ORIGINAL ARTICLE

An investigation of the application of laser-assisted indocyanine green fluorescent dye angiography in pedicle transverse rectus abdominus myocutaneous breast reconstruction

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BACKGROUND: Pedicle transverse rectus abdominus myocutaneous (pTRAM) flaps remain the most common method of autologous tissue breast reconstruction. Using pTRAM flaps, complications often arise postoperatively, secondary to inadequate circulation. Tissues from distant angiosomes are associated with poorer perfusion, but this differs among patients. Many modalities have been used to reduce the risk of complications, but none have achieved widespread application. The authors believe that laser-assisted indocyanine green fluorescent dye angiography (LA-ICGA) can potentially reduce the risk of complications.
METHODS: In two routine, single-pedicle, ipsilateral pTRAM flaps, LA-ICGA imaging was performed following the division of the distal rectus muscle and deep inferior epigastric pedicle. The resulting images were used to guide design of the flap and debridement.
RESULTS: In case 1, good perfusion was observed in zone 1 and part of zone 2. In case 2, good perfusion was observed in zone 1 and 50% of zone 3, with little perfusion in zone 2. In both cases, tissues with poor perfusion were debrided before transfer and inset. In both patients, there were no issues with wound healing, tissue necrosis or fat necrosis.
CONCLUSIONS: The variability of perfusion of the pTRAM flap among individuals is well appreciated. LA-ICGA helped to determine the limits of good perfusion and, therefore, the limits of tissue to be preserved for transfer and inset. This helped to avoid harvesting poorly perfused tissue that would have almost certainly experienced necrosis and, ultimately, would have reduced the risk of postoperative complications.

Key Words: *Immediate breast reconstruction; Indocyanine green angiography; Intraoperative flap perfusion; Mastectomy, TRAM flap*

Une investigation de l'application de l'angiographie au laser par coloration fluorescente au vert d'indocyanine par la reconstruction mammaire par lambeaux musculocutanés pédiculés du grand droit de l'abdomen

HISTORIQUE : Les lambeaux musculocutanés pédiculés du grand droit de l'abdomen (pTRAM) demeurent la principale méthode de reconstruction mammaire par tissus autologues. En présence de lambeaux pTRAM, des complications surgissent souvent après l'opération en raison d'une mauvaise circulation. Les tissus provenant d'angiosomes distants s'associent à une moins bonne perfusion, mais la situation diffère selon les patients. Les médecins ont utilisé de nombreuses modalités pour réduire le risque de complications, mais aucune de ces modalités ne s'est généralisée. Les auteurs sont d'avis que l'angiographie au laser par coloration fluorescente au vert d'indocyanine (AL-CFVI) pourrait réduire le risque de complications.
MÉTHODOLOGIE : Dans le cadre de l'installation courante de deux lambeaux pTRAM ipsilatéraux à simple pédicule, les chercheurs ont procédé à une AL-CFVI après avoir divisé le muscle droit distal et le pédicule épigastrique inférieur profond. Les images obtenues ont orienté la conception du lambeau et du débridement.
RÉSULTATS : Dans le premier cas, les chercheurs ont observé une bonne perfusion dans la zone 1 et une partie de la zone 2. Dans le deuxième cas, ils ont observé une bonne perfusion dans la zone 1 et 50 % de la zone 3, mais peu de perfusion dans la zone 2. Dans les deux cas, les tissus peu perfusés ont été débridés avant le transfert et l'installation. Aucun des deux patients n'a eu de problèmes de cicatrisation de la plaie, de nécrose tissulaire ou de nécrose adipeuse.
CONCLUSIONS : La variabilité de la perfusion du lambeau pTRAM d'une personne à l'autre est bien connue. L'AL-CFVI a contribué à déterminer les limites d'une bonne perfusion et, par conséquent, les limites des tissus à préserver pour le transfert et l'installation. Cette technique a permis d'éviter de prélever des tissus mal perfusés qui se seraient sûrement nécrosés et, au bout du compte, de réduire le risque de complications postopératoires.

