Breast Reconstruction Using Patients Own Tissue Based on CT Angiography and 3-D Surface Scanning

Jalil JALALI[1], Maximilian EDER[2], Stefan RAITH[2], Alexander VOLF[2], Fee von WALDENFELS[2], Laszlo KOVACS[2]
[1]Institute of Medical Engineering at the Technische Universität München (IMETUM), Garching, Germany
[2]Research Group CAPS (Computer Aided Plastic Surgery) – Department of Plastic Surgery and Hand Surgery, Klinikum rechts der Isar, Technische Universität München, Germany

Abstract
Breast reconstruction is mainly required for women who have had a breast to be removed (mastectomy) due to breast cancer. The aim of this surgery is to rebuild the natural shape of the breast mound in order to regain symmetry. The current state of the art in autologous breast reconstruction surgery is the transplantation of the patients' own soft tissue. One of the most popular methods is using soft tissue flaps from the abdominal region such as the deep inferior epigastric artery perforator flap (DIEP). Even though this technique has proven its applicability in reconstructive surgery with enough soft tissue supply at the donor region and a low rate of flap morbidity, one difficulty encountered during the operation planning is the decision of the size and the shape of the transplanted flap. In order to overcome this difficulty, and to provide planning aids for the surgeons, modern imaging technologies such as 3-D surface scanning and 3-D computed tomography angiography (3-D CTA) for volumetric imaging are used. In this study we introduce a computational approach to optimize the preoperative planning in autologous abdominal breast reconstruction using modern 3-D imaging techniques.

Keywords: 3-D surface scan, CT Angiography, breast reconstruction, breast cancer

1. Introduction
Breast reconstruction is a vital component of the overall treatment plan of breast cancer patients. Surgical breast reconstruction is not only desired by most patients, but is recommended by law in many countries [1]. The use of autologous tissue for breast reconstruction is considered to provide optimal results concerning natural appearance as well as similar mechanical properties as the normal breast tissue. One of the most popular methods is using the flap from the abdominal region such as the deep inferior epigastric artery perforator (DIEP) flap (see Figure 1). Even though this technique has proven its applicability in reconstructive surgery with enough soft tissue supply at the donor region and a low rate of flap morbidity, one difficulty encountered during the operation planning is the decision of the size and the shape of the transplanted free flap. In the past, 3-D computed tomography angiography (3-D CTA) was introduced as a clinical diagnostic tool to determine the vascular supply of the abdominal soft tissue area. 3-D CTA has proven to improve the surgical outcome and to shorten the operating times in abdominal free flap breast reconstruction [2]. In the presented study we expanded the diagnostic application of 3-D CTA to preoperative estimate the abdominal flap volume to be harvest and we introduce an algorithm based on 3-D surface imaging combined with 3-D CTA to optimize abdominal free flap breast reconstruction before surgery.

The process diagram is shown in Figure 2 and contains 5 major steps as followed:

1. Preoperative 3-D surface scanning of the chest wall area to create a 3-D polygonal breast model to determine the amount of missing breast volume and shape.
2. Preoperative 3-D CTA of the abdominal area to create a 3-D polygonal model of abdominal free flap regarding volume and flap dimensions.
3. Optimizing the size and shape of the harvested free flap considering the soft tissue deformations using finite element modeling.
4. Performing breast reconstruction operation using patients own soft tissue according to the planned flap dimensions in step 1-3.
5. Postoperative 3-D surface scanning of the breast area to evaluate the resulting breast symmetry after operation.

In the following we explain the steps 1, 2 and 5 in detail. Steps 3 and 4 are not covered in this study.

