Ultrasound and Plastic Surgery

Clinical Applications of the Newest Technology

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Background: Color Doppler ultrasound (CDUS) has not been routinely used in plastic and reconstructive surgery. Barriers to use have included large, cumbersome equipment, low-definition images, cost, and availability. In addition, programs in plastic surgery have not included training with ultrasound (US); thus, many current-day practitioners are unfamiliar with and reluctant to use this technology. Nevertheless, recent studies have demonstrated the utility of US in surgical planning. With the miniaturization, clearer imaging, and decreased costs of the latest US technology, previous barriers to use have largely been eliminated.

Methods: Fifty-six patients scheduled for either reconstructive or aesthetic surgery were evaluated preoperatively and/or intraoperatively by a single surgeon with the linear 12-4 probe of a Philips Lumify CDUS device (Philips, Reedsville, Penn). For patients undergoing flap reconstruction, potential donor sites were imaged in order to locate the largest perforator. For patients undergoing abdominal procedures, intraoperative visualization of the abdominal muscular layers was used for the delivery of anesthesia during transversus abdominis plane block. Lastly, the superficial fascial system (SFS) was subjectively evaluated in all preoperative patients.

Results: For flap reconstruction, 11 patients were preoperatively examined with CDUS in order to locate the largest perforators prior to perforator flap reconstruction. Flaps studied included the deep inferior epigastric perforator, anterolateral thigh, tensor fascia lata, thoracodorsal artery perforator, superior gluteal artery perforator, and the gracilis musculocutaneous. Color Doppler ultrasound findings were confirmed intraoperatively for all cases (100%). In 2 (18.2%) of 11 cases, CDUS identified perforators not detected by computed tomography angiography. Twenty-five patients undergoing either abdominoplasty or deep inferior epigastric perforator flap reconstruction had successful intraoperative visualization of the abdominal wall muscular layers, thus allowing administration of transversus abdominis plane blocks by the operating surgeon. Twenty patients undergoing body contouring surgery had preoperative visualization of the SFS. The SFS was found to be varied not only among different patients but also within individual patients.

Conclusions: The newest, miniaturized CDUS technology has a variety of applications that may improve patient outcomes and experience in plastic surgery. Our observations require further investigation to quantify the perceived benefits of this new technology.

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Plastic surgery is a dynamic field that evolves in tandem with the rapid advancement of medical technology. For example, following the discovery of the x-ray, radical improvements to imaging modalities utilizing ionizing radiation (eg, computed tomography [CT], CT angiography [CTA], 3-dimensional [3D] CT reconstruction) have greatly influenced the safety and effectiveness of our patient management.[1–6] However, imaging modalities that utilize ionizing radiation have significant limitations and risks. Computed tomography angiography—the current gold standard for preoperative perforator flap imaging—provides exquisite anatomical detail, yet it exposes the patient to the harmful effects of radiation. In addition, it is not always possible to utilize CTA because of metallic hardware image scattering or contrast allergy or in patients with renal injury/insufficiency because of nephrotoxicity. Finally, the anatomy within 2-dimensional CTA imaging can be difficult to correlate to surface anatomy of a rounded, 3D structure (eg, buttock, thigh). Therefore, there remains a need for an alternative, effective imaging modality with limited risks/limitations.

Previous studies have sought ultrasound (US) technology as a viable alternative; however, many of these early studies failed to demonstrate significant clinical benefit and/or reliability as they were performed using US equipment with limited technological capabilities in comparison to modern technology.[6–9] More recent studies utilizing US of recent technological advancements have already demonstrated the utility of US for a variety of applications. These applications include perforator flap planning, guidance during administration of transversus abdominis plane (TAP) blocks, and detection of seromas/hematomas among others.[10–14]

Despite these recent findings, US has yet to be routinely incorporated into the practice of a plastic surgeon. Previous barriers to use included lack of familiarity, cost, cumbersome equipment, and the need for specialized personnel for the collection and interpretation of imaging. However, with the introduction of the latest-generation US equipment, these barriers have largely been eliminated by increased clarity of images, accessibility, decreased costs, user-friendly interface, and portability (Fig. 1).

