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A Review of Objective Measurement of Flap Volume in Reconstructive Surgery

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Background: The utility and efficacy of 3-dimensional representation have been proven in bony reconstruction; however, its role in soft-tissue reconstruction remains limited. There is currently no reliable gold standard to objectively measure flap volume. This systematic review aims to summarize the available techniques used to objectively measure flap volume in reconstructive surgery.
Methods: A systematic literature search was performed to identify all relevant articles describing objective techniques to quantify flap volume. The search included published articles in 3 electronic databases—Ovid MEDLINE, EMBASE, and PubMed.
Results: A total of 16 studies were included. Flap volume was calculated using the following techniques: magnetic resonance imaging, computed tomography, 3-dimensional imaging and modeling, material templates, ultrasound, and weighing scales. Techniques and results of the included studies are summarized.
Conclusions: This systematic review provides a summary of various published techniques for objective pre- or intraoperative quantification of flap volume in reconstructive surgery. The preliminary results from this review are promising, and we believe that 3-dimensional representation and objective quantification is the future of reconstructive flap surgery. More studies are needed to study the clinical relevancy and impact of the various imaging modalities reviewed and to develop automated volumetric measurement technology with improved accuracy, efficacy, and reproducibility. *(Plast Reconstr Surg Glob Open 2018;6:e1752; doi: 10.1097/GOX.0000000000001752; Published online 15 May 2018.)*

INTRODUCTION

Reconstruction of soft-tissue defects with local or distant tissue transfer is an important tool for plastic surgeons. Although the volume of tissue transferred is often subjectively measured, notably in autologous breast reconstruction, breast symmetry plays an important role in patient satisfaction and in the quality of life of patients who undergo postmastectomy reconstructive surgery. It has been demonstrated that patient-perceived breast appearance is significantly associated with quality of life psychosocial outcomes.[1] Women with pronounced breast asymmetry are more likely to experience depressive symptoms, stigmatization related to their surgery, and perceived worse health after treatment of their breast cancer.[1] Accurate volume determination is also essential in controlling donor-site morbidity. Harvesting the minimally required flap volume can reduce donor-site morbidity and increase postoperative patient quality of life.

Computer-assisted 3-dimensional and volumetric representation has gained tremendous popularity in craniomaxillofacial surgery and has aided in mandibular reconstruction, Lefort 1 maxillary advancement, cranial defect repair, and orbital wall/floor reconstruction to name a few.[2–6] The utility and efficacy of 3-dimensional representation have been proven in bony reconstruction; however, its role in soft-tissue reconstruction remains limited. When designing and harvesting a flap, there is no

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practical way of measuring volume. Surgeons currently estimate the required volume by subjective tactile sensation and visual estimation. Objective measurement of the flap pre- and/or intraoperatively may be a useful adjunct to the artistic aspect of reconstructive surgery. Potential benefits include improving symmetry, increasing patient satisfaction, and decreasing revision rates. This systematic review aims to report described techniques used to objectively measure flap volume.

METHODS

A search of the Ovid MEDLINE, EMBASE, and PubMed databases was performed from database establishment to August 1, 2017. Different spellings and versions of the following key words were searched: [("quantitative" or "objective" or "measurement") and ("flaps" or "microsurgery" or "reconstruction" or "autologous") and "volume"]. Citations were limited to human studies published in the English language. Studies were included if objective flap volume measurement was described in the context of flap reconstruction. Cadaver studies and animal studies were excluded. Two independent reviewers assessed the eligibility of the studies using the same systematic inclusion/exclusion criteria. A total of 9,212 studies were identified and further narrowed to 316 potentially eligible studies after primary review. Studies were selected based on the relevance of the title and/or abstract of retrieved records (Fig. 1). The initial screen excluded studies with evidently irrelevant titles or abstracts. If content was unclear in the initial screen based on abstract review, a formal article review was undertaken. Potentially eligible studies were further reviewed, leading to a total of 16 eligible studies. Studies were also collected from an extensive manual Internet search and from the reference list of relevant articles, yielding an additional 4 studies. The systematic review followed the guidelines provided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement.[7]

RESULTS

A total of 16 studies were included in this review (Table 1). Flap volume was calculated using the following techniques: magnetic resonance imaging,[8] computed tomography (CT),[9–12] 3-dimensional virtual modeling or material templates,[13–19] ultrasound (US),[20] and weighing scales.[21–23] The results of each study are categorized by imaging modality used and described below. Table 2 provides a summary of the advantages, disadvantages, and cost.