Pedicle transverse rectus abdominus myocutaneous (pTRAM) flaps remain the most common method of autologous tissue breast reconstruction (1). Advantages of this traditional method – as opposed to microsurgical free tissue transfer – include a technically less-demanding procedure, shorter operative time and shorter hospital stay (2). However, complications of pTRAM reconstruction secondary to compromised circulation within the flap are well appreciated and include, among others, flap failure, skin necrosis and fat necrosis. The incidence of these complications have been reported to be as high as 8.5%, 8.9% and 58.5%, respectively (2,3).

There are three recognized blood supplies to the lower abdominal tissue that are used in TRAM flap breast reconstruction (4). These are the superior epigastric system (pTRAM), the inferior epigastric system (microsurgical free TRAM and deep inferior epigastric perforator flaps) and the superficial inferior epigastric system. In designing the skin island for TRAM flap transfer, the surgeon must be careful to include ample tissue for reconstruction while maintaining adequate blood supply. The concept of angiosomes, as described by Spear et al (3), Taylor et al (5) and Boyd et al (6), is useful in illustrating the differences in blood supply between free TRAM and pTRAM flaps. In any free TRAM flap, zone 1 is the primary angiosome, and zones 2 and 3 are considered to be the adjacent angiosomes. Zone 4, being two angiosomes away, is believed to be unreliable. By contrast, zone 1 in a pTRAM flap is separated from the primary angiosome (or vascular pedicle) by a choke system of vessels and, therefore, represents an adjacent angiosome. Therefore, according to these principles, it is suggested that zones 2 and 3 in a pTRAM flap

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are unreliable. Although they are usually reliable, this explains why we occasionally observe intraoperative congestion and ischemia, and subsequent partial flap necrosis in zones 2 and 3 in pTRAM flaps, which may lead to the abovementioned complications described in previous studies and observed in clinical practice (7).

Complications can occur even when operating on carefully selected patients and using properly designed pTRAM flaps. Any clinically obvious intraoperative findings of ischemia or congestion would naturally guide the surgeon to alter the flap design to include viable angiosomes and prevent complications. However, ischemia and congestion are often not apparent or certain at the time of surgery. Identification of poor perfusion is more difficult in complex cases such as patients with obesity, a history of smoking, darker skin colour or previous abdominal surgeries. Some of these patients are at an exceptionally high risk for postoperative complications, which can be exacerbated by the uncertainty of clinical judgment (in this instance). When clinical judgment may be confounded, a means to more accurately assess perfusion is necessary. A variety of modalities have been used in an attempt to assist the surgeon intraoperatively in identifying potential sources of complication. These include fluorescein dye, thermography, Doppler ultrasound, tissue oximetry and various radioisotopes, among others. Unfortunately, each has its own set of disadvantages, which has precluded their widespread clinical use for this purpose.

The benefits of laser-assisted indocyanine green angiography (LA-ICGA) in microsurgical breast reconstruction have been demonstrated by Newman et al (8). A later report published by Pestana et al (9) described early positive experience with the use of LA-ICGA for free tissue transfer of various types throughout the body. To our knowledge, the use of this technology in pTRAM reconstruction has not been previously described. This technology may provide advantages such as reducing the risks of these commonly noted complications. Several studies (10) have shown a remarkably high ischemic complication rate in pTRAM flaps, which can lead to additional wound care treatments, office visits, surgeries, compromised reconstructive results and increased overall health care costs. For example, a recent study by Janiga et al (11) demonstrated ischemic-related flap complications in 22.4% of ipsilateral pTRAM flaps and in 25% of contralateral pTRAM flaps; advanced patient age was strongly correlated with increasing ischemic complication rates. A study by Andrades et al (12) on ischemic complications of 399 TRAM flaps (147 pTRAMs) in 301 patients demonstrated a pTRAM ischemia rate of 42.9%, with a corresponding reoperation rate of 19.7% and a revision rate of 60.5%. A study by Spear et al (13) of 224 obese and nonobese patients undergoing pTRAM reconstruction demonstrated a partial flap ischemic necrosis rate of 21.6% in obese patients, 7.1% in overweight patients and 5.8% in normal weight patients (13).

