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Using Virtual Reality for Deep Inferior Epigastric Perforator Flap Preoperative Planning

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Introduction: This study was designed to compare VR stereoscopical three-dimensional (3D) imaging with two-dimensional computed tomography angiography (CTA) images for evaluating the abdominal vascular anatomy before autologous breast reconstruction.

Methods: This prospective case series feasibility study was conducted in two tertiary medical centers. Participants were women slated to undergo free transverse rectus abdominis muscle, unilateral or bilateral deep inferior epigastric perforator flap immediate breast reconstruction. Based on a routine CTA, a 3D VR model was generated. Before each procedure, the surgeons examined the CTA and then the VR model. Any new information provided by the VR imaging was submitted to a radiologist for confirmation before surgery. Following each procedure, the surgeons completed a questionnaire comparing the two methods.

Results: Thirty women between 34 and 68 years of age were included in the study; except for one, all breast reconstructions were successful. The surgeons ranked VR higher than CTA in terms of better anatomical understanding and operative anatomical findings. In 72.4% of cases, VR models were rated having maximum similarity to reality, with no significant difference between the type of perforator anatomical course or complexity. In more than 70% of the cases, VR was considered to have contributed to determining the surgical approach. In four cases, VR imaging modified the surgical strategy, without any complications.

Conclusions: VR imaging was well-accepted by the surgeons who commented on its importance and ease compared with the standard CTA presentation. Further studies are needed to determine whether VR should become an integral part of preoperative deep inferior epigastric perforator surgery planning. *(Plast Reconstr Surg Glob Open 2023; 11:e4773; doi: 10.1097/GOX.0000000000004773; Published online 17 January 2023.)*

INTRODUCTION

Autologous breast reconstruction is a standard procedure performed during mastectomy for the treatment of breast cancer.[1–6] The transverse rectus abdominis muscle (TRAM) and the deep inferior epigastric perforator (DIEP) are the most common flaps used, both of which are harvested from the lower abdomen.[4,7,8] To ensure flap viability, high-resolution imaging and meticulous surgical planning are required. The procedure itself can still involve complications, including venous congestion, fat necrosis in 1.28%–2.93% of cases, and even total flap loss in 1.16%–3.61% of all patients whether performed unilaterally or bilaterally, according to Serletti et al.[9]

Virtual reality (VR) has recently emerged as a comprehensive tool for stereoscopic three-dimensional (3D) imaging since it provides an interactive, realistic, and intuitive understanding of anatomical and pathological

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structures. VR technology has made considerable progress and is now used for presurgical design, intraoperative navigation, teaching, and medical training.[10–14] Currently, preliminary surgical planning is based on an abdominal computed tomography angiogram (CTA) image analysis, which is considered the gold standard. Tracking and analyzing the blood vessels supplying the abdominal wall provide insights into their position and quality.[15] Nevertheless, because two-dimensional (2D) blood vessel imaging is suboptimal for preoperative planning whether viewed as CTA axial slices or as a 3D reconstruction viewed on 2D screens, stereoscopic 3D visualization is likely to improve surgeons' ability to track the vessels, evaluate their correct location in relation to anatomical landmarks, and evaluate their track, all of which will contribute to the final design of the flap. However, there is little or no literature on the implementation of VR for breast reconstruction. The purpose of this study was to evaluate the applicability, precision, and ease of use of VR guidance technology for the preliminary planning of breast reconstruction procedures.

Takeaways

Question: What is the VR 3D-model added value for the preliminary planning of breast reconstruction procedures?

Findings: VR was ranked higher than CTA in terms of better anatomical understanding. In 72.4% of cases, VR models were rated having maximum similarity to reality. In more than 70% of the cases, VR was considered to have contributed to determining the surgical approach. In four cases, VR imaging modified the surgical strategy, without any complications.

Meaning: The 3D-VR model provides additional data over CTA and can provide surgeons with feedback on preoperative planning with CTA.

METHOD

This multicenter study was conducted at Sheba Medical Center in Tel Hashomer and Tel-Aviv Sourasky Medical Center in Israel from March 2020 to December 2021. It was approved by the internal board review committees of both centers and included women who were scheduled for free TRAM, unilateral, or bilateral DIEP flap immediate breast reconstruction in compliance with standard guidelines. All the participants provided their written informed consent. As part of our institution's exclusion criteria for DIEP flap procedures, patients were excluded if they had previously received radiotherapy to the base of the flap or to the mediastinum, had previously undergone surgical division of the pedicle, had previously undergone abdominoplasty, had multiple scarring on the abdominal wall, or had unfavorable microcirculation due to diabetes mellitus or smoking. Patients who did not stop smoking 6 weeks before surgery and diabetic patients with hemoglobin A1c levels above 5.7% were not referred for surgery.

