progressive thinking of these artists encouraged the transition to two-dimensional photography and provided the valuable foundation for plastic surgeons who routinely use clinical photography in practice.

Current Uses of Two-Dimensional Photography

The digital revolution of the past several decades has facilitated a seamless integration of clinical photography into plastic surgery practice. As photographic technology evolves, it is imperative for plastic surgeons to become familiar with and incorporate these new developments. As surgeons embrace new photographic technologies, the days of slide photography and oversized cameras have become history. The following are common ways in which two-dimensional photography is applied today.

Documentation. One of the well-recognized applications of standard photographic documentation is the ability to document the preoperative and postoperative patient state. Clinical photography in plastic surgery is analogous to radiography and other imaging modalities, and must be held to the highest standards of quality, no different from that applied to the surgery itself. Digital storage of these photographs follows the same privacy guidelines as other health information and should be stored on secure and privacy-compatible devices. In the authors' experience, certain institutions have even adopted programs [e.g., Haiku (EpicCare)] that can turn mobile phone cameras into Health Insurance Portability and Accountability

Fig. 1. Representative examples from *The Source Book of Plastic Surgery.* (Reprinted with permission from McDowell F. *The Source Book of Plastic Surgery*. Baltimore: Williams & Wilkins; 1977. Copyright © The Plastic Surgery Foundation.)

Act–compatible photographic tools that integrate photographs directly into the patient's medical record.[7]

Preoperative and Postoperative Analysis. Two-dimensional photography also plays a role in preoperative consultation and comparative postoperative assessment. Preoperatively, two-dimensional photographs guide the surgeon in evaluating the inherent anatomical and structural relationships of the individual's features, and provide a template for comparative analysis in the postintervention period. During preoperative discussion, it is important to educate the patient on asymmetries that exist, which may be more apparent to the patient when demonstrated photographically. The photographs help elucidate the intricacies of facial aging or asymmetry, and therefore serve as a critical part of the medical record. Furthermore, photographs help document changes for patient teaching, foster retrospective self-evaluation by the surgeon, and also help clearly demonstrate the postintervention transformation.

Research. Clinical photography is an important research tool, and the educational nature of clinical photographs must not be overlooked. The role of photography in plastic surgery research has evolved along with the journals, evidenced by the once black-and-white low-resolution images to the now high-resolution digital images. Photographic documentation in research is unique to plastic surgery. The reason is that these photographs are

Fig. 2. Representative examples from *The Principles and Art of Plastic Surgery.* (Reprinted with permission from Gillies SH, Millard RC. *The Principles and Art of Plastic Surgery*. Boston: Little, Brown; 1957. Permission granted by Wolters Kluwer.)

often evaluated by other individuals, including surgeons, independent observers, and patients themselves. There are countless bodies of research that have extensively reviewed the significance of photographic standardization and consistency, both in the surgeon's office and in the operating room.[8–10]

Development of Three-Dimensional Photography

Capturing three-dimensional surface anatomy using three-dimensional photography dates back to 1944, when Thalmann introduced stereophotogrammetry in his clinic. This technique was originally based on measurements from two-dimensional photographs of patients with facial asymmetry that were ultimately developed into three-dimensional contour maps by plotting machines. Over the subsequent 60 years, advancements in morphologic analysis matured, and the application of stereophotogrammetry was revitalized. As three-dimensional software innovation evolved, the ability to take multiple synchronous photographs from different angles to generate a three-dimensional image fostered a more powerful technology.[11–14]

Inspired by Thalmann's efforts, moiré topography was introduced as a low-cost adjuvant to the early photographic and cephalometric techniques for documentation of body surface deformities. Moiré topography is a quantitative principle whereby two different lights are projected onto a surface to create a topographic representation of a particular anatomical structure to facilitate symmetry analysis.[14–16]