Our study assessed the utility of color Doppler ultrasound (CDUS) in preoperative surgical planning for a variety of reconstructive and aesthetic cases. Importantly, all imaging was able to be performed independently by a surgeon with no prior CDUS experience. This article reviews 3 potential applications of CDUS for plastic and reconstructive surgery that directly impacts surgical planning and patient experience. To the best of our knowledge, there are no plastic surgery studies with the newest generation of CDUS technology; therefore, our article aims to elucidate the role that a tablet-sized, CDUS device may have as a reliable diagnostic and therapeutic tool in plastic surgery.

METHODS

Perforator Vessel Identification and Mapping

All patients undergoing perforator flap reconstruction were examined using the Philips Lumify 12-4 linear probe (Philips, Reedsville, Penn) on the soft tissue setting with color flow imaging. Examinations were performed either during an existing preoperative appointment or in the preoperative bay immediately prior to surgery. Flaps studied included the deep inferior epigastric perforator (DIEP), anterolateral thigh (ALT), tensor fascia lata (TFL), thoracodorsal artery perforator (T-DAP), superior gluteal artery perforator (S-GAP), and the gracilis musculocutaneous

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FIGURE 1. Demonstration of the portability and user-friendly interface of the Philips Lumify 12-4 linear probe when connected to a smart tablet.

(Table 1). When mirror-image flaps were available on opposite sides of the body, potential donor sites were examined to ascertain the flap with the largest perforator. Comparisons were made with conventional CTA when available. Because of the high sensitivity of the Philips equipment, all major perforators were initially located on the skin surface with a handheld, pencil Doppler prior to their characterization with CDUS.

Transversus Abdominis Plane Anesthetic Blocks

Four-quadrant TAP blocks were used for all patients undergoing either abdominoplasty or DIEP breast reconstruction. The Lumify 12-4 probe on the soft tissue setting was placed in a sterile sheath and then placed directly onto the anterior abdominal wall musculature where the 3 muscular layers could be clearly visualized. Under direct US visualization, the TAP plane between the internal oblique and transversus abdominis muscles was accessed through the subcostal (2 cm below the costal margin in the anterior axillary line) and iliohypogastric approaches (1 cm above the anterior superior iliac spine in the anterior axillary line) using a 22-gauge spinal needle (Fig. 2). A test dose of bupivacaine was then placed under US guidance to ensure proper anesthetic placement (Fig. 2). A total of 17.5 mL of 266 mg (20 mL) liposomal bupivacaine plus 125 mg (50 mL) 0.25% bupivacaine was used for each injection. This method was performed in all 4 quadrants (subcostal and iliohypogastric, bilaterally).

Superficial Fascial System Characteristics

For all patients undergoing body contouring, the US device on the soft tissue setting was used to subjectively evaluate the presence and quality of the superficial fascial system (SFS) in the preoperative setting. The SFS was evaluated for all patients undergoing abdominoplasties and brachioplasties. Images of the SFS captured by the senior operative surgeon were independently interpreted and verified by a radiologist.

RESULTS

Perforator Vessel Mapping and Identification

In 11 (100%) of 11 cases, the largest perforator was correctly identified preoperatively via CDUS and subsequently verified intraoperatively via direct visualization. In 2 (18.2%) of 11 cases, perforators were identified by CDUS that were not detected via CTA. Of note, in 1 of the 2 cases, the originally undetected perforator identified by CDUS proved to be the dominant perforator and was used intraoperatively (Fig. 3). Perforators identified by CDUS ranged in size from 0.30 to 3.60 mm. In this study, preoperative CTAs were performed for all DIEP flaps; however, no CTAs were performed for the T-DAP, S-GAP, TFL, ALT, and gracilis musculocutaneous flaps after imaging with CDUS. Planning and execution of these flaps were based entirely on perforator characteristics provided by US imaging. Notably, the preoperatively targeted perforator was successfully used in 10 (90.9%) of 11 cases. The S-GAP was abandoned intraoperatively because of inadequate size of the perforator proximally.