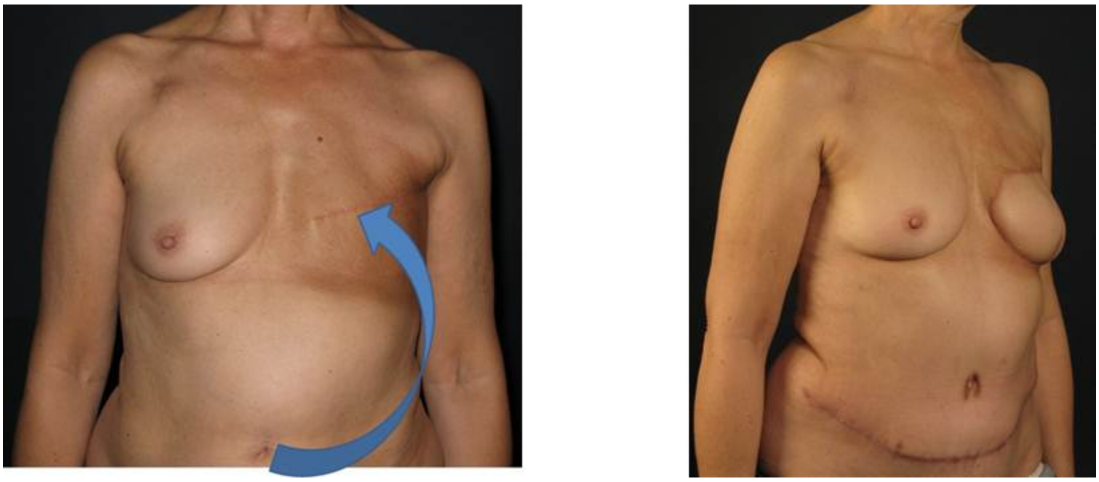

Fig. 1. Breast reconstruction using autologous tissue from the abdominal region: 2-D photography of the patient no. 1 included in the presented retrospective study before (left) and after breast reconstruction (right).

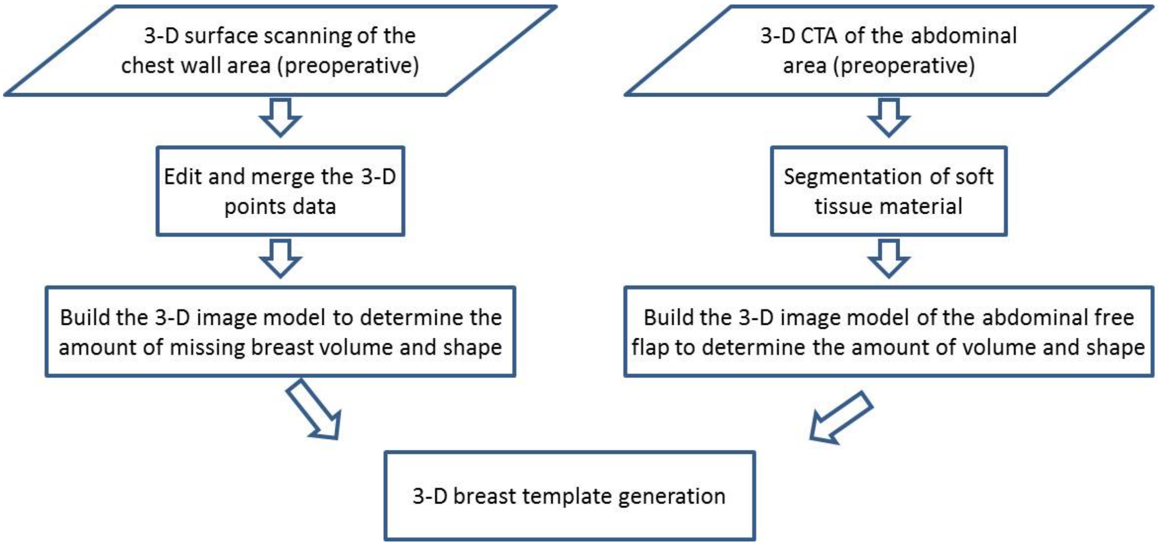

Fig. 2. Process diagram of 3-D body scanning application in Breast reconstruction using patients own tissue.

2. Computational approach

In order to explain the steps 1, 2 and 5 in the process diagram, three patients undergoing secondary breast reconstruction, i.e. breast reconstruction in a separate operation after total mastectomy were selected. All patients gave their written informed consent to take part in the study and the Declaration of Helsinki protocols were strictly followed.