STRUCTURED LIGHT-CAPTURING MODALITIES/ STEREOPHOTOGRAMMETRY

Traditionally, it was thought that laser scanners were the most accurate of the three-dimensional capture systems; however, the clinical utility of these is impeded by long capture times and cost. More recently, there have been relatively low-cost capture systems introduced that can obtain a three-dimensional image in milliseconds. Examples of three-dimensional stereophotogrammetric systems include the Vectra (Canfield Scientific, Inc., Fairfield, N.J.), 3dMDface (3dMD, Inc., Atlanta, Ga.), and Di3D (Dimensional Imaging Ltd., Glasgow, Scotland) systems. All use passive stereophotogrammetry to construct a fully textured, high-resolution, three-dimensional surface image.[17]

Three-dimensional photography surpasses the conventional imaging modalities and enables surgeons to translate a preoperative concept into a reliable result. Despite demonstrated efficacy in other surgical disciplines, many clinicians question whether the cost-to-benefit ratio justifies its ongoing use. With regard to the financial implications of three-dimensional imaging capture systems, the cost burden has lessened over recent years and the technology has become more appropriately priced for a surgeon in both the private practice and academic settings, with cost ranging from $30,000 for the multiple-camera systems to $1000 for the portable structured light systems used with an iPad (Apple, Inc., Cupertino, Calif.). In addition, the new Vectra handheld camera, which captures impressive three-dimensional images, has a reduced cost of under $10,000, which is comparable to that of the advanced two-dimensional single-lens reflex cameras with regard to pricing and size.

Handheld scanner technology uses an infrared camera to capture shape and distance to create an image. Examples include the Vectra H1 handheld imaging system (Canfield Scientific) and the Web-based three-dimensional imaging program by Crisalix (Crisalix Virtual Aesthetics, Bern, Switzerland), which connects an occipital scanner to an iPad so that physicians can capture images and simulate results for patients by a more portable means at lower cost (Fig. 3). More advanced cameras are currently used to capture four-dimensional images to create incredibly realistic and dynamic facial animation without the use of any optical markers or special makeup (e.g., Di4D; Dimensional Imaging).

CURRENT APPLICATIONS OF THREE-DIMENSIONAL PHOTOGRAPHY

In large part, three-dimensional photography was introduced into the field of plastic surgery for the purposes of simulation. Giving patients the ability to see themselves in three dimensions has enhanced both the consultation experience and presumably conversion-to-surgery rates. Contrary to standard two-dimensional photography, the three-dimensional systems provide valuable information about contour and geometry, such as volume, area, and depth. Whereas only linear distances and angles can be determined by use of two-dimensional images, soft-tissue volumetric analysis and surface topography are possible three-dimensionally.

Given that the inherent goal of facial plastic surgery is to balance facial deficits and asymmetries by interpreting depth and shape, texture, and tonicity, two-dimensional photography is limited in ways that three-dimensional photography is not. For instance, frontal, lateral, oblique, and base views of the nose are among the standardized images. However, the face and nose are three-dimensional structures, and subtle irregularities can be lost when they are portrayed two-dimensionally.

A major advantage of three-dimensional imaging is the ability to perform absolute measurements. Traditionally, absolute measurements from photographs needed to be recalibrated to actual size by using measurements of known distances in the photographs, using either a ruler for a life-size photograph or fixed points on the face, whereas technology such as the Vectra system is capable of recalibrating these images in a life-sized manner.

Three-dimensional photography thereby outperforms its predecessor throughout the perioperative period. Below is a summary of current and future applications of three-dimensional photography in plastic surgery.

Preoperative Consultation

The most common application of three-dimensional photography today is surgical simulation during the consultative visit. Within cosmetic

Fig. 3. Images demonstrating various three-dimensional capture devices currently available. (*Left*) Traditional laser scanner (Konica Minolta three-dimensional digitizer scanner). (*Center*) Stereophotogrammetry (Canfield Vectra H1 handheld camera). (*Right*) Structured light handheld scanner (Crisalix).

surgery, three-dimensional photography of the face has mostly been used to preoperatively simulate aesthetic results and procedures, such as rhinoplasty, genioplasty, neck lifts, and rhytidectomy.

