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Three-Dimensional Photography and Computer Modeling as a Reconstructive Surgical Training Tool

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Abstract

Background: Reconstructive surgery operations are often complex, staged, and have a steep learning curve. As a vocational training requiring thorough three-dimensional (3D) understanding of reconstructive techniques, the use of 3D photography and computer modeling can accelerate this learning for surgical trainees.
Objectives: The authors illustrate the benefits of introducing a streamlined reconstructive pathway that integrates 3D photography and computer modeling, to create a learning database for use by trainees and patients alike, to improve learning and comprehension.
Methods: A computer database of 3D photographs and associated computer models was developed for 35 patients undergoing reconstructive facial surgery at the Royal Free Hospital, London, UK. This was used as a training and teaching tool for 20 surgical trainees, with an MCQ questionnaire assessing knowledge and a Likert scale questionnaire assessing satisfaction with the understanding of core reconstructive techniques, given before and after teaching sessions. Data were analyzed using the Mann–Whitney *U* test for trainee knowledge and Wilcoxon rank sum test for trainee satisfaction.
Results: Trainee ($n = 20$) knowledge showed a statistically significant improvement, $P < .01$, as did trainee satisfaction, $P < .05$, after a teaching session using 3D photography and computer models for facial reconstruction.
Conclusions: Three-dimensional photography and computer modeling are useful teaching and training tools for reconstructive facial surgery. The authors advocate the implementation of an integrated pathway for patients with facial defects to include 3D photography and computer modeling wherever possible, to develop internal databases for training trainees as well as patients. This algorithm can be extrapolated to other aspects of reconstructive surgery.

Level of Evidence: 5

5
Therapeutic

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The principles learned from facial reconstructive surgery can be extrapolated for use in all aspects of plastic surgery and aesthetic medicine. Developing an understanding of complex, often multi-staged, three-dimensional (3D) reconstruction is a lengthy process with a steep learning curve, and a necessary part of surgical training. As a vocational specialty requiring as much engaged training as possible, modern techniques can be utilized to minimize the time taken to achieve understanding and competency, where continuous time in theater is not always possible or practical. The integration of 3D photography and computer modeling using real-life patient databases and structured teaching sessions is one of these techniques. We illustrate the development of an integrated reconstructive pathway for patients which involves streamlined 3D photographs preop, postop, and before each subsequent operative stage, along with computer modeling of photographs and where necessary, computed tomography (CT) scans, to develop a comprehensive database of 35 patients undergoing various facial reconstructive procedures. This database has then been used as a training tool for surgical trainees, with a statistically significant improvement in trainee knowledge and satisfaction. Future uses include use as an educational resource for patients, and the pathway is being expanded to other aspects of our reconstructive and plastic surgery practice to further develop our database following the positive feedback we have had.

The evidence basis for the development of our reconstructive database is robust, with 3D models having been shown to improve surgical decision-making as they allowed for improved planning, understanding, and simulation preoperatively.[1] Furthermore, they are widely utilized in the planning and customized printing of 3D prostheses and implants. What is unique in our study is that these techniques are used to develop an ever-expanding educational database for use in teaching trainees as well as patients.

Understanding the principles of reconstructive options and their fundamental anatomy is essential. With this in mind, a knowledge-based assessment using multiple choice questions was developed and used to assess trainee knowledge before and after 3D photography and model-based teaching. The use of MCQs is a well-established technique for assessment. To quantify trainee satisfaction with the reconstructive technique, a questionnaire was developed and collected before and after the session.

Our computer database of 3D photographs and associated computer models was developed for 35 patients undergoing reconstructive facial surgery at the Royal Free Hospital, London, UK. These patients were all requiring unique reconstructions but illustrated fundamental reconstructive techniques such as the paramedian forehead flap (Figure 1), cervicofacial rotation flaps, pedicled nasolabial flaps, free tissue transfer (Figure 2), autologous costal and conchal cartilage harvesting, skin grafting, and custom made bony implants (Figure 3), in staged methods, demonstrating the principles of reconstruction including like-for-like tissue wherever possible, the formation of trilaminar reconstructions for full-thickness nasal defects, and aesthetic subunit-based reconstruction.[2] The defects' etiology included those congenital (eg, hemifacial microsomia), traumatic, malignancy, and acquired (eg, rhinophyma).