2.1. 3-D Surface scanning of chest area (pre- and postoperative)

The 3-D imaging was performed using a surface scanner working with laser triangulation (Konica-Minolta Co., Ltd., Osaka, Japan). This system has largely shown its applicability to breast shape measurements in preliminary studies [2-5].The 3-D surface scans of the patients were performed in standing position on predefined markers on the ground under standardized lighting conditions (light intensity 350-400 lux) with a 10 degree upward angle of the scanner facing the participants +30, 0 and -30 degrees relative to the lens in standing position [3]. During acquisition the female patients were asked to hold their breath. The arms have to be put down the side at the height of the pelvis and the back was supported by a wall to guarantee reproducible data by minimizing potential artifacts due to movements [3-5]. The acquired single shots from different angles (see Figure 3) of each patient were converted into virtual 3-D models using appropriate software tools (Geomagic

Studio 12®, Raindrop Geomagic, Inc., NC, USA) as previously described [3-5]. All potential problems for later work with the data such as holes due to insufficiently clear scanning data or intersections between different acquisitions were fixed. In Figure 4 and 5 the surface model derived from 3-D laser scanning is given for all patients before and after the operation.

Fig. 3. Three surface scans acquired with the Konica Minolta Vivid 911 device. The upright positions have been varied in 30 degrees to both sides in order to get the patient's side viewed surface information as well. These single shots have to be merged in a manual procedure using the software tool Geomagic.

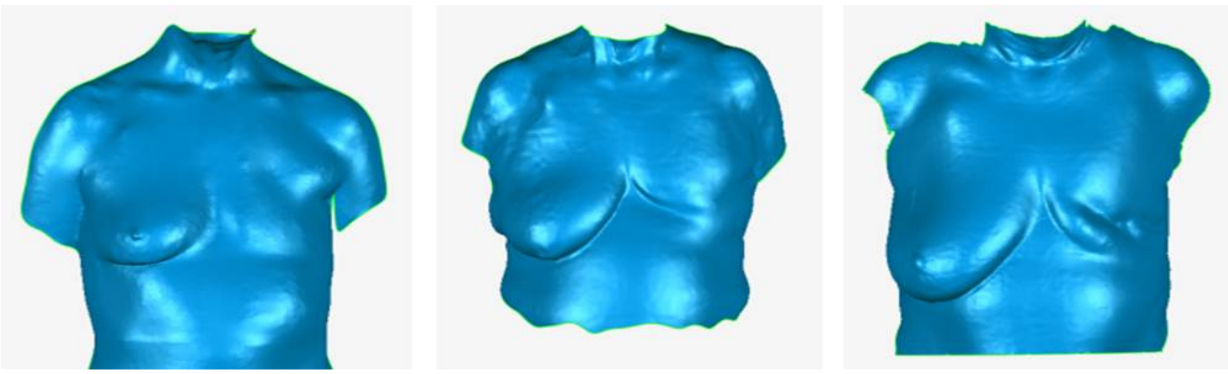

Fig. 4. Polygonal 3D models of the patients' chests before surgery.

Fig. 5. Polygonal 3D models of the patients' chests after surgery.

2.2. 3-D CTA of the abdominal area (preoperative)

The CTA images were used to reconstruct the soft tissue material at the abdominal area (see Figure 6). An intravenous line was placed in one appropriate arm vein; 70 ml of a contrast medium was injected containing 300 mg of iodine per milliliter (Ultravist 300®, Bayer HealthCare Pharmaceuticals, Berlin, Germany) at a rate of 4 ml/second. Bolus tracking was performed for the distal abdominal aorta and the image capturing was achieved from a minimum of 5 cm above the umbilicus to the pubic symphysis. The average radiation exposure was about 6-8 mSv at a dose-length product (DLP) value of 300 mGy-cm. The images were captured with a 64 multislice CT scanner (SOMATOM® Sensation, Siemens AG Medical Solutions, Erlangen, Germany) with 120 kV, 120 mAs and 0.5 mm slice thickness and saved in DICOM format. The soft tissue material were semi-automatically segmented and triangulated using the Mimics® 14.0 software (Materialise Inc., Leuven, Belgium)