As the standard, all patients underwent a CTA scan before surgery. In addition, 3D models of all the patients were created in VR to confirm the CTA findings. In several cases, the VR showed the intramuscular course, arterial split, and/or a deep arterial system that were not identified in radiologist's CTA interpretation. In these cases, the CTA was reexamined. After approval from the radiologist and the surgeons, the surgical approach was modified to account for these differences.

Preprocedure Imaging

Before the procedure, each patient underwent an abdominal wall CTA scan using a 128-detector-row CT scanner. The CTA scans were performed in the supine position with the following parameters: 0.4-second gantry rotation speed, 0.625-mm slice thickness (× 128), and travel per rotation. The tube voltage was 100 kV, and the tube current was 300–500 mA. The acquisition range was from 5 cm above the umbilicus down to the upper thigh. The caudal-cranial image was acquired after intravenous administration of 110 ml of iodinated contrast medium (Omnipaque, Ireland) at a concentration of 350 mg/ml. During imaging, the umbilicus was filled with the contrast agent for later identification and as a spatial reference point. The CTA images were first interpreted by a senior radiologist (O.S.), who specializes in CTA scans of abdominal wall arteries specific to DIEP flap procedures. The radiologist then recommended the most appropriate perforator and confirmed the image quality.

VR Imaging

Based on the CTA acquisition, a VR model was generated. The CTA scan was loaded as DICOM files onto the D2P software (3D Systems Inc., Littleton Colo.) for segmentation of the patient's abdominal wall vessels, the targeted muscles (rectus abdominis, and pyramidalis), and the fat and skin tissues. Each segmentation was colored in a systematic way to differentiate the anatomical structures and facilitate visualization for the surgeon. This system is equipped to generate a semiautomatic structure segmentation according to the Hounsfield unit range selected by the operator. Since the opacity of the vessels varied throughout, the model was completed by a specialized technician who traced the vessels and manually corrected the models to provide accurate segmentation. 3D models were generated within 45 minutes to 1 hour, allowing for rapid analysis without significant delay.

In each case, the abdomen and pelvis were segmented, and the abdominal wall was intensified as part of the VR 3D reconstruction (Fig. 1). The operator was able to see the segmented parts along with their surrounding organs and tissues in a stereoscopic view as displayed on a Vive system (HTC, San Francisco, Calif.). At any plane, the original CTA scan could be intensified and viewed over the VR model (Fig. 2).

A standardized color highlighting scheme was developed. The deep inferior epigastric artery (DIEA) and external iliac artery were in green up to the insertion into rectus abdominis muscle, the intramuscular course was in magenta, the superficial internal epigastric artery was in yellow, the umbilicus was purple, and