Magnetic Resonance

The radiation sparing and high-quality images of magnetic resonance angiography (MRA) make it a valuable imaging technique, particularly for soft tissues such as the breast. Currently, only 1 study has reported the use of MRA for preoperative volume estimation of various free flaps including deep inferior epigastric perforators, posterior thigh, and gluteal artery perforator flaps in 102 patients.[8] Predetermined landmarks were used for virtually estimated flap volumes, which closely correlated to surgically harvested flap volumes (r = 0.97). Determining flap volume can be performed manually or with an automated reporting software based on standard flap territory. Moreover, the addition of gadolinium contrast has the advantage of simultaneously mapping perforator arteries. Although MRA appears to be accurate and safe for flap volume estimation, restricted access to this costly imaging modality limits its widespread applicability.

CT

The use of CT for objective free flap volume measurement is a relatively new concept. Most studies describing this technique were performed in the past decade, with the oldest study published in 2005.[13] A multitude of preoperative volume estimation techniques have been described using enhanced CT and CT angiography (CTA), primarily in breast and craniofacial reconstruction.[9–12]

CTA has been proven to be an accurate method in preoperatively estimating flap volume.[9–11] Preoperative markings and radiopaque markers have been described in guiding virtual volume estimation.[9] Several authors have demonstrated that preoperative CT-estimated flap volumes closely correlate to intraoperative harvested flaps (Pearson correlation coefficient = 0.88–0.99).[9–12] Moreover, in breast reconstruction, premastectomy or contralateral breast volume (in delayed reconstruction) can be measured to adjust abdominal flap volume.[9–11] This becomes challenging when a concomitant balancing procedure, such as a reduction mammaplasty, is planned on the contralateral breast. Preoperative volumetric measurement by means of virtual surgical planning, commonly practiced in craniomaxillofacial surgery,[2–6] will play an important role in these patients.

In addition to simple volume calculation, CT results have been used to create virtual 3D models of desired structures. In a cohort of patients undergoing craniofacial reconstruction for hemifacial atrophy or following tumor resection, preoperative enhanced CT was performed before surgery and a 3D computer model of the patient's face was constructed.[12] A mirror image of the unaffected side was constructed and used as a guide for reconstruction. The preoperative evaluation of the 3D computer model allowed for the determination of the ideal size, shape, and position of the desired flap. A free anterolateral thigh flap was subsequently harvested and deepithelialized according to the 3D model dimensions and transferred to a subcutaneous pocket.

Compared with MRI, CT has the advantage of generally being more easily accessible and cost-effective. Exposure to ionizing radiation remains the main disadvantage. Like MRA, CT with contrast allows for the simultaneous mapping of perforator vessel anatomy. Preoperative CT has been proven to reduce morbidity and time in perforator flap reconstruction,[24] and its efficacy in flap volume estimation for breast reconstruction has been widely reported.

US

US is a widely available, cost-effective, nonionizing and portable imaging modality. US has good penetration of soft tissues and can be used to measure adipose tissue thick-