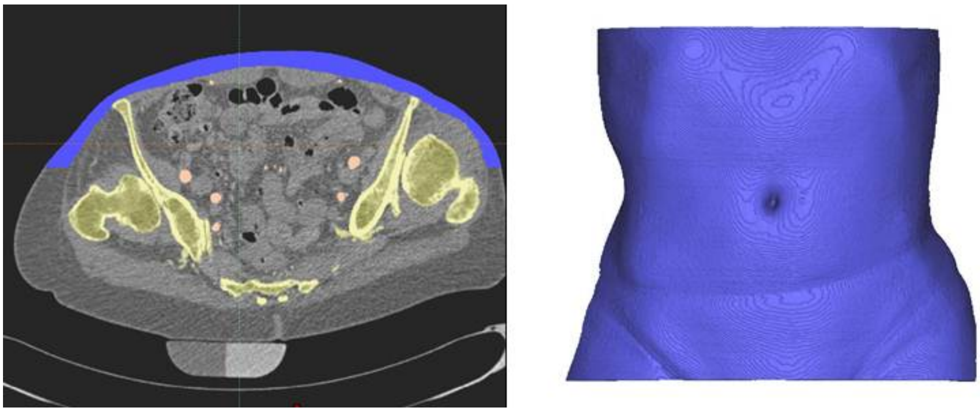

Figure- 6: Segmentation and triangulation of soft tissue material using CTA images

2.3. 3-D planning of flap volume and dimension planning

After creating the 3-D image model of the chest area from preoperative surface scan data, it is possible to measure the volume and dimensions of the missing part of the breast. The method for estimating the breast volume using 3D surface imaging has already presented and validated by Kovacs et al. [4]. In the case of delayed or secondary breast reconstruction the healthy contralateral breast is used as the reference volume to calculate the needed amount of abdominal soft tissue to match the to be reconstructed breast size. Therefore, it is necessary to define a mirror plane in the centre of the breast model and to mirror the healthy breast onto the removed breast area. 3-D compare between healthy and the missing breast is performed to precisely determine the missing part of the breast and to calculate the amount of breast volume needed for reconstruction (see Figure 7).

The dimensions of the missing part of the breast were measured based on the method presented by Tregaskiss et al. [6]. This approach is used to determine the flap design needed to match breast symmetry according to the contralateral healthy breast shape. According to specific measurements a breast shape template is generated which can be later projected onto the abdominal area to define the flap dimensions. The measurements are based on the projection of the mastectomy scar onto the normal breast. The following lengths were measured (see Figure 7, left)

- Infill to scar (a)
- Scar to MP (the point of maximal projection) (b)
- MP to IMF (infra-mammary fold) (c)
- Projected scar length, divided into medial (d) and lateral (e) components by the breast meridian
- IMF length, divided into medial (f) and lateral (g) components by the breast meridian

Tregaskiss et al. [6] presented a template technique for breast mound planning according to these measurements. Their method is based on the measurements on the body of the patients. It is obvious that such measurements and operations can be performed more precise and accurate with more comfort for the patient using a computerized 3-D model.