More recently, as systems have become more affordable, body imaging systems have been incorporated into practice to simulate body contouring procedures and breast augmentation. For surgeons who use this technology, many feel that these simulations greatly enhance the consultation by demonstrating simulated morphologic changes to their patients. However, without the ability to transfer the virtual plan into reality, it remains a useful tool for patient education, with little prognostic value for the surgeon.

Preoperative Analysis Incorporated into Consultation

The advantage to three-dimensional imaging software is the ability to review the preoperative analysis with the patient while manipulating the images in real time. After the patient image is captured, landmarks are selected on a three-dimensional model, which can be adjusted manually to increase the accuracy of the measurements. The nasolabial and nasofrontal angle, nasal tip, and dorsal hump are examples of features that can be manipulated in variable positions during rhinoplasty consultation, and the changes are visualized with the patient present in the room.

Before the advent of three-dimensional photography and its volumetric analytic capabilities, there was no reliable method to quantitatively demonstrate facial volume and structure preoperatively. Structural restoration and rejuvenation of the forehead, periorbital region, and midface depend on a comprehensive understanding of the facial fat distribution and its age-related changes to obtain an aesthetically youthful and rejuvenated appearance.[17–19] In addition, the senior author (O.M.T.) has previously described the concept of mammometrics, whereby three-dimensional photography can be used to analyze breast asymmetry to facilitate planning aesthetic and reconstructive breast procedures.[20,21]

Three-dimensional software highlights breast asymmetry and volume differences between the two breasts, which can be shown to patients preoperatively to illustrate existing symmetry issues, even if mild enough to not cause alarm to the naked eye. Certain three-dimensional imaging systems incorporate technology that has integrated the majority of the available breast implants on the market to simulate postoperative results. Preoperative simulation has been proven to increase patient satisfaction; thus, three-dimensional technology in the appropriate setting offers the physician a valuable tool, making the decision-making process more transparent and manageable for the patient.

Surgical Planning

Whereas two-dimensional photography–based measurements are only semiquantitative and relatively inaccurate compared with three-dimensional imaging, the stereophotogrammetric capabilities of three-dimensional photography have a substantially more valuable role. An underappreciated application of three-dimensional photography is its applicability during surgical planning, particularly when paired with a focused volumetric surgical algorithm, such as for facial fat grafting.

For instance, in the aging patient, the physician is able to quantitatively measure volume deficits of the midface using the three-dimensional imaging software to compare the volume difference between the pretreatment and posttreatment images during subsequent visits. Quantifying baseline midface volume before intervention enables the surgeon to focus on volume-deficient areas, areas that preferentially retain augmentation, or areas that do not retain the grafted filler or autologous fat.

Objective three-dimensional analysis of the surface changes produced with facial compartmental volumization is valuable for documenting the effectiveness, longevity, and repeatability of specific fat grafting techniques, and enables the surgeon to objectively study how surface topographic anatomy responds to targeted fat grafting, such as the malar region of the deep medial cheek (Fig. 4).[19,22]

Stern et al. recently demonstrated the significance of morphologic and anatomical surface changes in response to volume augmentation of facial compartments. A cadaver study was undertaken in which volumization of the deep medial cheek compartment was performed at intervals up to 4 cc. Three-dimensional photographs were taken after each injection to analyze the topographic surface changes, and it was concluded that volumization of the deep medial cheek led to unique topographic changes of the malar region, specifically, that volumization created an "augmentation zone" and led to increased projection of the augmentation zone.[22]