METHODS

A computer database of 3D photographs and associated computer models was developed for 35 patients undergoing reconstructive facial surgery at the Royal Free Hospital, London, UK. These patients all required unique reconstructions but illustrated fundamental reconstructive techniques, principles of reconstruction, and aesthetic subunit-based reconstruction.[2] The defects' etiology included congenital, traumatic, malignant, and acquired.

Three-dimensional photographs were taken preoperative, predefect, postreconstruction, and for follow-up, allowing for each patient's reconstructive journey to be meticulously documented using 3D images. Computer modeling was used to illustrate the reconstructive plan and appropriate measurements to be taken, for both soft tissue, and where necessary, CT images (Figure 3). The 3D photographs taken are then transferred to the educational database where they can be interpreted in 3-dimensions on a computer screen. An in-house 3D printer is also available to print hardcopy versions, particularly of the bone images from the 3D CT scans. This allows a digital and hard version of each stage of the reconstruction. Computer models are designed by the authors of this study for each specific set of images (Figure 2). Teaching sessions are then planned within the department to discuss each computer model as an educational and surgical planning tool, led by consultants for our trainees.

This database was then used as a training and teaching tool for 20 plastic surgery trainees at registrar level, with a multiple choice (MCQ) assessment (Appendix A) quantifying knowledge and a Likert scale questionnaire assessing trainee satisfaction (Appendix B) with operative technique, given before and after teaching sessions to objectively determine if there was an improvement. Data were analyzed using the Mann–Whitney *U* test for trainee knowledge and Wilcoxon sum rank test for trainee satisfaction using Microsoft Excel (Microsoft; Redmond, WA). Written consent was provided, by which the patients agreed to the use and analysis of their data.

