CASE REPORT

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THREE-DIMENSIONAL PHOTOGRAMMETRY FOR SURGICAL PLANNING OF TISSUE EXPANSION IN HEMIFACIAL MICROSOMIA

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Abstract: *Background.* We aim to illustrate the applications of 3-D photogrammetry for surgical planning and longitudinal assessment of the volumetric changes in hemifacial microsomia.

Methods. A 3-D photogrammetric system was employed for planning soft tissue expansion and transplantation of a vascularized scapular flap for a patient with hemifacial microsomia. The facial deficiency was calculated by superimposing a mirror of the normal side on the preoperative image. Postsurgical volumetric changes were monitored by serial superimposition of 3-D images.

Results. A total of 31 cm^3 of tissue expansion was achieved within a period of 4 weeks. A scapular free flap measuring 8 cm × 5 cm was transplanted to augment the facial deficiency. Postsurgical shrinkage of the flap was observed mainly in the first 3 months and it was minimal thereafter.

Conclusion. ~~A~~ 3-D photogrammetry can be used as a noninvasive objective tool for assessing facial deformity, planning, and postoperative follow-up of surgical correction of facial asymmetry. © 2009 Wiley Periodicals, Inc. *Head Neck* **00:** 000–000, 2009

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Hemifacial microsomia (HFM) is characterized by facial asymmetry resulting from unilateral congenital deficiency of both hard and soft tissues. It mainly affects the structures derived from the first and second branchial arches. HFM is considered to be the second most common craniofacial anomaly after cleft lip and palate.[1]

Surgical management of HFM should address the correction of both the hard and soft tissue components of the deformity. Distraction osteogenesis or orthognathic surgery can be employed for correction of the osseous anomalies depending on the age of the patient and the severity of the deformity. Soft tissue correction is usually performed after skeletal stability has

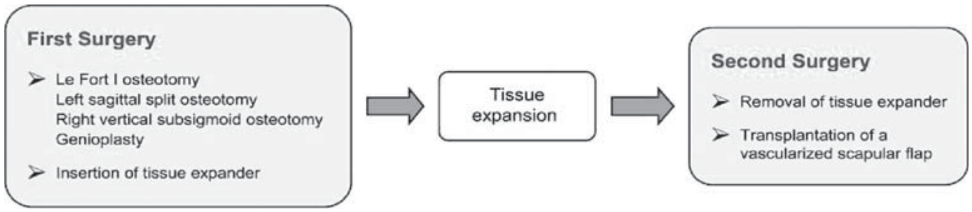

FIGURE 1. The treatment sequence in 2 stages with tissue expansion being performed during the intervening period of 4 weeks. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

been achieved.[2] Fat injections have been tried but significant posttreatment atrophy has been reported,[3] possibly due to the insufficient skin expansion. Although free vascularized flaps are currently preferred for soft tissue augmentation of the transverse deformity, skin color mismatch between the donor site and the recipient site still poses a potential aesthetic problem.[4,5] The use of soft tissue expansion (STE) at the donor site prior to harvesting free flaps are well described in the scientific literature.[6,7] However, there were no publications on STE of the recipient site prior to transplantation of free flaps in the cranio-maxillofacial region. Such expansion can be a useful adjunct to transplantation of free flaps, as the expanded skin of the recipient site provides a superior match of both color and texture when compared with composite free flaps and their skin components from the donor site. Furthermore, STE allows the transfer of sufficient bulk of tissue to the recipient site as a pocket is created beforehand. It also permits tensionless skin closure.

The main challenge when planning surgery for HFM is volume restoration.[3] This is further complicated by the complex three-dimensional (3-D) nature of the maxillofacial skeleton coupled with the aesthetic and functional considerations. Therefore, objective information on the extent and magnitude of tissue deficiency is required when planning treatment for HFM patients. Furthermore, progressive volumetric changes during different stages of treatment need to be monitored to evaluate the soft tissue response to STE and transplantation of the free flap.