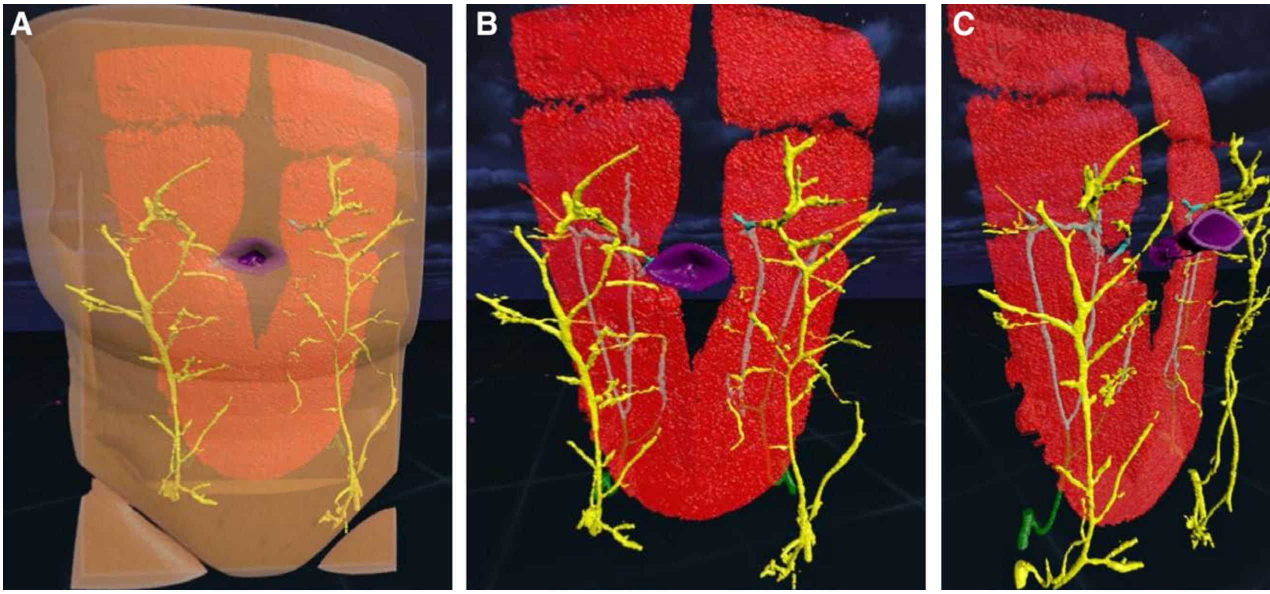

Fig. 1. The full 3D model of a patient's CTA. SIEP is depicted in yellow, DIEP in green, and the DIEP intramuscular course in magenta. The umbilicus appears in purple. A, 3D model including skin segmentation. B, Anterior view of the abdominal wall vessels and muscles. C, Antero-lateral (Lt. lateral rotation) view of the abdominal wall vessels and muscles.

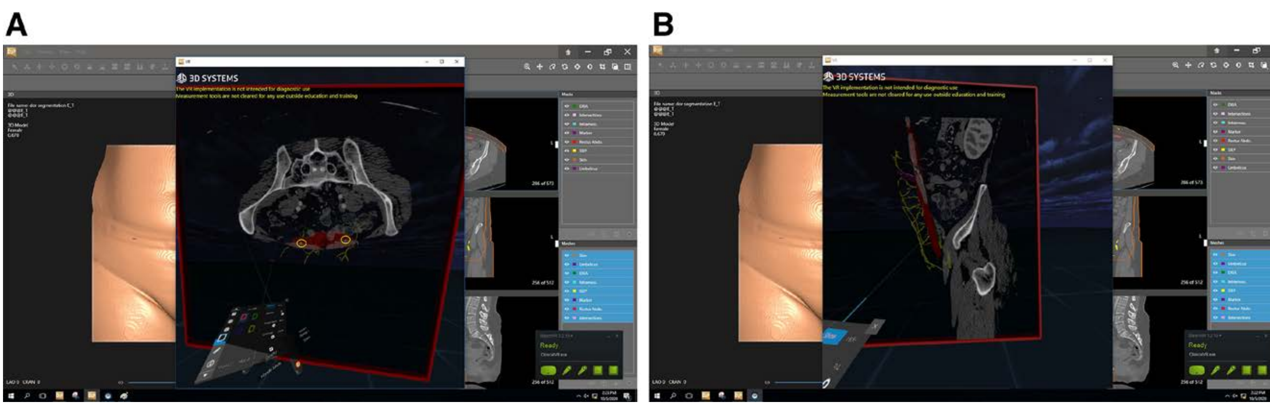

Fig. 2. Adjusting the patient's CTA to the exact location in the 3D model. The complete overlap between the 3D segmentation and the CTA is circled in green. A, An example of an axial section of the CTA before surgery, projected on the 3D model at sacral height. B, An example of a sagittal section of the CTA before surgery, projected on the 3D model.

the rectus abdominis and pyramidalis muscles were red. (**See Video [online]**, which shows how the 3D model is controlled by the surgeon, and at the same time what is seen through the VR glasses.) Before the first use of the system, all the surgeons were given a brief presentation on instructions for use, which took roughly 5 minutes, followed by a self-experimentation time of about 15 minutes.

Surgical Guidance

On the morning of the surgery, the surgeon assigned to harvest the flap and perforators used CTA to locate the exact location of the DIEA and the perforators that would be used to supply the flap. Then, the surgeon was shown the patient's 3D VR model, and a second identification and measurement of the selected vessels was performed. Approximately 10 more minutes were spent by the surgeon examining the 3D model from the moment the model was received up to the final decision on the surgical method. If any new information emerged after examining the VR model, it was reverified on the CTA scan.

Postoperative Questionnaire

After each procedure, all the surgeons who harvested the perforator in both medical centers were asked to fill in a 12-item questionnaire adapted from Wellens et al.[16] (**See questionnaire**, **Supplemental Digital Content 1**, which displays surgical questionnaire, **http://links.lww.com/PRSGO/C358**.). The questionnaire was completed immediately after surgery. The selected perforator anatomical course was adapted from the five-level Vandevoort et al[17] artery classification as follows: (1) short: the course through the muscle was less than 4 cm in length; (2) long: the course through the muscle was more than 4 cm in length; (3) subfascial: the perforator ran under the fascia before entering the muscle; (4) paramedian: the perforator was located at the medial border of rectus abdominis muscle; and (5) intersection: the perforator was located at the tendinous intersections.

Data and Statistical Analysis

To test for differences between the surgeons' clarity and applicability ratings of the CTA versus the VR, a Spearman's correlation coefficient was used. To test for differences between the surgeons' rankings of the clarity and applicability and whether the surgeons' ratings differed from a score of 3 (the midrange of 1–5 Likert scale), a Wilcoxon signed-rank test was used. A Kruskal-Wallis test was used to test whether the surgeons' ratings on different questions depended on the complexity of the perforator. All the statistical analyses were run on R software version 4.1.2.