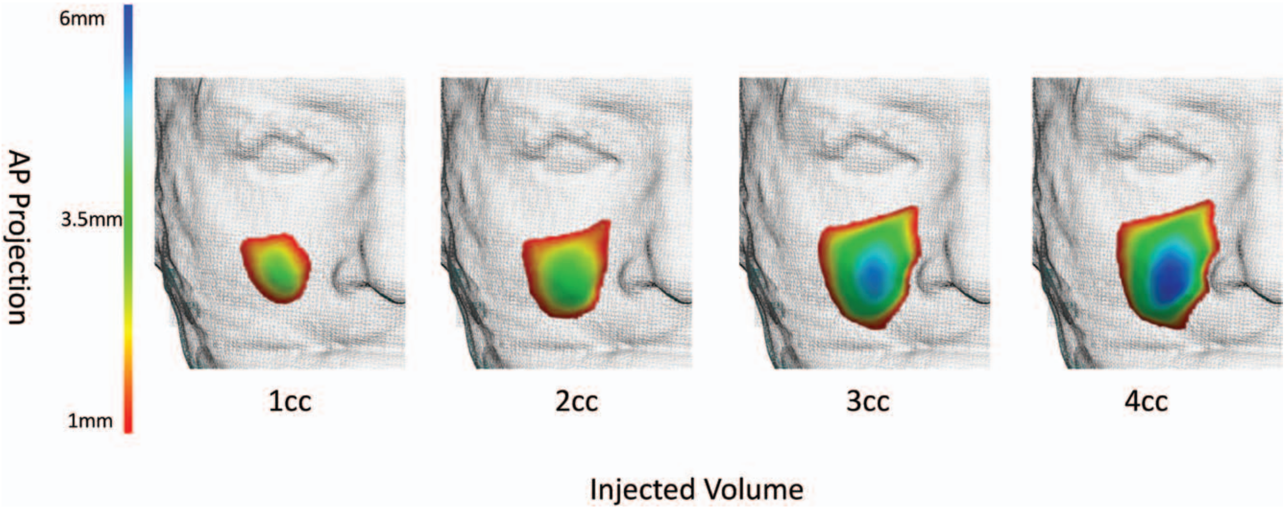

Fig. 4. Zone of augmentation for the deep medial cheek compartment. Surface change caused by deep medial cheek augmentation from 1- to 4-cc injection of fat analogue. Color scale demonstrates range of surface change from 1 mm (*red*) to a maximum of 6 mm (*blue*). (Reproduced with permission from Stern CS, Schreiber JE, Surek CC, et al. Three-dimensional topographic surface changes in response to compartmental volumization of the medial cheek: Defining a malar augmentation zone. *Plast Reconstr Surg*. 2016;137:1401–1408.)

As three-dimensional photographic technology has evolved, surgeons have found value in incorporating three-dimensional photography intraoperatively. For example, one current application is the use of three-dimensional photography during rhinoplasty to gauge intraoperative changes. Three-dimensional images used intraoperatively illustrate progressive changes in dorsal tip aesthetics as they occur in a stepwise fashion. In addition, these baseline and/or simulated three-dimensional images can be printed as tangible models for use as intraoperative blueprints to replace traditional two-dimensional photographs (Fig. 5).

The ability to comprehensively evaluate and define the anatomical subtleties preoperatively raises the question of accuracy when taking a three-dimensional simulation from the office into the operating room. With regard to accuracy of three-dimensional capture and printing, there are several studies that address this. The fidelity of three-dimensional print technology intraoperatively is still yet to be defined and has encouraged our authors to design a study to compare