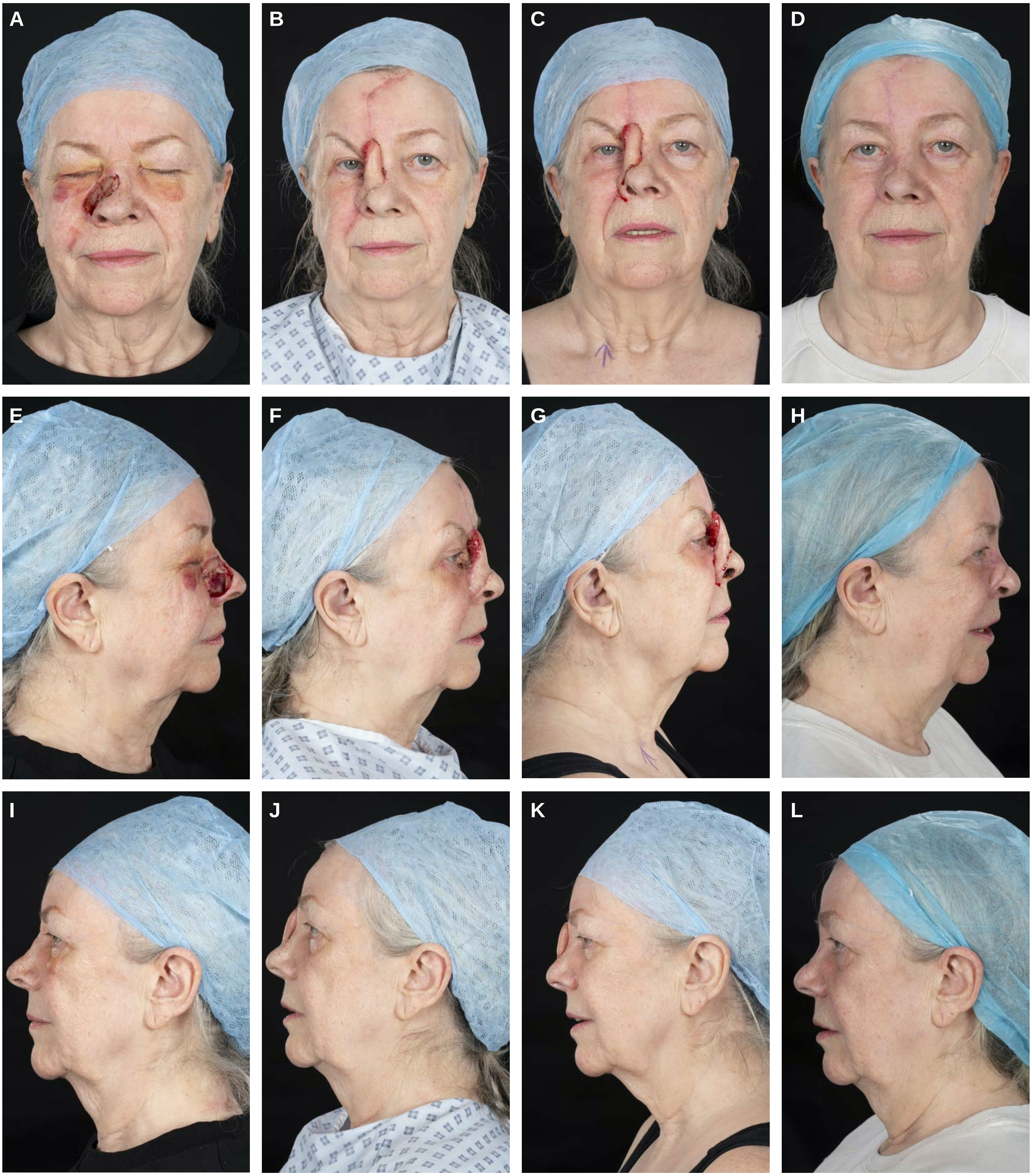

Figure 1. Stages of a paramedian forehead flap on a 70-year-old female with basal cell carcinoma (BCC) on nose. She is shown (A, E, I, M, Q) 2 months after Mohs excision of BCC, (B, F, J, N, R) 2 months after first stage of paramedian forehead flap, (C, G, K, O, S) 2 months after second stage with flap division inset, and (D, H, L, P, T) fully healed at frontal, right lateral, left lateral, right oblique, and left oblique views, respectively. Reprinted from *Journal of Oral Biology and Craniofacial Research,* Volume 12, Issue 5, Faderani R, Singh P, Krumhuber E, Mosahebi A, Ponniah A, 3D photography and computer modelling in nasal reconstruction, 512-515, 2022, with permission from Elsevier.

Figure 1. Continued

RESULTS

A comprehensive database of 35 patients undergoing facial reconstruction was developed, with a female:male proportion of 21:17, a mean age of 52 years old (range, 23-91 years), a range of etiologies from malignancy ($n = 25$), trauma ($n = 5$), congenital ($n = 3$), and other acquired ($n = 2$), those requiring soft-tissue construction only ($n = 30$) and those requiring bony reconstruction also ($n = 5$). A cohort of trainee plastic surgery registrars ($n = 20$) undertook a multiple choice questionnaire assessing knowledge before and after a training session using 3D photographs and computer modeling for facial reconstruction, with a statistically significant improvement in knowledge acquired as a result of this training tool ($P < .01$), an improvement of 139%. The same cohort of trainees undertook a Likert scale satisfaction questionnaire on understanding of core facial reconstruction techniques which illustrated a statistically significant improvement ($P < .05$) after the training, an improvement of 193%.

DISCUSSION

In this paper, we illustrate the benefits for surgical training in terms of improvement in knowledge of ($P < .01$), and satisfaction with ($P < .05$) the comprehension and understanding of, fundamental facial reconstruction techniques using a database of 3D photographs and computer models developed for patients attending out unit for facial reconstruction. We have previously published our reasoning and methodology behind the development of this facial reconstruction pathway and how we have integrated 3D photography and computer modeling into an MDT.[3,4] The additional benefit of this was the development of a