This form of intraoperative angiography (LA-ICGA) begins with the intravenous injection of indocyanine green fluorescent dye, which may be administered via an existing central line or through peripheral access. The dye, which binds to plasma proteins, travels through the vascular system and courses through the microvasculature. As it does, the subdermal plexus can be visualized through the skin in real time. Images are dynamic and are captured in video format on a monitor in the operating room. The format is black and white – white represents the dye within the microvasculature (eg, perfusion) and black represents the lack of dye (eg, lack of perfusion). Varying shades of grey demonstrate gradients of perfusion throughout the imaged tissue.

In an effort to evaluate the efficacy and usefulness of LA-ICGA in reducing or preventing known complications of pTRAM reconstruction, this technology was used in pTRAM breast reconstruction surgery. Two cases illustrating our initial experience, lessons learned and outcomes follow.

METHODS

Case 1

A routine, single-pedicle, ipsilateral TRAM flap was performed for left breast reconstruction immediately following mastectomy and negative sentinel lymph node biopsy on a 57-year-old African-American woman. In addition to breast cancer, her medical history was significant for hypercholesterolemia and a previous caesarean section. She was not, nor had she ever been, diabetic or a smoker. Her metastatic workup was negative and her laboratory tests were within the normal limits. Her body mass index at operation was 25.7 kg/m^2. Following routine workup and clearance, the patient was taken to the operating room for left mastectomy and immediate reconstruction. No preoperative 'delay' procedure was performed. The single-pedicle, ipsilateral TRAM flap was designed and performed traditionally.

In an effort to evaluate the overall perfusion of the flap, and the limits thereof, LA-ICGA imaging using the SPY system (Novadaq Technologies, Canada) was performed following division of the distal left rectus muscle and the deep inferior epigastric pedicle. In this case, images were obtained in this manner and analyzed with respect to cutaneous perfusion in real time. At operation, these images helped to determine which tissues should be debrided before transfer and inset, and which tissues should be preserved and included in the reconstruction. Following transposition and inset, the abdominal donor site was closed and the patient was admitted to the hospital. She had an unremarkable postoperative course and was discharged home on postoperative day 4.

Case 2

A routine, single-pedicle, ipsilateral TRAM flap was performed for left breast reconstruction several months following modified radical mastectomy, chemotherapy and radiation therapy on a 65-year-old African-American woman. In addition to breast cancer, her medical history was significant for type II diabetes and a previous vaginal hysterectomy. She was not, nor had she ever been, a smoker. Her metastatic workup was negative and her laboratory tests were within normal limits. The patient's body mass index at operation was 26.7 kg/m^2. Following routine workup and clearance, the patient was taken to the operating room for reconstruction. No preoperative 'delay' procedure was performed. The single-pedicle, ipsilateral TRAM flap was designed and performed traditionally.

As in the previous case, LA-ICGA imaging was performed following division of the distal left rectus muscle and the deep inferior epigastric pedicle. Again, images were obtained and analyzed with respect to cutaneous perfusion in real time. At operation, these images helped to determine which tissues should be debrided before transfer and inset, and which tissues should be preserved and included in the reconstruction. Following transposition and inset, the abdominal donor site was closed and the patient was admitted to the hospital. She had an unremarkable postoperative course and was discharged home on postoperative day 4.

At the Cleveland Clinic Florida (USA), the nomenclature regarding zones of perfusion identifies zone 1 as the skin and soft tissue directly overlying the ipsilateral rectus abdominis pedicle. Zone 2 refers to the tissue lateral to the ipsilateral rectus abdominis pedicle. Zone 3 is the skin and soft tissue directly overlying the contralateral rectus abdominis muscle, and zone 4 refers to the tissue lateral to the contralateral rectus abdominis muscle (Figure 1).