Photogrammetry is the process of obtaining measurements from photographs and stereophotogrammetry refers to the use of 2 or more cameras for acquiring 3-D information.[8] The novel stereophotogrammetry systems provide a quick and a noninvasive method for acquiring 3-D data on facial surface characteristics and aid surgeons when planning surgery in challenging cases.

The 3dMD face (3dMD, Atlanta, GA) is a stereophotogrammetric system capable of 180-degree face captures (ear-to-ear) in less than 2 milliseconds. The procedure of image acquisition is neither demanding for the patient or the operator. It provides images of superior quality and facilitates calculation of anthropometric measurements, proportions, and volume changes.

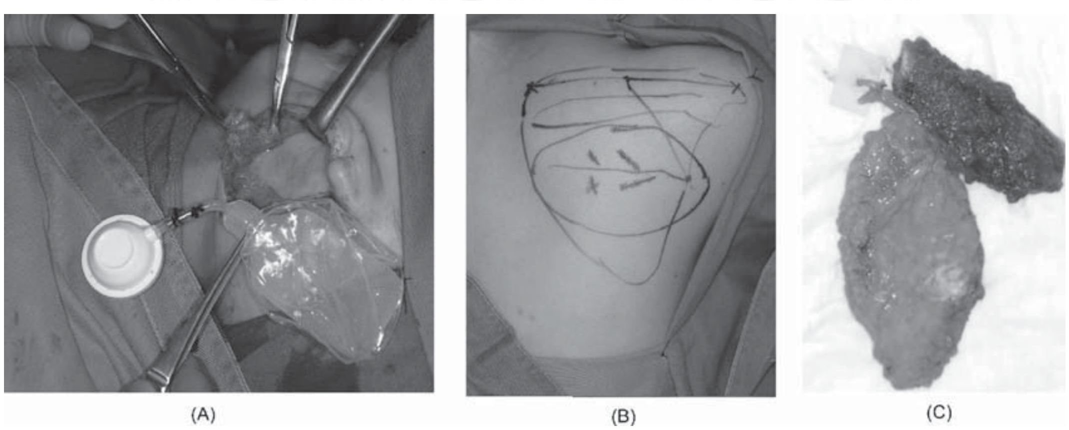

FIGURE 2. Operative views from the second surgery. **(A)** Expansion device at the time of its removal. **(B)** Dimensions of the flap marked on the donor site. **(C)** The harvested composite scapular free flap. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

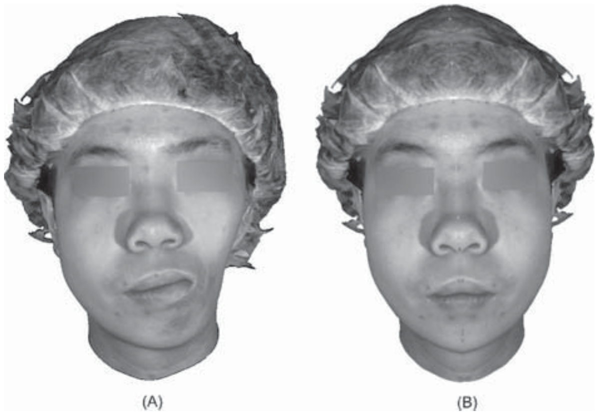

FIGURE 3. The process of creating the mirror image. **(A)** Preoperative image of the patient. **(B)** The new mirror image created based on the preoperative image of the right face. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

This system has been validated in terms of its accuracy and reliability.[9,10]

The aim of this report is to illustrate the applications of 3-D photogrammetry for surgical planning, monitoring treatment response, and longitudinal assessment of the volumetric changes in HFM.

CASE REPORT

A 19-year-old woman with a known history of HFM (Pruzansky type IIa) presented with left facial deficiency, maxillary canting, and mandibular asymmetry. Distraction osteogenesis had been performed during her childhood but the condition relapsed following growth.

A 3-staged surgical treatment comprising of: (1) bimaxillary osteotomies and implantation of a tissue expander, (2) soft tissue expansion, and (3) removal of the tissue expander plus transplantation of a vascularized scapular flap, was
F1 planned (Figure 1). Informed written consent was obtained from the patient.