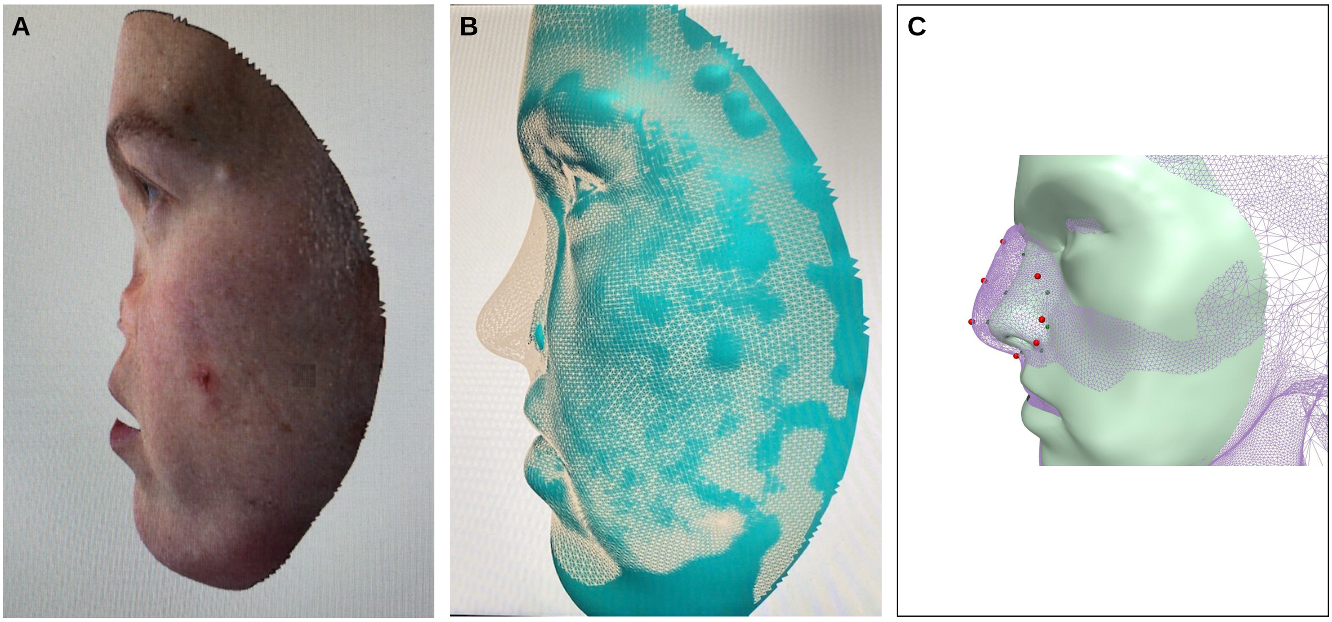

Figure 2. Planning for a total nasal reconstruction using (A) a forehead flap, costal cartilage sandwich graft, and radial forearm free flap, (B) 3D photography modelling of completed reconstruction, and (C) modelling for second stage refinement after first stage reconstruction.

database which has been beneficial for trainees and patient education alike.

Once 3D photographs or CTs have been produced, and computer models made on them, 3D models can be printed and used in simulation. This technique has been described in the literature and is a recognized tool for improving surgical outcomes. Meyer-Szary et al carried out a multi-specialty cross-sectional review on the role of 3D printing in planning surgical and medical procedures and training medical professionals. They found that across a range of specialties, 3D models aided decision-making, as surgical approaches could be planned and simulated in advance. For example, in pediatric cardiac surgery, a prospective case-crossover study showed that 3D models improved surgical planning in complex congenital cardiac operations and in certain cases led to a change in the surgical approach taken.[1,5] In spinal surgery, 3D printing was used to create customized drill templates to allow for optimal placement of transpedicle screws. This resulted in greater precision in screw placement and less "time spent per screw" which in turn meant less radiation exposure to the patient.[1] In head and neck surgery, 3D-printed models have also been used to aid the harvesting of iliac crest flaps in reconstruction post maxillectomy. The use of these models resulted in the surgical approach being optimized, fewer incisions being made, a reduction in intraoperative bleeding and improved cosmesis.[1] A similar technique has been applied to mandibular reconstruction surgery, and it has been shown that the combined use of computerized 3D models and 3D-printed models has led to reduced operative times, as most of the surgical planning can be carried out preoperatively. A retrospective review of 57 patients who underwent free fibula reconstruction of the mandible between 2002 and 2011 found a significant reduction in operative time in computer-assisted mandibular reconstructions (CAMRs) compared to conventional free-hand mandibular reconstructions (CFMRs); 707 to 534 min ($P < .0003$).[1,6] A meta-analysis that compared CFMR with CAMR also found that 3D planning was associated with a significantly shortened ischemic time 35 min ($P < .01$).[7]

Other studies investigating the role of 3D models in surgery have reported similar advantages. Galvez et al conducted a study that evaluated the use of 3D models in simulating surgical procedures in 7 cases. They found that the 3D-printed models enhanced surgical planning, reduced operative time by 42.5%, reduced intraoperative bleeding by 50.4% and allowed surgeons to visualize the anatomical structures to scale. In 2 of the 7 cases, the 3D model led to the operating team modifying their surgical approach. A secondary benefit of the 3D models was that they could be used to explain procedures to patients. However, some limitations of the 3D models were cited in the study; these included lengthy preparation times for the models, increased preoperative planning time, and the dependency on high-resolution images to create the models.[8] This can be minimized by interactive software, allowing 3D visualization of photographs and models without the need to print them out which is resource and time heavy, and as we have demonstrated, not necessary when used as a training adjunct.