RESULTS

Case 1

In the continuous 60 s of video obtained for this case, two frames were selected for illustration and discussion (Figure 2). Figure 2A was obtained from the periumbilical area, centred over the patient's midline. This image demonstrated good perfusion in zone 1, clearly definable and in contrast to the poor perfusion across the midline in zone 3. Figure 2B was obtained from the most lateral portion of the ipsilateral flap overlying zone 2. The image demonstrates good flow to a clearly definable point. Lateral to this point, perfusion remained poor, indicating the limits of flow and, therefore, the limits of tissue adequate for transfer and inset. Tissue demonstrating poor perfusion (as described above) was debrided before transfer and inset. The tissue selected for retention and incorporation into the flap is represented schematically in Figure 3.

Case 2

In the continuous 60 s of video obtained for this case, two still images were selected for illustration and discussion (Figure 4). As above, Figure 4A was obtained from the periumbilical area, centred over the patient's midline. This image demonstrates not only good perfusion in zone 1, but equally good perfusion in up to 50% of zone 3 that is clearly identifiable across the midline. Figure 4B was obtained from the lateral portion of the ipsilateral flap overlying the lateral portion of zone 1 and all of zone 2. The image demonstrates good flow to a clearly definable point at the border of zone 1 and zone 2. Lateral to this point, perfusion remained poor indicating the limits of flow and, therefore, the limits of tissue adequate for transfer and inset. Tissue demonstrating poor perfusion (as described above), which in this case included most of zone 2, was debrided before transfer and inset. The tissue selected for retention and incorporation into the flap, zone 1 and at least 50% of zone 3, is represented schematically in Figure 3.

Following the flap inset, the patients followed a routine postoperative course. They were followed up for six months. Throughout this period, no patient demonstrated wound healing issues, fat necrosis or skin necrosis.

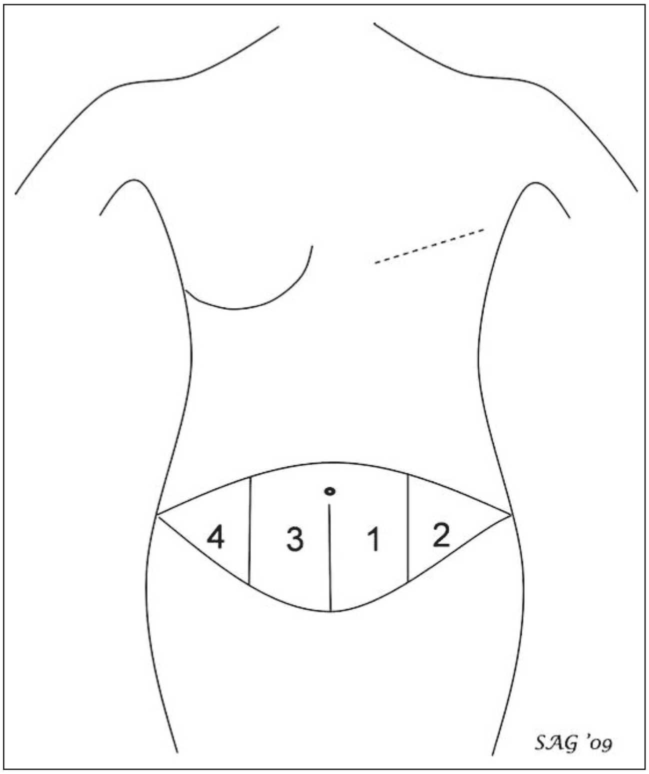

Figure 1) *Zones of perfusion in a single-pedicle transverse rectus abdominus myocutaneous flap based on the left rectus abdominis muscle*