Once the tissue expander (Mentor, Minneapolis, MN) was implanted during the initial surgery, saline was injected into the device on 3 consecutive occasions over a period of 4 weeks. Thereafter, a second surgery was performed to remove the expander and transplant the de-epithelialized osteocutaneous scapular flap (Figure
F2 2). Capsulectomy was not performed and the transplanted flap was secured with multiple subcutaneous 3/0 vicryl sutures, especially on the superior part of the developed pocket. A 3-D photogrammetry system was employed during treatment planning and postoperative follow-up.

METHODS

Image Acquisition. The patient's 3-D photographs were acquired with the "3dMD face" system while the patient was seated in a chair located at a set distance from the cameras.

Estimation of Facial Tissue Deficiency. A mirror image was created based on the unaffected side of the patent's preoperative 3-D photograph
(Figure 3). The resulting mirror image was then F3
superimposed on the original preoperative image.

The two 3-D photographs were manually approximated initially, overlaying them on top of each other. The right side of the face was

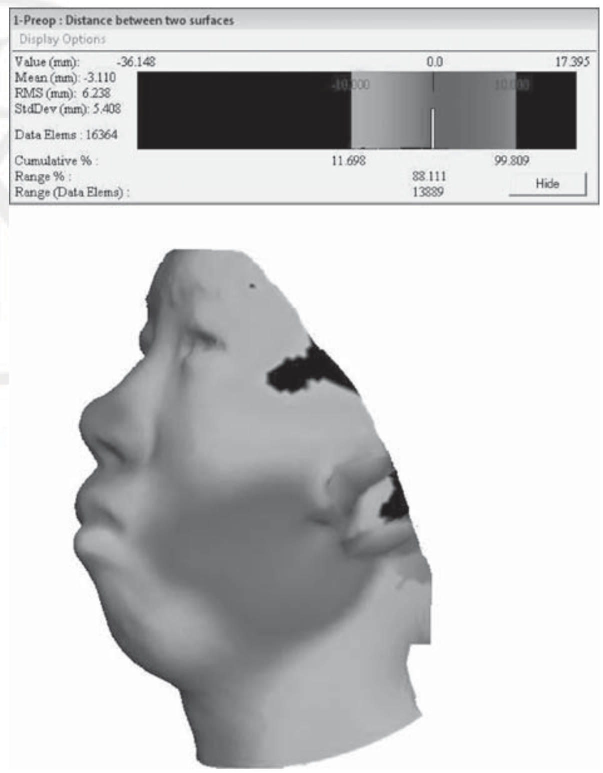

FIGURE 4. A color-millimetric map comparing the preoperative and mirrored images. The preoperative image has been used as the reference surface. The red end of the scale shows regions that are in front of the reference surface (ie, the most positive distances) and the green, the most negative. The black color indicates regions that do not fall within selected distance range (ie, +10 mm to -10 mm). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

FIGURE 5. The process of determining volumetric changes. **(A)** The images are registered with the template (blue) and subsequently converted to the wire-frame mode. As the template is clearly visible through the images, a region in line with the margins of the template can be cropped out from the superimposed images. **(B)** The cropped out areas from images corresponding to the different time intervals. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

used as a reference for the registration of images. Thereafter, the registration software was invoked and the aligning process occurred automatically. For each registration, a root mean square (RMS)[11] error below 0.5 mm was considered satisfactory.

The accuracy of superimposition was assessed with color-millimetric maps (Figure 4). These maps indicate ~~in a graphic format~~ the distance between the 2 superimposed surfaces. The green color indicates more negative values and the red color represents more positive values compared to the reference surface. The maximum and minimum distances for this color-coding scale were set at +10 mm and −10 mm, respectively. The facial region most deficient of tissue was delineated using this color-millimetric map and its dimensions were measured.

A template created from the preoperative image was used to crop out an area with a constant margin from the superimposed images. This template encompassed an area extending from the left infraorbital region to the lower border of the mandible (Figure 5). The volume differences between cropped out areas were calculated.