TAP Blocks

Twenty-five patients underwent intraoperative, US-guided placement of anesthetic into the TAP by the operating surgeon. With the US probe placed directly on the abdominal wall musculature, clear visualization of the external oblique, internal oblique, and transversus abdominis muscles allowed confirmation of proper anesthetic delivery into the

TABLE 1. Characteristics of Patients Undergoing Perforator Flap Reconstruction

No.	Age, y	Sex	Race	BMI, kg/m^2	Procedure	Indication	Complication
1	55	F	AA	35.8	DIEP	Multifocal breast cancer	Cellulitis
2	72	F	W	27.6	DIEP	DCIS	Local wound breakdown
3	40	F	AA	25.6	DIEP	IDC and DCIS	
4	64	F	W	24.6	DIEP	Multifocal DCIS	
5	73	F	W	27.6	DIEP	IDC	Fat necrosis
6	56	F	W	26.8	DIEP	Multifocal breast cancer	
7	54	F	W	22.0	S-GAP	DCIS	Abandoned intraoperatively
8	32	M	W	27.9	TFL	Leg wound secondary to tibial shaft fracture	
9	85	F	W	21.2	ALT	Oral SCC	Death due to *Clostridium difficile* sepsis
10	54	F	W	24.2	Gracilis	Vaginal reconstruction secondary to rectal cancer	
11	57	M	W		T-DAP	Infected total knee arthroplasty	

AA indicates African American; BMI, body mass index; DCIS, ductal carcinoma in situ; F, female; IDC, invasive ductal carcinoma; M, male; SCC, squamous cell carcinoma; W, white.

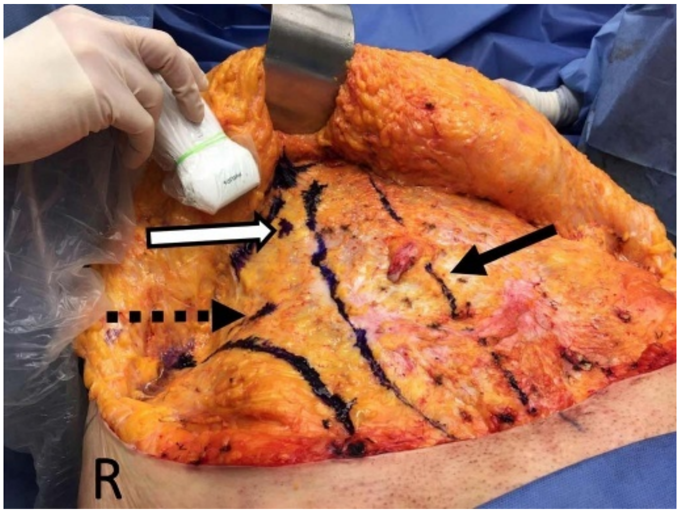

FIGURE 2. Abdominal fat retracted cephalically in preparation for 4-quadrant TAP block. Empty arrow marks the site of injection for the right subcostal approach (2 cm below the subcostal margin along the anterior axillary line). Dashed arrow marks the site of injection for the right iliohypogastric approach (1 cm above the ASIS along the anterior axillary line). Full arrow marks the linea alba. ASIS indicates anterior superior iliac spine; R, patient's right.

TAP plane (Fig. 4). Successful abdominal wall analgesia was achieved in each case (100%) without adverse events or complications.

Superficial Fascial System Analysis

The SFS for each anatomical area and for all 20 patients undergoing body-contouring surgery was assessed preoperatively. A variety of configurations of the SFS was identified in the abdominoplasty patients: disorganized diffuse, unilaminar, and multilaminar (Fig. 5). Interestingly, brachioplasty tissues unanimously demonstrated a paucity of SFS.

DISCUSSION

Latest-generation US technology can be found in a tablet-sized device with a quality that rivals the imaging capabilities of bulkier hospital-based equipment (Fig. 1). In addition, the user-friendly interface allowed the operating surgeon, with no formal training in US, to independently image various body structures for therapeutic and diagnostic purposes. As the latest US technology has overcome many of the previous barriers to use (eg, cost, size, and need for a specialist operator/interpreter), US has a future in every plastic and reconstructive surgeon's armamentarium. This newest technology allows for the following clinical applications heretofore not commonly performed by plastic surgeons.