DISCUSSION

The variability of perfusion of the TRAM flap among individuals is well appreciated. Studies by Wagner et al (14), attempted to demonstrate the 'safe zones' of the pTRAM flap. These studies showed that approximately 2.5 zones of tissue are carried by the pTram flap, with significant individual variability – 70% of zone 2 and 60% of zone 3 are potentially viable, although unpredictable. Other authors somewhat disagree, for example, Spear et al (15) believed that at most two zones can be carried reliably, with 80% of zone 2 and 20% of zone 3 typically considered to be viable (15). These differences are likely attributable to the differences among individual patients, and underscore the difficulty in reliably predicting a safe flap design based on anticipated blood supply. In addition, it is often difficult, if not impossible, to accurately predict flap viability clinically at the time of surgery. Therefore, more refined technology that can assist the surgeon in this task could dramatically decrease the complication rate in patients selected for pTram surgery.

The technology behind the SPY system continues to advance rapidly. Since the preparation of the present article, its ability to provide objective, real-time numerical data reflecting flap perfusion has been improved. An example of this is observed in Figure 5. Depicted are the periumbilical region of the flap presented in case 2 (previously described as Figure 4) and a computer analysis of the perfusion represented by colour and numerical data (Figure 5). We anticipate maturation of this technology shortly to a point in which the operating surgeon may be able to use objective numerical data to quantify the perfusion of different parts of the flap; thus, adding to his or her

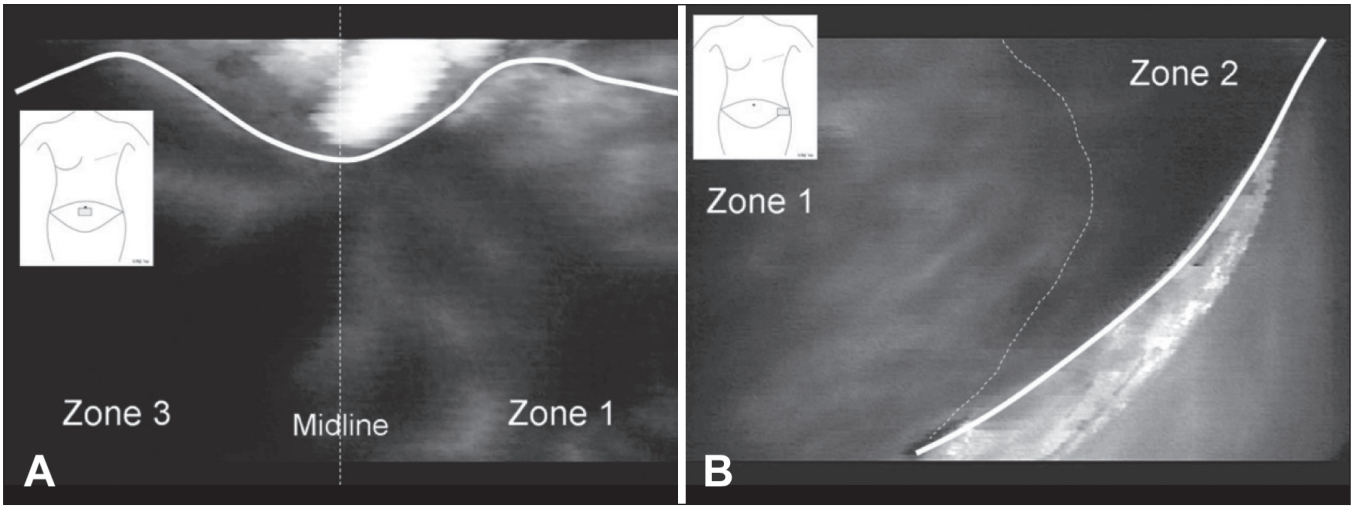

Figure 2) **A** *The periumbilical area (inset). This image demonstrates good perfusion in zone 1 (right), clearly definable and in contrast to the poor perfusion across the midline in zone 3 (left).* **B** *The most lateral portion of the ipsilateral flap overlying zone 2 (inset). The image demonstrates good flow to a clearly definable point. Lateral to this point, perfusion remained poor, indicating the limits of flow and, therefore, the limits of tissue adequate for transfer and inset*