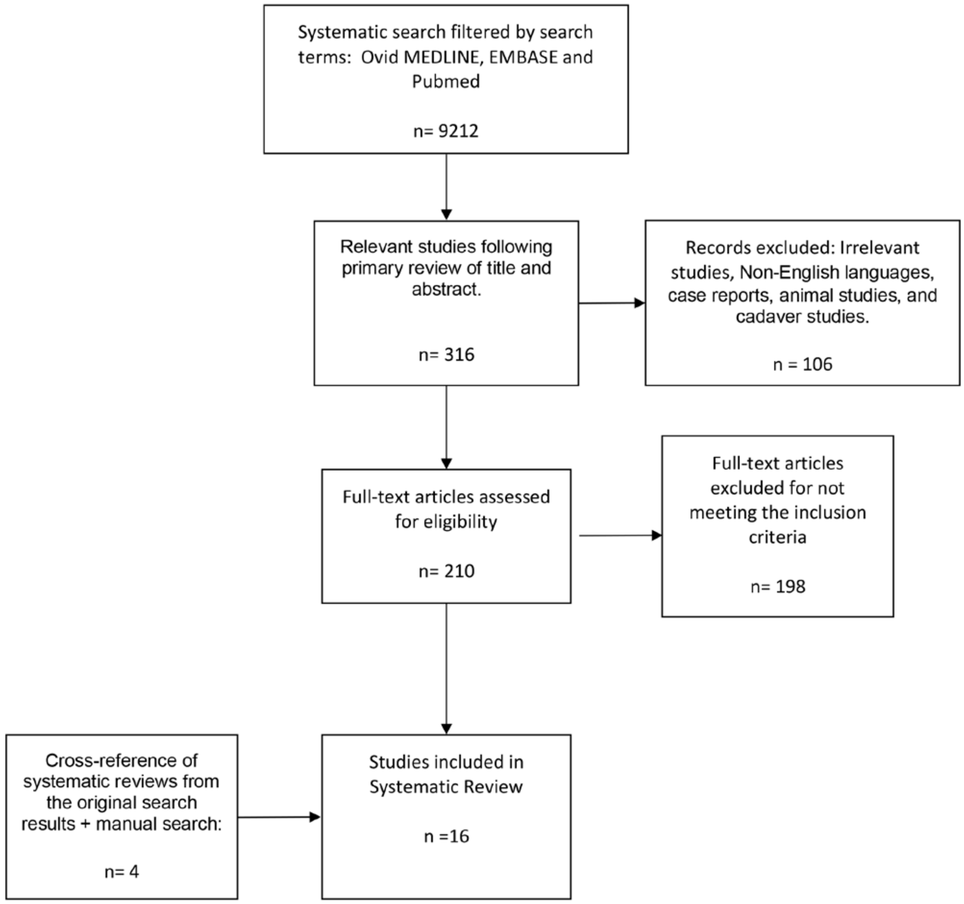

Fig. 1. Flow diagram of systematic review study selection and eligibility.

ness; however, its role in measuring flap volume is limited to date. One study reported its use for preoperative transverse rectus abdominis myocutaneous (TRAM) flap volume estimation in breast reconstruction.[20] TRAM flap area was designed on the patient's abdomen, based on approximate breast volume determined by manual examination. US was used to measure tissue thickness at various zones of the proposed flap site. These depth measurements were used to estimate volume (by multiplying area and volume). To confirm the reliability of this technique, excised flap volume was measured intraoperatively by water-displacement before detaching it from its pedicle and was modeled to match the desired flap volume. Mastectomy volume measured by water-displacement was used to further adjust flap volume. The authors found a strong correlation between US-estimated and measured flap volumes ($r = 0.9258$).

Breast volume assessment using ultrasound is limited somewhat by the convex breast shape and heterogeneous density. More global limitations of US imaging is the narrow field of view in a typical ultrasonic probe making it difficult to assess the volume of large areas (eg, an abdomen or thigh). Moreover, US imaging is operator dependent, where the scanned image can vary significantly depending on tissue pressure or probe angulation. As such, there is potential for US as a modality for assessing flap volumes but significant technical advances are still required.

Three-dimensional Modeling and Material Templates

Three-dimensional laser scanners are an accurate tool to determine a structure's dimensions and volume. The technology has been successfully used in breast and craniofacial reconstruction.[13–15,17,18] The low cost and portability of the scanner is unique compared with other imaging techniques such as MRI and CT. Although radiographs and CTs provide pertinent tissue information, their ability to analyze surface anatomy is limited compared with 3D photogrammetry. Before this technology, physical templates of craniofacial defects have been described using wax or alginate molds.[16,19] These molds can be used to guide intraoperative flap volume and design. The development of virtual planning with 3-dimensional imaging has led to more practical methods of measuring defect volume.[13–15,17,18]

Due to its portability and small size, laser scanners can be used intraoperatively. One study described the use of intraoperative 3D scans for autologous breast reconstruction with TRAM flaps.[13] After mastectomy, scans of the reconstructed and contralateral breasts were performed and compared. Corrections were made by excising excess flap tissue until acceptable volume differences and a symmetrical appearance wass established. Such a technique can be highly useful for less experienced surgeons.

Three-dimensional laser imaging has also been used to create a mold for determining flap volume.[14,15] In delayed

Table 1. Summary of Various Published Techniques for Objective Pre- or Intraoperative Quantification of Flap Volume in Reconstructive Surgery

Study	Design	N (Total)	Specialty	Method of Flap Volume Quantification
Ahcan et al.[14]	Cohort: prospective	12	Breast	3D imaging and modeling
Chang et al.[22]	Cohort: prospective	28	Breast	Scales
Eder et al.[11]	Cohort: retrospective	40	Breast	CTA
Jayaratne et al.[18]	Case report	1	Craniofacial	3D imaging and modeling
Kim et al.[10]	Cohort: prospective	71	Breast	CTA
Kubo et al.[23]	Cohort: retrospective	21	Breast	Scales
Lange et al.[8]	Cohort: retrospective	102	Breast	MRA
Minn et al.[20]	Cohort: prospective	37	Breast	US
Pribaz et al.[16]	Cohort: prospective	19	Craniofacial	Material template
Rosson et al.[9]	Cohort: prospective	15	Breast	CTA
Shimizu et al.[12]	Cohort: prospective	3	Craniofacial	CT
Tanabe et al.[13]	Case report	1	Breast	3D imaging and modeling
Tomita et al.[15]	Cohort: prospective	11	Breast	3D imaging
Shamoun and Hartrampf[21]	Case report	2	Breast	Scales
Ji et al.[17]	Case report	1	Craniofacial	3D imaging and modeling
Kadam et al.[19]	Cohort: retrospective	8	Craniofacial	Material template

Table 2. Advantages, Disadvantages, and Cost of Various Flap Quantification Methods