Ultrasound Visualization of Perforating Vessels

Ultrasound has been previously shown to be efficacious in the preoperative assessment of perforator flap reconstruction in the lower extremities.[9,15,16] The most recent study showed the GE Voluson E-8 was as equally useful as preoperative CTA in the planning and execution of perforator-based flap reconstruction of the lower extremity.[15] Strengths of US noted in that study were its ability to offer precise perforator analysis including location, diameter, flow qualities, and path. This represented a major departure from previous publications where CTA was shown superior to US imaging.[17–19]

The CDUS technologies used in these studies have since been improved. For example, a limitation of the CDUS equipment cited in the literature was the inability to image perforators in areas of high adiposity due to the amount of intervening fat.[15] In our study, the ability of the latest CDUS equipment to image abdominal perforators in patients with a body mass index of up to 35.8 kg/m^2 has been demonstrated by a surgeon with no previous US experience (Table 1). We have found that another major advantage of latest-generation US technology is that it can precisely and quickly identify the location of the perforator on the skin surface in relation to its emergence from the underlying fascia

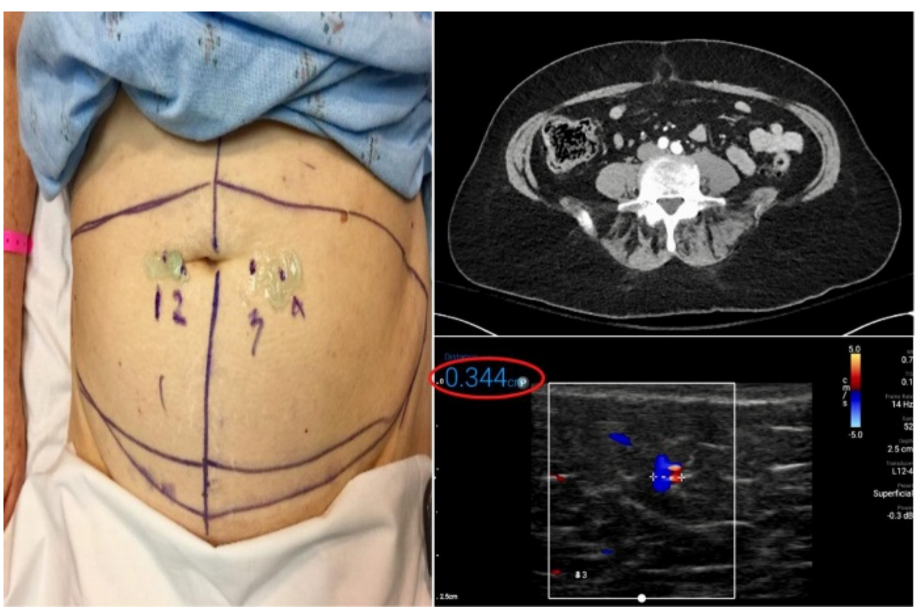

FIGURE 3. Left, Preoperative markings of perforator "hot spots" as identified by handheld, pencil Doppler. Top, Computed tomography angiography fails to identify a perforator at position 3 (3 cm left of patient's umbilicus). Bottom, Color Doppler ultrasound properly identifies a perforating artery-vein (3.44 mm) at position 3 that was ultimately utilized as the dominant DIEP intraoperatively.