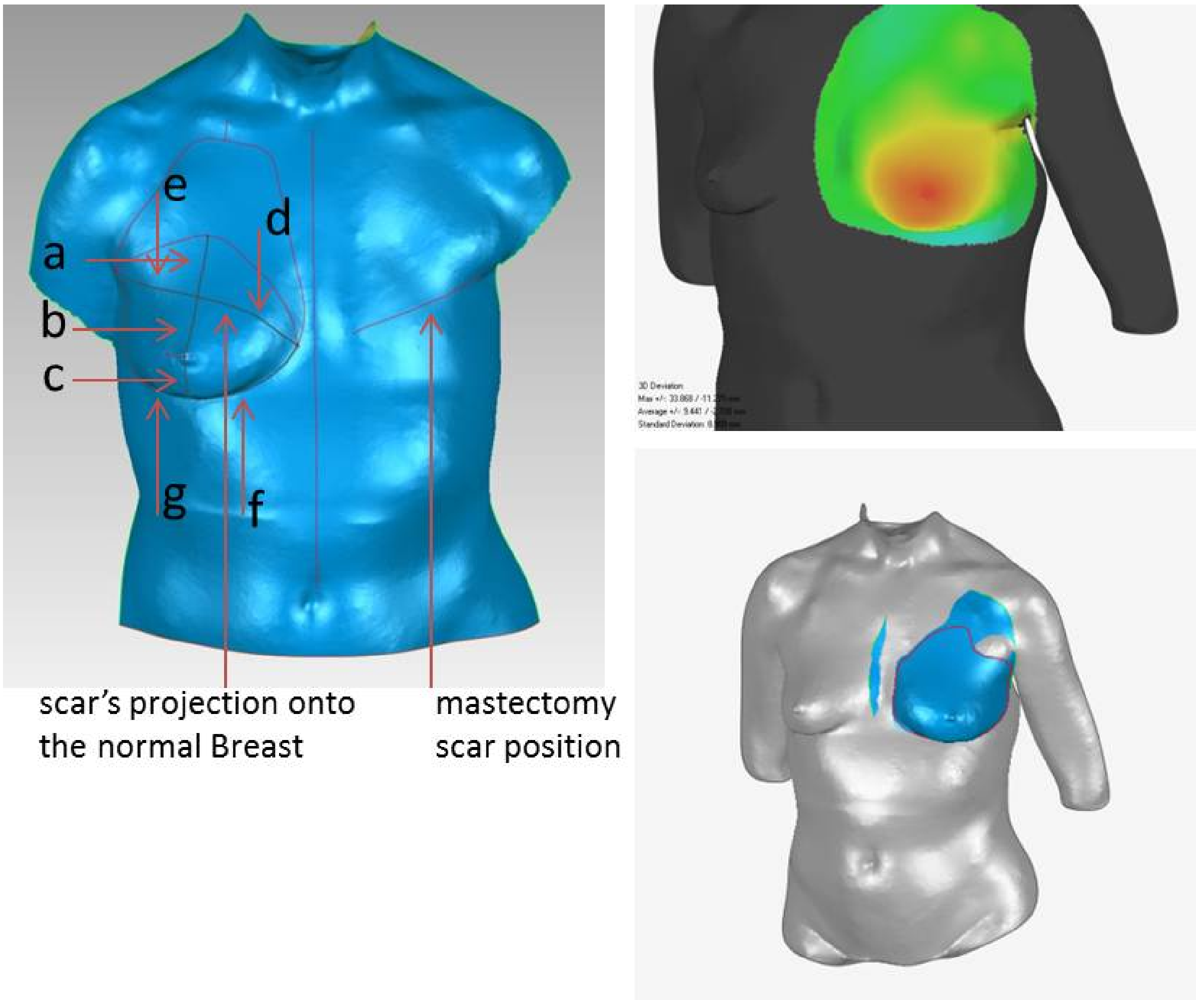

Fig. 7. 3-D image model of missing part of the breast
Measuring the dimensions of the breast to determine the flap dimensions to be harvested (left)
3-D compare between the healthy and the missing breast (above, right)
3-D image model of the missing breast volume according to the determined breast boundary gained from the performed 3-D compare (below, right).

2.4. 3-D flap model creation

After creating the 3-D image model of the abdominal soft tissue area from preoperative 3-D CTA data, it is possible to measure the flap volume and dimension. The method for estimating the flap volume has already presented and validated by Rosson et al. [2]. Figure 8 shows the amount of abdominal soft tissue which is usually harvested for abdominal flaps according to the surgeon's preoperative markings.

Projecting the missing part of the breast onto the abdominal area is a very useful application which supports the surgical preoperative planning. Figure 9 shows the created template model using the 3D surface imaging based measurements. By projecting the template of the missing breast parts onto the abdominal area, the flap volume according the designed flap outline can be calculated. A software tool was implemented for this purpose based on the described template technique by Tregaskiss et al. [6].