Figure 3. Three-dimensional computed tomography image illustrating the location of the custom made PolyEtherEtherKetone orbital implant.

Specifically within the field of plastic and reconstructive surgery, 3D models have also contributed to operative planning and surgical training. Lynn et al carried out a systematic review on the role of 3D printing in plastic surgery from 2016 to 2020. The authors found that 3D printing assisted with surgical planning as defects could be visualized and dimensions of flaps harvested could be measured beforehand. For example, in facial reconstruction surgery requiring fat grafting, the exact amount of fat required for the graft could be measured with a 3D-printed model. In breast reconstruction surgery, 3D-printed "perforasome templates" were created to guide flap harvesting and reduce the chance of flap necrosis. These models could also be taken into the operating room and provide intraoperative guidance.[9] Ogunleye et al carried out a retrospective single-center review of 58 abdominal-based (DIEP and MS-TRAM) breast-free flaps performed with 3D-printed models and compared them with a matched cohort of free flaps performed using conventional CT angiogram (CTA). The study found a significant reduction in flap harvest time in the cohort of free flaps performed with the aid 3D-printed models ($P = .001$).[10] Additionally, in this cohort, there were no cases of change in preoperative decision with respect to the type of flap harvested compared to a 24.1% change in the CTA cohort. Nicklaus et al described a method of using a handheld 3D scanner to take intraoperative 3D photographs of mastectomy specimens during breast reconstruction surgery. These photographs could then be processed, and measurements of the specimens could be computed. Semistructured interviews with a group of plastic surgeons were then conducted to gather information about the usefulness of this technique. The speed at which the photographs could be taken and processed was noted as an advantage, illustrating the swiftness by which a database like ours can be compiled and grown.[11]

Computational modeling has been used to simulate craniofacial procedures and analyze surgical outcomes. Computational skull models have been shown to be useful to evaluate differences in skull shapes following surgery and have the potential to be used to simulate surgical outcomes and adjust any parameters accordingly when planning a procedure.

Three-dimensional models have the capacity to play a valuable role in surgical training and education. In ear, nose, and throat (ENT) surgery, 3D models of temporal bones have allowed surgical trainees to practice procedures such as tympanic membrane paracentesis.[1] Barber et al found that a 3D-printed endoscopic ear surgery simulator was an inexpensive and high-fidelity tool for practicing transcanal endoscopic ear surgery.[12] In craniofacial surgery, 3D-printed models were found to increase surgical trainees' understanding of craniofacial procedures and improve the accuracy of their proposed surgical plans.[13] Another study assessed how the use of 3D reconstruction software impacted surgical residents' knowledge on resectability of pancreatic lesions. This was evaluated through the use of a questionnaire, which included questions related to the staging of the tumor and resection margins. There was a statistically significant increase in the scores of senior surgical residents who used the 3D reconstruction software in conjunction with CT scans compared to those who used CT scans alone.[14]

The development of a training database like ours can be extrapolated to other areas of reconstructive surgery as well as aesthetic practice; both surgical and nonsurgical. As aesthetic medicine is founded on the development and improvement of physical structures, the outcomes and stages can be accurately mapped using 3D photographs. These can be compiled to produce a before and after database, and modeled to illustrate aesthetic techniques and what outcomes can be expected. Integrating this into aesthetic practice involves the need for 3D photographs, which can be produced using handheld devices or fixed devices such as the Vectra XT (Canfield Scientific, Parsippany, NJ).

Our study is limited by the number of surgical trainees in our department, and the development of a patient database of only 35 patients. This is due to departmental size and also the time taken to produce a comprehensive set of 3D scans and models for each patient. Over time, this database will grow and we plan to roll it out across London for all deanery trainees.

CONCLUSIONS

We demonstrate how the development of a database using patient 3D photographs and computer modeling can be successfully used in the improvement of surgical trainee education through improved knowledge and satisfaction with the understanding of facial reconstructive techniques. This is an adjunct that can be integrated into other units, can be used for all future trainees, and can be expanded to improve patient understanding and in all aspects of reconstructive and aesthetic practice.

Supplemental Material

This article contains supplemental material located online at www.asjopenforum.com.

Disclosures

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