MRI	Advantages	No ionizing radiation
		High quality images, particularly of soft tissue (superior to CT and US)
		Possibility of including gadolinium for perforator artery mapping
		Existing software to design virtual 3D models from MRI data
	Disadvantages	Restricted access
		Costly
	Cost*	$1,400 CAD/scan[31,32]
CT	Advantages	Good quality images, allowing accurate estimation of flap volumes
		Allows perforator artery mapping with contrast
		Existing software to design virtual 3D models from CT scan data
		Easily accessible
		Cost-effective
	Disadvantages	Exposure to ionizing radiation
	Cost*	$550 CAD/scan[33]
US	Advantages	Portable
		Widely available
		Cost-effective
		Good penetration of soft tissue
	Disadvantages	Probes have a narrow field of view, increasing difficulty to assess volumes of large areas
		Operator dependent; requires skilled personnel
	Cost*	$70 CAD/scan[34]
3D Laser scan	Advantages	Accurate measurements of a structure's dimensions
		High-quality analysis of surface anatomy
		Existing software to design virtual 3D models from laser scanner data
		Cost-effective
		Portable
	Disadvantages	Inability to assess tissue and structures deeper than skin
	Cost*	$20,000–100,000 USD/machine[35]
		Minimal expense/scan
Scales	Advantages	Highly portable due to small size; can be brought into the operating room
		Cost-effective
		Easy to use; operator-independent
	Disadvantages	Only measures tissue weight
	Cost*	Minimal expense/machine and use

*Costs are variable between institutions and countries. CAD, Canadian dollar; USD, United States dollar.

breast reconstruction, the use of a cast of the unaffected breast has been described as a template for msTRAM and deep inferior epigastric perforator flap reconstruction. The excised flap was placed into the cast, which provided surgeons with the target flap volume and orientation. Excess flap volume was excised before flap anastomosis. Intraoperative use of the cast showed reduction in surgery time and improved symmetry.

Laser scanning has also been used to monitor tissue expansion. One study used 3D digital color scanning of a facial skin graft contracture induced defect.[17] Expanders were placed in preparation for cervicofacial and scalp flaps. The expanders were progressively inflated until the expanded area reached a similar value to that of the facial defect, confirming the availability of adequate flap area to over the defect of the excised facial scar. The contralateral side of the face can also be used as a guide to determine adequate expansion volume.[18]

Scales

The weight of 1 g of abdominal adipose tissue has an approximate volume of 1 cm^3.[9–11,25–28] Under this assumption, scales can be used intraoperatively to convert the weight of abdominal flaps to corresponding volumes. The size, portability, low cost, and ease of use of scales are incomparable with any other volume measuring technique. The disadvantage of this technique is that over- or underestimation of flap volume can occur. Subcutaneous adipose tissue density varies from 0.925 ml/g to 1.32 ml/g[9-11,25-28]. Moreover, unlike previously described techniques, flap shaping and molding is not possible.

Scales have been used to estimate flap volume and improve postoperative symmetry in breast reconstruction. Excised mastectomy specimens can be weighed and raised flaps trimmed to match the mastectomy specimen's weight.[21,22] This technique has proven to be quick and can help improve postoperative breast symmetry.[21,22] Scales have also been used in conjunction with body mass index measurements to construct an equation aimed at estimating the required latissimus dorsi flap weight based on a patients' body mass index or body weight.[23]

Limitations and Future Direction

Volumetric measurement is only 1 aspect of computer-assisted 3-dimensional representation. For example, with more complex 3-dimensional procedures such as breast reconstruction, the skin envelope, pocket, projection, and breast footprint are also critical variables and must be accounted for. There is no guarantee of a symmetric outcome by simply estimating the volume in breast reconstruction, for example with a scale. Three-dimensional imaging is a promising modality for breast reconstruction due to its relatively low cost, excellent topographical surface measurements, and its proven utility in reduction mammaplasty and alloplastic breast reconstruction.[29,30] The current review focuses on adipose tissue measurement; however, practical imaging modalities must also discriminate between various tissues, such as muscle and skin. Future advancements in the field must focus on overcoming the above-mentioned limitations. Future studies must also evaluate the impact of objective quantification in reconstructive surgery on symmetry, patient satisfaction, procedure length, and cost-effectiveness.

CONCLUSIONS

This systematic review provides a summary of various published techniques for objective pre- or intraoperative quantification of flap volume in reconstructive surgery. Potential benefits include improved symmetry, increased patient satisfaction, decreased procedure length, and revision rates when compared with subjective measurements. Potential risks may include exposure to ionizing radiation (eg, CT scan) and increased cost or time. The preliminary results from this review are promising, and we believe that 3-dimensional representation and objective quantification is the future of reconstructive flap surgery. More studies are needed to study the clinical relevancy and impact of the various imaging modalities reviewed and to develop automated volumetric measurement technology with improved accuracy, efficacy, and reproducibility.

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