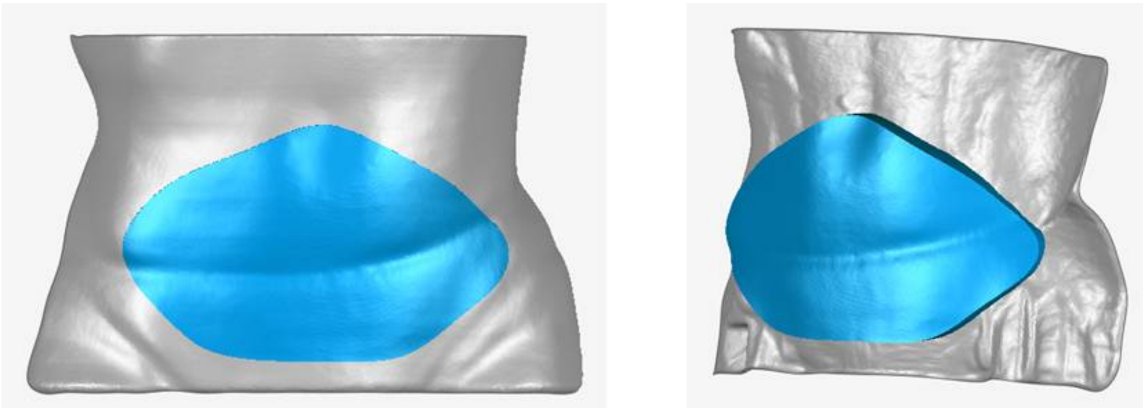

Fig. 8. 3-D image model of the abdominal free flap harvested in breast reconstruction.