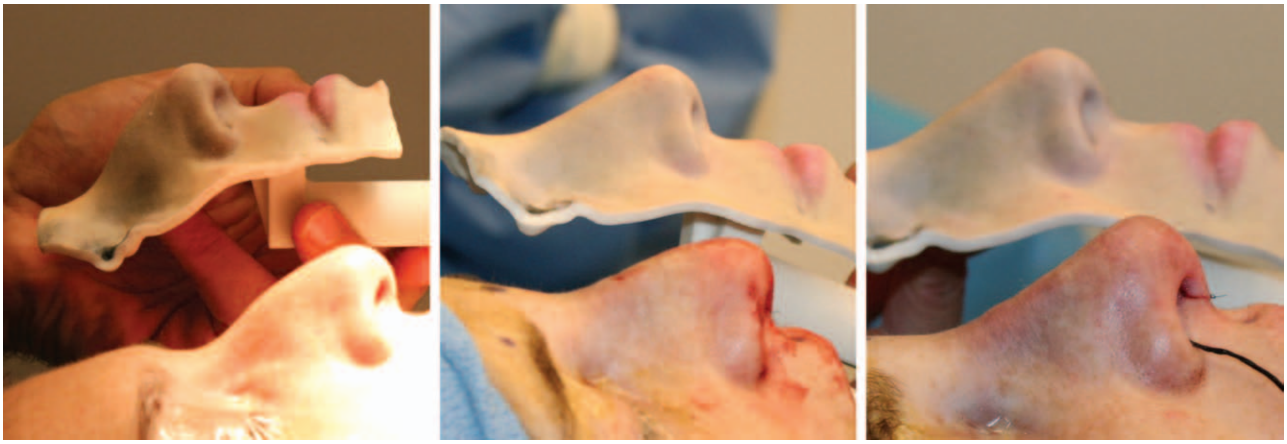

Fig. 5. Use of intraoperative three-dimensional models during rhinoplasty. (*Left*) Preoperatively: baseline print compared to patient before surgery. (*Center*) Intraoperatively: comparing simulated print “ideal” result with intraoperative photograph demonstrating additional modifications needed. (*Right*) Postoperatively: final surgical result in the operating room compared with the ideal outcome.

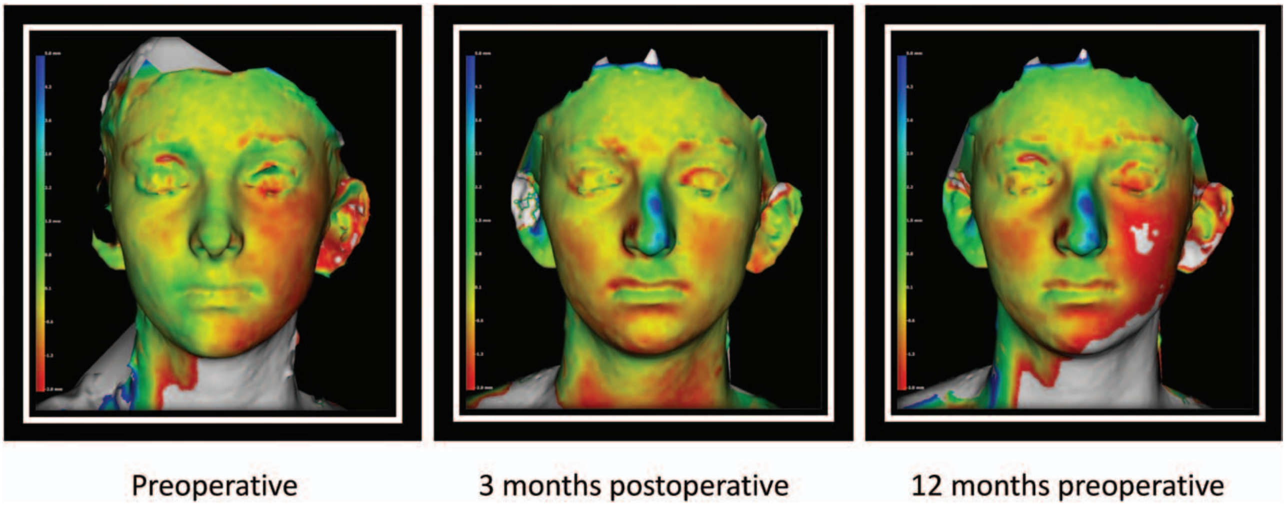

Fig. 6. Assessing postoperative gradual volume change and swelling of the postrhinoplasty nose. Volume change caused by swelling can be assessed with volumetric analysis. An increase in the *blue* area reflects less swelling, and an increase in the *red* area reflects an increase in postoperative swelling.

simulation with actual results. Furthermore, in addition to the applications of three-dimensional photographic technology in facial surgery, there have been studies published describing the value of three-dimensional technology in hand surgery.[23–28]

Postoperative Follow-Up

Although it is clear that three-dimensional photography has great utility in the preoperative and intraoperative setting, it carries significant value in the postintervention period as well. The ability to capture and measure topographic and volumetric transformation after a procedure enables the surgeon to track results over time. Three-dimensional surface data obtained from patient images allow for a more objective assessment after intervention.