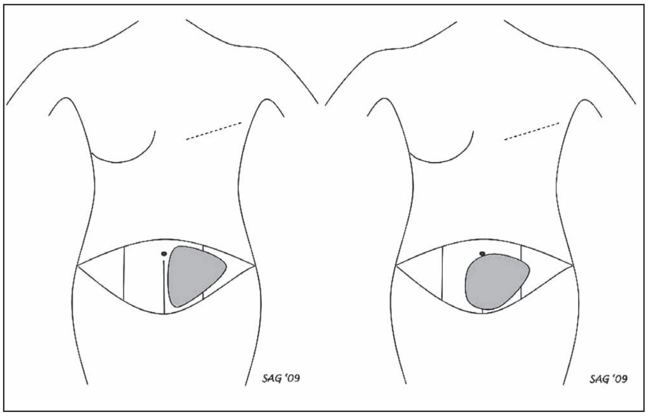

Figure 3) *Contrasted are the schematic images of the tissue selected for preservation, transposition and inset in cases 1 and 2 as guided intraoperatively by laser-assisted indocyanine green angiography*

armamentarium of tools by which to judge which portion of the flap to preserve for transposition.

Collectively, these cases serve to not only demonstrate the interindividual variability of the zones of perfusion, but also the potential benefits of using intraoperative LA-ICGA to identify the tissues best suited for preservation, transposition and inset in routine TRAM reconstructions. In both cases, LA-ICGA proved to be helpful in determining the limits of good perfusion and, thereby, the limits of tissue to be preserved for transfer and inset. In retrospect, it helped us avoid harvesting poorly perfused tissues that would have almost certainly experienced fat and/or skin necrosis following operation (eg, zone 3 tissue in case 1, and zone 2 tissue in case 2).

CONCLUSION

It is imperative that we reduce the risk of postoperative fat and skin necrosis in flap-based reconstruction. In our opinion, using LA-ICGA to guide intraoperative debridement can help us accomplish this. Doing so would, in turn, reduce the risk of having to return the patient to the operating room for debridement and revision, and would eliminate costs associated with complications and reoperation. In our initial experience, we found that LA-ICGA also enabled us to confidently harvest adequate tissue volume to reconstruct the opposite breast. Ultimately, the potential reduction in reoperation rates could lead to a reduction in the cost of health care for these patients, in addition to improved clinical outcomes.

Previously, we demonstrated the benefits of LA-ICGA intraoperative imaging in microsurgical breast reconstruction. Considering the benefits identified in these index cases, we hypothesize that the SPY