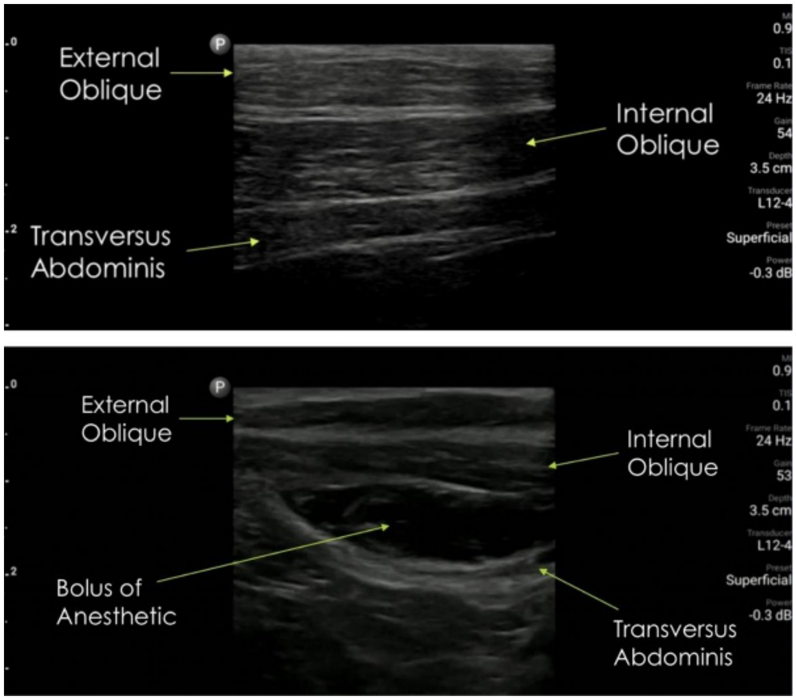

FIGURE 4. Top, Intraoperative visualization of the 3 muscular layers of the abdominal wall by CDUS. Such high-clarity images are possible by retracting the abdominal fat, which allows for precise CDUS-guided, TAP block instillation by the operating surgeon. Bottom, Confirmation of correct anesthetic delivery as demonstrated by the hypoechoic signal formed by the bolus of anesthetic within the TAP plane.

(Fig. 6; see Video, Supplemental Digital Content 1, which demonstrates the ability of CDUS to visualize a perforator's emergence in real time, http://links.lww.com/SAP/A271). This is a particularly important advantage when designing perforator flaps on the thigh, back, or buttock where printed 2-dimensional templates do not conform well to 3D, curved surfaces. The difficulty of localizing perforators preoperatively identified by CTA on the skin surface of a patient has been addressed by Shen et al.[20] They placed markers on the skin surface, created a 3D CT reconstruction, projected that onto a virtual template with a grid, and subsequently printed that onto film or paper. In that study, the virtual CT navigation was found to be more accurate than CDUS, but the US technology used in that study was never mentioned.

Another major advantage of US assessment of perforators is that it can be used to evaluate a variety of donor sites as possible solutions for a reconstructive problem. Therefore, the best donor site can be selected based on the superior available anatomy. This is most commonly applicable for unilateral DIEP flap selection but was also used for selection of our gracilis musculocutaneous and T-DAP flaps. In the case of the T-DAP, the right T-DAP was ultimately selected because it had by far the best perforator of the bilateral T-DAP and ALT regions examined. Conversely, CTA of multiple remotely located donor sites is not practical from a cost and safety perspective. Our US visualizations were highly consistent and reproducible as they were always able to be identified intraoperatively. Preoperatively selecting the best possible perforator can reduce operative times by not having to determine the best perforator via dissection.

A handheld, pencil Doppler was used to initially locate perforator "hot spots" in this study. Localization of the "hot spots" on the skin was necessary because the CDUS was too sensitive to allow scanning of large surface areas for perforating vessels. Vessels were visualized in multiple planes and followed to the location of fascial penetration. In this way, reticular arteries and other subdermal vessels that were originally detected by handheld Doppler but not able to be followed to a perforator of interest by CDUS were effectively screened out. This eliminates the false-positive results created by the older, acoustic Doppler devices.