Estimation of Volumetric Changes. Volumetric changes during STE and subsequent to scapular flap transplantation were monitored by serial superimposition of 3-D images taken after each treatment session. The images were registered using the forehead as a reference.[12] Volumetric changes were calculated using the same template and method described previously (Figure 5). All measurements were performed twice by the same investigator, with a minimum of 48 hours elapsing between measurement sessions. Paired sample *t* test was performed to

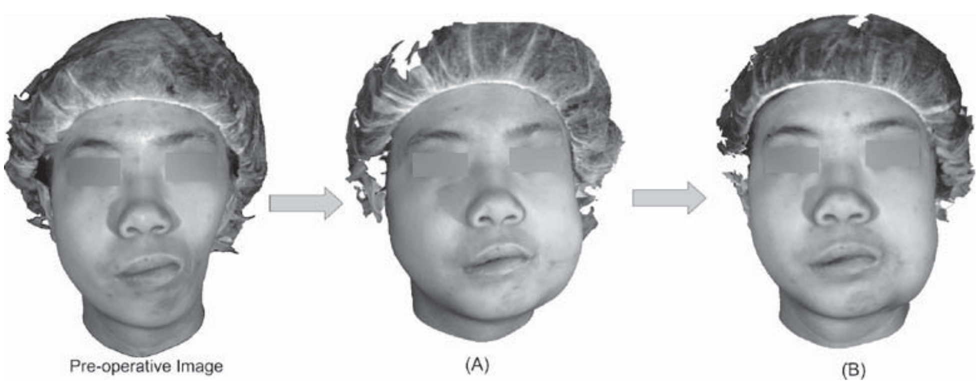

FIGURE 6. Postoperative changes at 1 month **(A)** and 1 year **(B)** after scapular flap transplantation. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

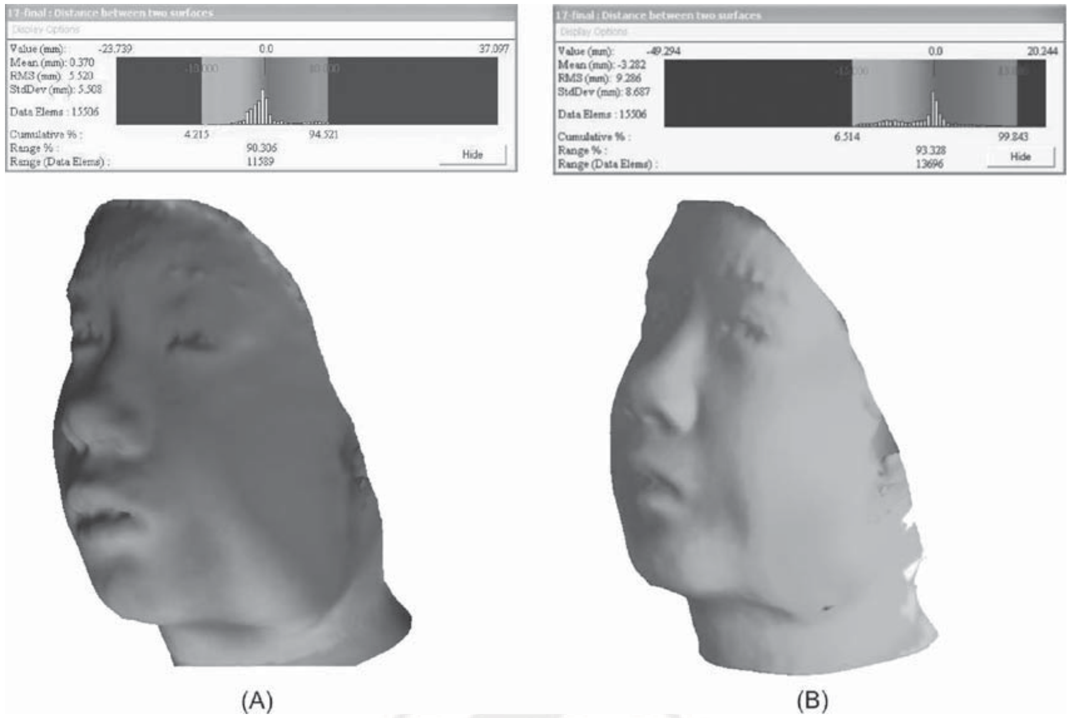

FIGURE 7. Color-millimetric map comparing the **(A)** 1-month (reference surface) and 12-month postoperative images **(B)** 12-month postoperative image (reference surface) and the preoperative mirror image. The red end of the scale shows regions that are in front of the reference surface (ie, the most positive distances) and the green shows the most negative. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

determine differences between values obtained at the 2 measurement sessions.