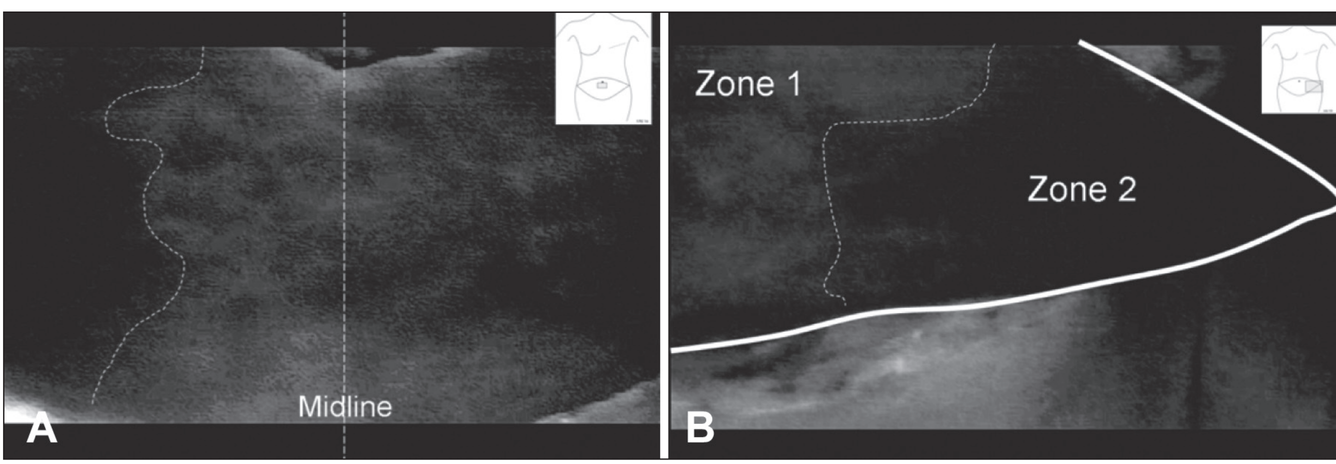

Figure 4) **A** *The periumbilical area (inset). This image demonstrates good perfusion in zone 1 (right), clearly extending across the midline and involving at least 50% of zone 3 (left).* **B** *The most lateral portion of the ipsilateral flap overlying the lateral portion of zone 1 and all of zone 2 (inset). The image demonstrates good flow to a clearly definable point. Lateral to this point, which in this case involves most of zone 2, perfusion remained poor, indicating the limits of flow and, therefore, the limits of tissue adequate for transfer and inset*

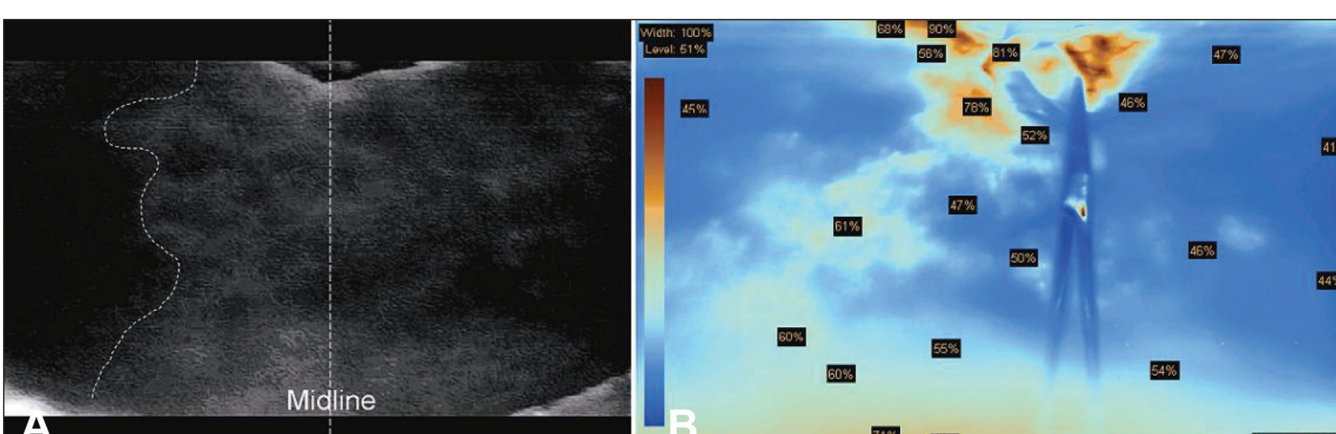

Figure 5) *The periumbilical area of case 2. This image on the left (previously described as Figure 4A) demonstrates good perfusion in zone 1 (right), clearly extending across the midline and involving at least 50% of zone 3 (left). The image on the right reflects the levels of perfusion through colours and objective numerical data*

system may also have significant value in pTRAM reconstruction. In an effort to determine the validity of this hypothesis, a prospective study is needed to compare outcomes using this technology with traditional methods.

CONFLICTS OF INTEREST: Dr Newman, Dr Samson and Ms Swartz are paid consultants for Novadaq Technologies Inc.

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