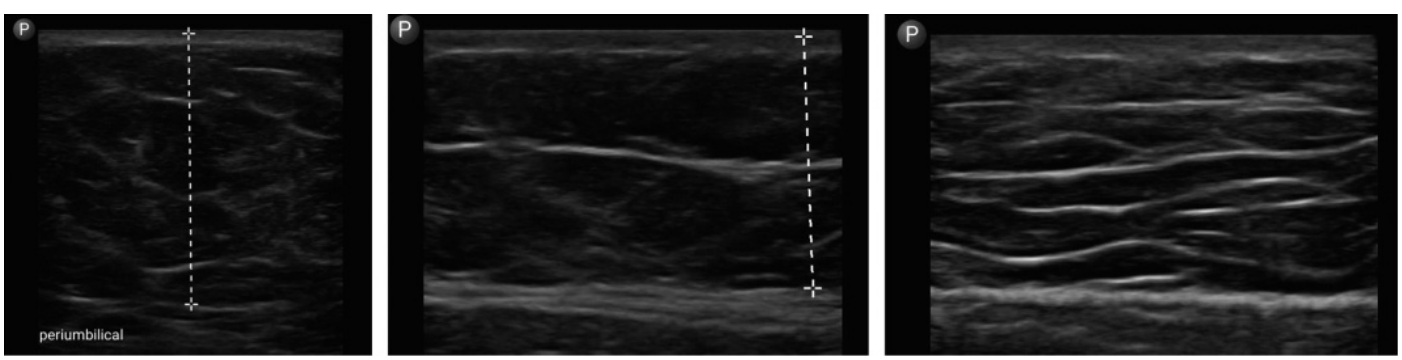

FIGURE 5. Variable configurations of periumbilical SFS found within 3 different patients. Left, Disorganized, diffuse SFS. Middle, Unilaminar SFS. Right, Multilaminar SFS.

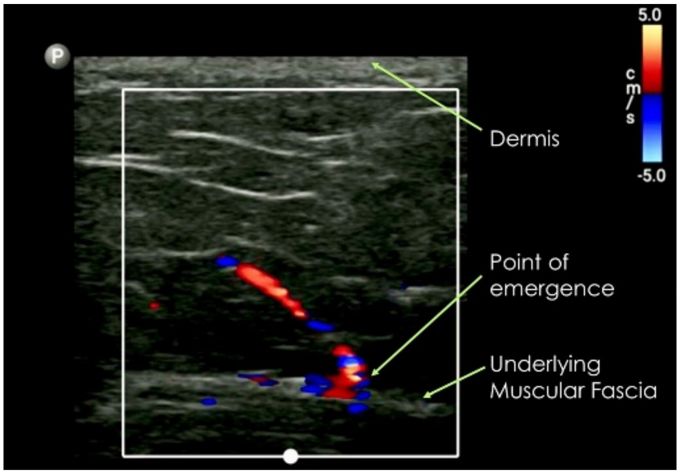

FIGURE 6. The emergence of an abdominal perforator from the underlying muscular fascia.

While the perforator's point of emergence from the underlying fascia can be determined by CDUS, it is important to note that the perforator's intramuscular course cannot be visualized. This represents a major limitation of CDUS. For example, in the case of the S-GAP, CDUS demonstrated 2 perforators of adequate size exiting the gluteus maximus muscle. Intraoperatively, the location and size of both perforators as they exited the muscle were confirmed via direct visualization; however, the S-GAP had to be abandoned intraoperatively because of inadequate perforator diameter proximally as a result of significant intramuscular branching not able to be visualized by CDUS (Table 1). Therefore, a significant limitation of the CDUS equipment utilized in this study is its inability to visualize the intramuscular course of perforating vessels.

TAP blocks

Transversus abdominis plane blocks were first introduced in 2001 by Rafi[21] and were performed through the inferior lumbar triangle of Petit—bound anteriorly by the posterior border of the external oblique muscle, posteriorly by the lateral border of the latissimus dorsi muscle, and inferiorly by the iliac crest.[22] Rafi[21] originally utilized the auscultation or palpation of 2 sequential "pops" while inserting a needle through the external oblique and internal oblique fascial layers to access the anatomical plane deep to the internal oblique muscle and superficial to the transversus abdominis muscle. This plane is known as the TAP, and analgesic success is reliant on correctly delivering anesthetic within this plane as it carries the sensory nerves that innervate the anterior abdominal wall.[21,22] The original technique was dramatically improved in 2007 by the introduction of US-guided TAP blocks.[23] Numerous subsequent publications showed greatly improved patient analgesia for a wide variety of surgeries such as hernia repair, both laparoscopic and open abdominal surgery, hysterectomy, cesarean delivery, and DIEP flaps.[14,24–30] Improved analgesia was possible because of the more accurate placement of the anesthetic with US guidance. In fact, the anesthetic can be visualized spreading within the desired TAP plane following a successful injection (Fig. 4). Recent reports in *Plastic and Reconstructive Surgery* showed a decreased length of hospital stay for patients undergoing DIEP surgery and increased patient comfort and decreased narcotic usage in abdominoplasty and DIEP patients who received TAP blocks.[12,14,31,32]