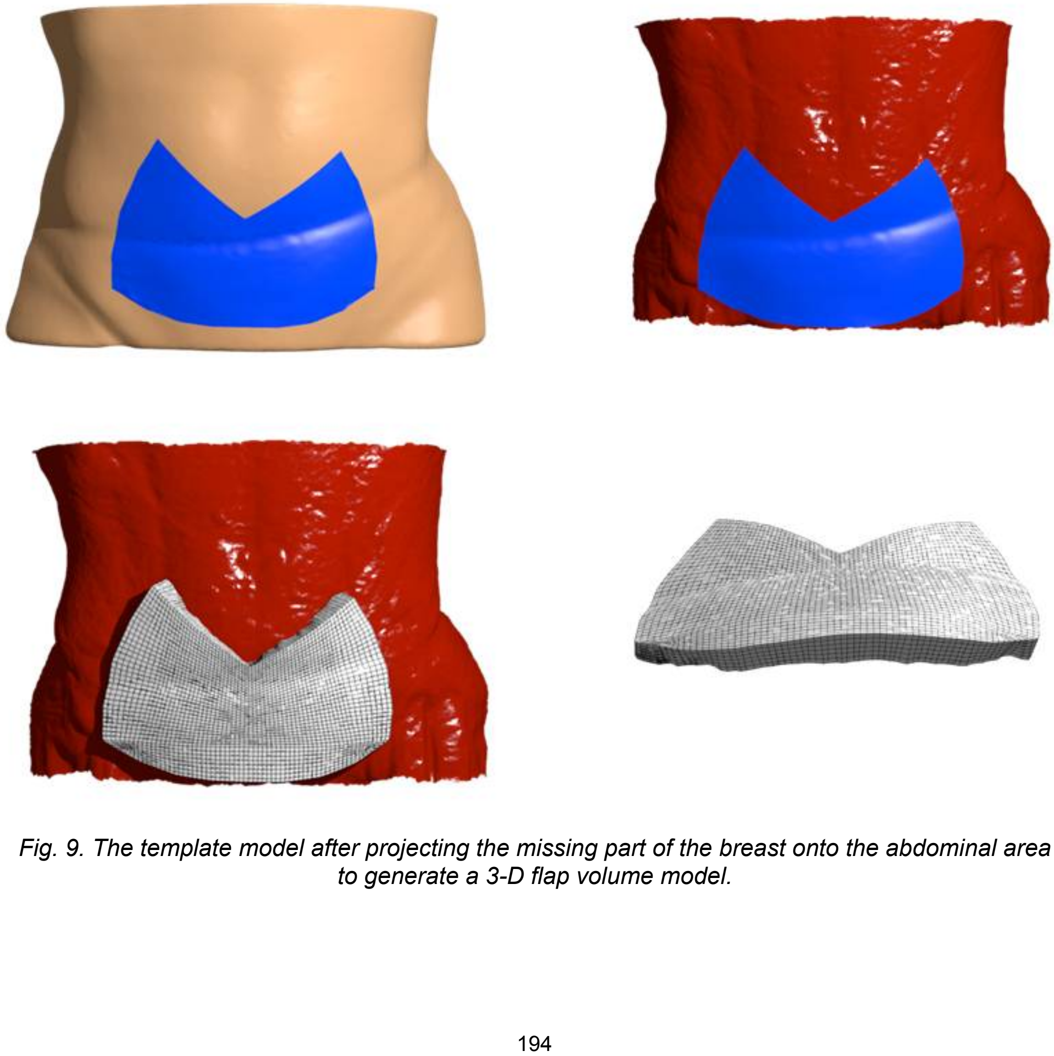

Fig. 9. The template model after projecting the missing part of the breast onto the abdominal area to generate a 3-D flap volume model.

3. Discussion and conclusion

A computational refinement of the well known template technique for delayed autologous abdominal breast reconstruction using modern 3-D imaging techniques was presented. The presented approach enables the surgeon to estimate the needed amount of abdominal tissue to reconstruct a symmetric breast matching volume and dimensions. The template technique for breast mound planning by Tregaskisset al. [6] can only take the approximate flap dimensions into account, neglecting the needed volume. The suggested method by Tregaskisset al. is based on the measurements on the patient's body surface according to the gained measurements of the contralateral breast. By mirroring the healthy breast onto the affected breast side, it is possible to take the existing amount of skin envelope into account to optimize flap design. In addition, by expanding 3-D CTA to preoperative flap volume calculation a more precise flap design is possible. Future clinical study must be performed to determine the accuracy of 3-D CTA based flap volume calculation, to analyze the clinical benefit compared to other existing planning methods and to implement the presented technique to surgical planning of immediate or primary breast reconstruction. Furthermore, the above described step 3 will be clinically validated in the near future. As the soft tissue undergo relevant intraoperative changes, the numerical simulation of these deformations are part of ongoing studies to optimize flap harvesting and trimming in breast reconstruction to achieve considerable breast symmetry.

The present study shows that modern 3-D imaging techniques may provide essential additional information to the surgeons at the stage of preoperative surgical planning. Especially the combination of 3-D surface scanning for flap design determination and 3-D CTA for flap volume estimations has demonstrated clinical potential.

References

1. Granzow J. W. et al., (2006): "Breast reconstruction with the deep inferior epigastric perforator flap: history and an update on current technique", J Plast Reconstr Aesthet Surg., Vlo.59, No.6, pp.571-579.
2. Rosson G. D. et al., (2011): "Three-dimensional computed tomographic angiography to predict weight and volume of deep inferior epigastric artery perforator flap for breast reconstruction", Microsurgery, Vol.31, No.7, pp. 510-516.
3. Kovacs L. et al., (2006): "Optimisation of the three-dimensional imaging of the breast region with 3D laser scanners", Ann Plast Surg., Vol56, pp.229 –236.
4. Kovacs L. R et al.,(2007): "Comparison between breast volume measurement using 3D surface imaging and classical techniques", The Breast, Vol. 16, No.2, pp.137-145
5. Eder M. et al., (2011): "Objective breast symmetry evaluation using 3-D surface imaging", The Breast, Vol. 21, No.2, pp. 152-158.
6. Tregaskiss A. et al., (2012): "The template technique for breast mound planning when using abdominal flaps for breast reconstruction", The Breast, 2012 Mar 8. [Epub ahead of print]