For example, various studies have addressed the durability, longevity, and long-term outcomes of autologous fat transfer. However, studies on volume retention have been mostly based on the subjective analysis of two-dimensional photographs, and not objectively measurable data, citing volume retention rates anywhere from 20 to 90 percent.[29]

The value of three-dimensional photography has also been quantitatively demonstrated in various studies through analysis of midface volume augmentation after rhytidectomy and facial rejuvenation. In a study by Jacono et al., patients who underwent a deep-plane vertical vector rhytidectomy were followed prospectively to assess long-term midface volume augmentation by creating three-dimensional topographic representations to depict the volume change between the preoperative and postoperative three-dimensional photographs.[19]

Furthermore, gradual volume change because of swelling of the postrhinoplasty nose can be assessed three-dimensionally in fixed areas, and the variable areas can be assessed with color-coded depictions of volumetric change (Fig. 6). This technology affords surgeons the ability to more precisely measure grafts and nasal changes in augmentation rhinoplasty by performing measurements along the three-dimensional contour of the nose.

Postsurgical three-dimensional analysis undoubtedly has great utility in the postoperative period, and with its proven applicability, this technology will soon become standard practice for measuring and documenting surgical outcomes in plastic surgery. No longer will outcomes be measured by simply documenting patient satisfaction postoperatively; they will need to be accompanied by objective data that can be gleaned from using this invaluable technology.

CONCLUSIONS

This review provides historical context of plastic surgery photography and highlights the clinical utility of three-dimensional photography for assessing changes that occur after various plastic surgery procedures. With the continued technologic innovation in plastic surgery, surgeons will have the ability to integrate three-dimensional surface imaging into their practices with smaller and less costly cameras to facilitate surgical planning while improving postoperative results by providing clearer objective measures, holding us, as a discipline, to a higher surgical standard.

Oren M. Tepper, M.D.
Craniofacial Surgery, Aesthetic Surgery
Division of Plastic Surgery
Montefiore Medical Center
Albert Einstein College of Medicine
1776 Eastchester Road, Suite 200
Bronx, N.Y. 10461
orenteppermd@yahoo.com