A prospective evaluation of the facial changes subsequent to scapular flap transplantation was conducted with 3-D photogrammetry at 1, 3, 6, and 12 months postoperatively (Figure 6 and Figure 7). F6 F7

RESULTS

There was no significant difference between the values calculated during the 2 separate measurement sessions ($p = .229$). Therefore, the mean of 2 measurements were used for subsequent calculations.

The Amount of Tissue Expansion Required. By comparing the preoperative image and the mirror image, the volume of tissue required to restore facial symmetry was estimated to be 16.41 cm^3. Overexpansion was performed because once the implant has been removed, stress relaxation shortens the predicted volume gain. At the moment, there are no clear guidelines on the amount of overexpansion required to overcome this volume loss. Therefore, we

Table 1. Volumetric changes at different time intervals.

Procedure	Time interval	Volume difference *(cm^3)* *	Volume change †
Tissue deficiency (*assessed using the mirror image*)	Preoperative	−16.41	Not applicable
Following initial surgery	1 week	+20.23	23.28%
Tissue expansion	4 weeks	+30.84	87.93%
Following scapular flap transplantation	1 month	+27.08	65.02%
	3 months	+23.81	45.09%
	6 months	+22.38	36.38%
	1 year	+21.43	30.59%

**The pre-operative image was used as the reference.*
†Compared to the initial tissue deficiency.

attempted to expand approximately twice the amount of the required volume. A total of 30.84 cm^3 of STE was achieved within a period of 4 weeks (Table 1).

Surface Dimensions of the Flap to be Harvested. With the color-millimetric map, the dimensions of the deficient region were determined as 7 cm × 4 cm (Figure 4). A scapular flap measuring 8 cm × 5 cm was transplanted to augment the facial deficiency (Figure 3). An overcorrection was performed to compensate for the potential shrinkage of the flap following surgery.

The Volume Changes Subsequent to Scapular Flap Transplantation. The volume changes observed at different time intervals are depicted in Table 1. The postsurgical shrinkage observed at the recipient site after 3, 6, and 12 months compared to the first month were 12.1%, 17.4%, 20.9%, respectively. Shrinkage was primarily seen in the posterosuperior aspect of the recipient site as evident in the color-millimetric map comparing the 1-month and 12-month postoperative images (Figure 7).

DISCUSSION

Although radiographs and CTs provide excellent hard tissue images, the information that can be derived from them pertaining to the soft tissue counterparts and their surface anatomy is limited. Clinicians have to rely solely on their visual judgment when assessing surface changes of facial soft tissues. Such visual assessments are highly subjective and do not provide any quantitative information. Furthermore, some abnormalities may be invisible to the naked eye but may be of significant diagnostic value.[13]

A 3-D photogrammetry provides the clinician a powerful tool for objectively evaluating and quantifying the facial soft tissues. It is also convenient for the patients because the number of recall visits can be minimized, as the 3-D images can be stored digitally, retrieved, and examined when the need arises. The images can be manipulated and viewed in a variety of angles in order to extract the maximum diagnostic information. Apart from volume estimation, the system has a number of applications which can be valuable for the cranio-maxillofacial surgeons. These include diagnosis of craniofacial anomalies, orthognathic surgical planning, and simulation of soft tissue changes.[14–18] Furthermore, the 3-D facial images could be fused with CT data to generate virtual craniofacial models.[19]

The mirror image provides a photo-realistic goal to the surgeons about the ideal outcomes. However, determination of the midline in the preoperative image may influence the quality of the resulting mirror image.[20] There may be some inter-examiner variability in selecting the facial midline in patients with asymmetry. This shortcoming was minimized in the present study by developing several mirror images and selecting the most appropriate image with the consent of all parties involved.