At this time, many institutions routinely rely on the anesthesia service to administer TAP blocks preoperatively for patients undergoing abdominal or pelvic surgery. Our CDUS provides the opportunity for plastic surgeons, even those not operating in a hospital environment, to more precisely and more effectively administer anesthesia, increasing patient comfort and experience. Plastic surgeons have the advantage of directly imaging the anterior abdominal wall musculature while the abdominal skin flap is retracted. Visualization of the abdominal wall layers via US has exceptional clarity at this time and makes infiltration of the TAP plane straightforward, as there is no intervening skin or subcutaneous tissue. In addition, the patient can expect a longer period of postoperative pain relief as the anesthetic is delivered intraoperatively versus preoperatively.

In this study, the senior operating surgeon was able to intraoperatively deliver TAP blocks following exposure of the anterior abdominal wall musculature that routinely occurs during DIEP and abdominoplasty surgeries. A 4-quadrant TAP block was administered via bilateral subcostal and iliohypogastric approaches. The subcostal approach anesthetizes the epigastric area (T7–T11), and the iliohypogastric approach anesthetizes the hypogastric and groin areas (T12–L1).[33,34] It is important to note that a 4-quadrant block is required to obtain profound analgesia throughout the entire anterior abdominal wall.

For patients receiving 4-quadrant TAP injections in this series, profound analgesia of the anterior abdominal wall was achieved without complication. These findings have resulted in a significant change in the anesthetic management of both abdominoplasty and DIEP flap patients in our practice, which now includes the routine use of 4-quadrant US-guided TAP blocks intraoperatively. Given that postoperative pain greatly affects patient satisfaction, the typical plastic surgery patient undergoing abdominal contouring or abdominal-based breast flap reconstruction may benefit from surgeon-administered TAP blocks.[35]

Analysis of the Superficial Fascial System of the Integument

The importance of the SFS for body contouring was noted and popularized by Lockwood[36–38] in 1991 and has been a cornerstone of body contouring since its initial description and application in plastic surgery. Previous studies have documented significant variation of the SFS by CT/magnetic resonance imaging, biomechanical analyses, and/or histological sections.[39–41] Variations have been further shown among slim and obese patients.[42] Ultrasound has been used previously to quantitate presence and variability of the SFS throughout the body.[43] Our findings in this clinical series corroborate the conclusions of these previous studies, which demonstrated variability of the SFS throughout the body. This new technology facilitates easy assessment of the presence and quality of the SFS prior to body contouring surgeries. In this study, we found that the SFS could be absent or exist in single or multiple layers. Furthermore, we identified a wide variation of the SFS not only among different patients (Fig. 5) but also within individual patients, depending on the bodily region examined. Prior knowledge of patient-specific characteristics of the SFS may have implications with regard to the planning of body contouring procedures and is currently under investigation. Further study is warranted to quantify the perceived benefits of surgeon-operated CDUS in the preoperative period.

Lastly, preoperative US evaluation provides a unique opportunity for the patient to be directly engaged in treatment planning. While radiographs are often puzzling for patients because of their static nature combined with the patient's lack of anatomical knowledge, the real-time imaging and relative intuitiveness of US imaging provide an experience that, in the author's opinion, increases patient satisfaction and strengthens the patient-physician relationship.

Limitations to this study are that the opinions expressed herein are from the experiences of a single surgeon. Also, the time necessary to capture and interpret CDUS images was neither recorded nor reported. Finally, pain scores were not used to objectively determine the efficacy of our 4-quadrant TAP blocks. Our observations require further investigation to quantify the perceived benefits of this new technology.

CONCLUSIONS

This new handheld, relatively inexpensive, and easily portable US technology has a variety of applications that may improve patient outcomes and experience in both reconstructive and aesthetic plastic surgery.

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