REFERENCES

1. Rogers B. The first pre- and post-operative photographs of plastic and reconstructive surgery: Contributions of Gurdon Buck (1807–1877). *Aesthetic Plast Surg.* 1991;15:19–33.
2. Rogers B. Reed B. Bontecou, M.D.—His role in Civil War surgery and medical photography. *Aesthetic Plast Surg.* 2000;24:114–129.
3. Spear M, Hagan K. Photography and plastic surgery: Part 1. *Plast Surg Nurs.* 2008;28:66–68; quiz 69.
4. Wallace AF. The early history of clinical photography for burns, plastic and reconstructive surgery. *Br J Plast Surg.* 1985;38:451–465.
5. McDowell F. *The Source Book of Plastic Surgery*. Baltimore: Williams & Wilkins; 1977.
6. Gillies SH, Millard RC. *The Principles and Art of Plastic Surgery.* Boston: Little, Brown; 1957.
7. INOVA. EpicCare Mobile Apps: Haiku and Canto. Available at:https://www.inova.org/for-physicians/epiccare-apps. Accessed May 4, 2016.
8. Becker DG, Tardy ME Jr. Standardized photography in facial plastic surgery: Pearls and pitfalls. *Facial Plast Surg.* 1999;15:93–99.
9. Henderson JL, Larrabee WF Jr, Krieger BD. Photographic standards for facial plastic surgery. *Arch Facial Plast Surg.* 2005;7:331–333.
10. Aveta A, Filoni A, Persichetti P. Digital photography in plastic surgery: The importance of standardization in the era of medicolegal issues. *Plast Reconstr Surg.* 2012;130:490e–491e; author reply 491e.
11. Karlan MS. Contour analysis in plastic and reconstructive surgery. *Arch Otolaryngol.* 1979;105:670–679.
12. Hajeer MY, Ayoub AF, Millett DT, Bock M, Siebert JP. Three-dimensional imaging in orthognathic surgery: The clinical application of a new method. *Int J Adult Orthodon Orthognath Surg.* 2002;17:318–330.
13. Kau CH, Richmond S, Incrapera A, English J, Xia JJ. Three-dimensional surface acquisition systems for the study of facial morphology and their application to maxillofacial surgery. *Int J Med Robot.* 2007;3:97–110.
14. Tzou CH, Frey M. Evolution of 3D surface imaging systems in facial plastic surgery. *Facial Plast Surg Clin North Am.* 2011;19:591–602.
15. Yavuzer R, Smirnes S, Jackson IT. Guidelines for standard photography in plastic surgery. *Ann Plast Surg.* 2001;46:293–300.
16. García-Rabasco A, Marín-Bertolín S, Esteve-Martínez A, García-Ruiz R. Intraoperative photography for dermatologic and plastic surgery. *Dermatol Surg.* 2011;37:404–406.
17. Tzou CH, Artner NM, Pona I, et al. Comparison of three-dimensional surface-imaging systems. *J Plast Reconstr Aesthet Surg.* 2014;67:489–497.
18. Herold C, Ueberreiter K, Busche MN, Vogt PM. Autologous fat transplantation: Volumetric tools for estimation of volume survival. A systematic review. *Aesthetic Plast Surg.* 2013;37:380–387.
19. Jacono AA, Malone MH, Talei B. Three-dimensional analysis of long-term midface volume change after vertical vector deep-plane rhytidectomy. *Aesthet Surg J.* 2015;35:491–503.
20. Galdino GM, Nahabedian M, Chiaramonte M, Geng JZ, Klatsky S, Manson P. Clinical applications of three-dimensional photography in breast surgery. *Plast Reconstr Surg.* 2002;110:58–70.
21. Tepper OM, Choi M, Small K, et al. An innovative three-dimensional approach to defining the anatomical changes occurring after short scar-medial pedicle reduction mammaplasty. *Plast Reconstr Surg.* 2008;121:1875–1885.
22. Stern CS, Schreiber JE, Surek CC, et al. Three-dimensional topographic surface changes in response to compartmental volumization of the medial cheek: Defining a malar augmentation zone. *Plast Reconstr Surg.* 2016;137:1401–1408.
23. Hoevenaren IA, Maal TJ, Krikken E, de Haan AF, Bergé SJ, Ulrich DJ. Development of a three-dimensional hand model using 3D stereophotogrammetry: Evaluation of landmark reproducibility. *J Plast Reconstr Aesthet Surg.* 2015;68:709–716.
24. Maschio F, Pandya M, Olszewski R. Experimental validation of plastic mandible models produced by a "low-cost" 3-dimensional fused deposition modeling printer. *Med Sci Monit.* 2016;22:943–957.
25. Gálvez JA, Gralewski K, McAndrew C, Rehman MA, Chang B, Levin LS. Assessment and planning for a pediatric bilateral hand transplant using 3-dimensional modeling: Case report. *J Hand Surg Am.* 2016;41:341–343.
26. Nord F, Ferjencik R, Seifert B, et al. The 3dMD photogrammetric photo system in cranio-maxillofacial surgery: Validation of interexaminer variations and perceptions. *J Craniomaxillofac Surg.* 2015;43:1798–1803.
27. Stekelenburg CM, Jaspers ME, Niessen FB, et al. In a clinimetric analysis, 3D stereophotogrammetry was found to be reliable and valid for measuring scar volume in clinical research. *J Clin Epidemiol.* 2015;68:782–787.
28. Verhiel SH, Piatkowski de Grzymala AA, Van den Kerckhove E, Colla C, van der Hulst RR. Three-dimensional imaging for volume measurement of hypertrophic and keloid scars: Reliability of a previously validated simplified technique in clinical setting. *Skin Res Technol.* 2016;22:513–518.
29. Chan CW, McCulley SJ, Macmillan RD. Autologous fat transfer: A review of the literature with a focus on breast cancer surgery. *J Plast Reconstr Aesthet Surg.* 2008;61:1438–1448.