The influence of surgical and nonsurgical factors should be considered when evaluating the dimensional changes of the transplanted flap. Capsulectomy was not performed for this patient as the interval between the first and the second surgery (4 weeks) was too short for a mature capsule to develop. The flap was secured by several subcutaneous sutures. Despite these measures, sagging of the flap under the influence of gravity was noted (Figure 7). The volume loss observed in the superiolateral aspect may be partly due to this reason. The influence of the osseous component of the flap on volume changes also warrants some attention. It has been shown in previous studies that vascularized bone grafts undergo minimal resorption and are quite stable in the long-term.[21–23] Hence, the contribution of the osseous component of the flap on volume changes could be minimal.

Baseline information on the extent and degree of tissue deficiency is important when planning treatment for HFM as they indicate the dimensions of change required. With the color-millimetric maps, it was possible to localize the area that was most deficient of tissues in our patient. Such quantitative information aids the selection of the most appropriate tissue expander (Figure 2) suitable for the individual patient, as several devices of different sizes are available on the market.

A variety of methods including complex mathematical formula,[24–26] grid measurements,[27] and distances between anatomic landmarks[28] have been proposed for the quantification of STE. However, the majority of STE cases reported in the literature has been performed blindly without considering progressive volumetric changes.[29–31] Ji et al[32] has used a 3-D digitizer in the assessment of STE based on the surface area for scar revision in a burn victim. However, reliance on the surface area measurements may be inappropriate for evaluating volumetric changes. In their study, a single assessment of flap shrinkage was performed 12 days after surgery. Such a short-term assessment may not be a true indicator of shrinkage as hematoma and edema resulting from surgery may not have resolved completely by the twelfth postoperative day. In contrast, with information acquired from 3-D photogrammetry, it was possible to quantify the progressive volume changes up to 12 months postoperatively and further if necessary.

~~A~~ 3-D photogrammetry was utilized to estimate the dimensions of the surgical flap required from the donor site in our patient. Although the deformity was estimated to be 7 × 4 cm, an overcorrection was planned as non-innervated free flaps can undergo shrinkage with time. To compensate for such shrinkage, an 8 × 5 cm scapular flap was harvested. Only the surface dimensions of the flap were estimated. The thickness of the vascular flap cannot be controlled as it is largely determined by the fascial plane below the vascular pedicle and the subcutaneous fat layer above. Furthermore, reducing the flap thickness may compromise the perfusion and ultimately affect its survival.

Since there are no quantitative data in the scientific literature on the longitudinal dimensional changes of vascularized scapular flaps, the overcorrection was intentionally planned to compensate for eventual postsurgical shrinkage. It is evident from Table 1 that the flap has undergone considerable shrinkage throughout its postoperative course. At 12 months after the surgery, the overcorrection was only 5.02 cm^3. Nevertheless, further shrinkage after the first year cannot be ruled out. Thus, an overcorrection was preferred rather than leaving the deformity under-corrected as a result of shrinkage. This study demonstrates the need for data from a larger patient sample on the longitudinal dimensional changes following vascular flap transplantations in the maxillofacial region. Objective data on such longitudinal changes would help to achieve better aesthetic outcomes.

This article describes a new application of 3-D photogrammetry which has not been explored previously. We have used a clinical case to illustrate this technique. As with any new technology, the technique of volumetric estimations with photogrammetry may need time to mature and refine. Therefore, some of the methodologic challenges we faced could be overcome in the future. We hope that this technique will indeed take much of the guesswork out of surgical planning and provide a more objective assessment of the postsurgical changes. This is only a preliminary report and we plan to repeat this study with a larger sample size.

CONCLUSION

~~A~~ 3-D photogrammetry provides the surgeons with a noninvasive objective tool for planning surgery in HFM. It facilitates the identification of the extent and degree of tissue deficiency, selection of the tissue expander of appropriate dimensions, monitoring of volumetric changes during STE, and estimation of the tissue volume required from the donor site.

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