RESULTS

The cohort consisted of 30 patients 34–68 years of age (mean 47.1 years), who were scheduled to undergo immediate DIEP or free TRAM flap breast reconstruction, of whom 12 patients had a bilateral reconstruction, for a total of 42 flaps. The preoperative planning and operations were performed by a team of three experienced plastic surgeons specialized in microsurgery and breast reconstruction (A.T., A.L., and Y.B.). All the patients had a presurgical CTA that was evaluated, and a 3D VR model was constructed to be viewed and compared according to protocol. In all cases, the DIEA perforators were considered the relevant donor blood vessels. Forty of the flaps were planned as DIEP reconstructions, and two as free TRAM reconstructions based on the initial CTA evaluation. However, based on the VR evaluation, two of the 40 planned DIEP procedures were switched to free TRAM, and both planned free TRAMs were switched DIEPs. In six flaps, minor postoperational complications were observed, including partial flap loss, flap infection, and congestion. There was complete flap loss in one case; the remaining 41 flaps were all successful. None of the complications occurred in the patients where the surgical plan was changed after the VR viewing.

For purposes of evaluation of the DIEA perforator, an initial assessment of clarity and applicability of the CTA and VR images was conducted. The first question on the questionnaire assessed the anatomical course complexity of the arteries as determined during surgery based on an adaptation of the Vandevoort terminology. Each perforator was classified into one of three complexity levels: *simple*, corresponding to Vandevoort class 1; *complicated*, corresponding to Vandevoort class 2; and *very complicated*, corresponding to the combination of Vandevoort classes 2 and 3. A more clinical division was established rather than Vandevoort's purely anatomical classes 4 and 5. Vandevoort class 4 (paramedian location) was defined as simple in cases where a paramedian location was found. No perforators in this study were located at tendinous intersections, and thus, Vandevoort class 5 was excluded.

Questions 2 and 3 evaluated the ease of interpretation of each modality. As shown in Figure 3, there was a significant difference of 1.242 and a median difference of 2 between the preferred VR and CTA ranking (V = 19.5, $P < 0.00001$). As shown in Figure 4, there was no significant difference between the ratings of the two imaging methods (rs. = −0.246, $P = 0.1976$) for level of complexity of the perforators.

Questions 4 and 5 evaluated the planned surgical approach chosen after evaluating the imaging provided by each modality. A Kruskal-Wallis test showed that the difference between the means for the three different anatomical complexities was not significant ($X^2 = 2.921$, $p = 0.2321$); that is, there was no effect of the complexity of the anatomical course of the artery on the chosen perforator.

Question 6 evaluated the complexity of the perforator and showed that the type of model had no effect on the extent to which the model provided additional guidance ($X^2 = 4.2024$, $p = 0.1223$). In other words, VR was considered useful in evaluating all types of perforator blood vessels, irrespective of the Vandevoort classification.

Question 7 on the surgical approach showed that in 55.17% of the cases, the surgeons rated the 3D model as either 4 or 5 in providing additional guidance. The median was not 3, as would be expected in a normal distribution (X^2 (4), $P = 0.1059$). A Wilcoxon signed-rank test showed that the midrange of the Likert scale was above 3 (V = 185, $P = 0.01331$).

Question 8 examined whether VR was seen as an essential tool for future procedures. In 86.21% of the cases, the surgeons rated VR as 5, thus indicating they would use the VR model as part of preoperative planning for their next procedure (Fig. 5).

Question 9 examined whether the VR 3D prompted the surgeons to change their decision as to the CT-aided, selected perforator. As shown in Figure 6, 55.17% of the surgeons responded negatively, with ratings of 1 or 2. The uniform distribution was found to be marginally significant (X^2 (4) = 8.069, $P = 0.101$), and the median rating score for this question was significantly lower than 3 (V = 52, $P = 0.013$), showing that in most cases, the VR 3D model did not cause the surgeons to revise their decision as to the selected perforator.

Question 10, as shown in Figure 7, examined the artery representation in the VR. Here, 72.4% of the surgeons rated the VR 3D model as having a maximum similarity to reality, where satisfactory resemblance was defined as a score greater than or equal to 4 of 5, and the median rating was significantly higher than 3 (V = 369, $P < 0.00001$). No difference was found between surgeons' ratings and the levels of perforator anatomical course complexity (X^2 (2) = 4.67, $P = 0.968$).

Questions 11 and 12 examined whether the VR contributed new information. In 86.21% of the surgeons' ratings, the VR was considered to have provided new information that the CT alone did not reveal (Fig. 8A). According to the surgical records, the use of VR did not shorten the duration of the abdominal flap harvest, and the surgical procedure did not change (Fig. 8B).

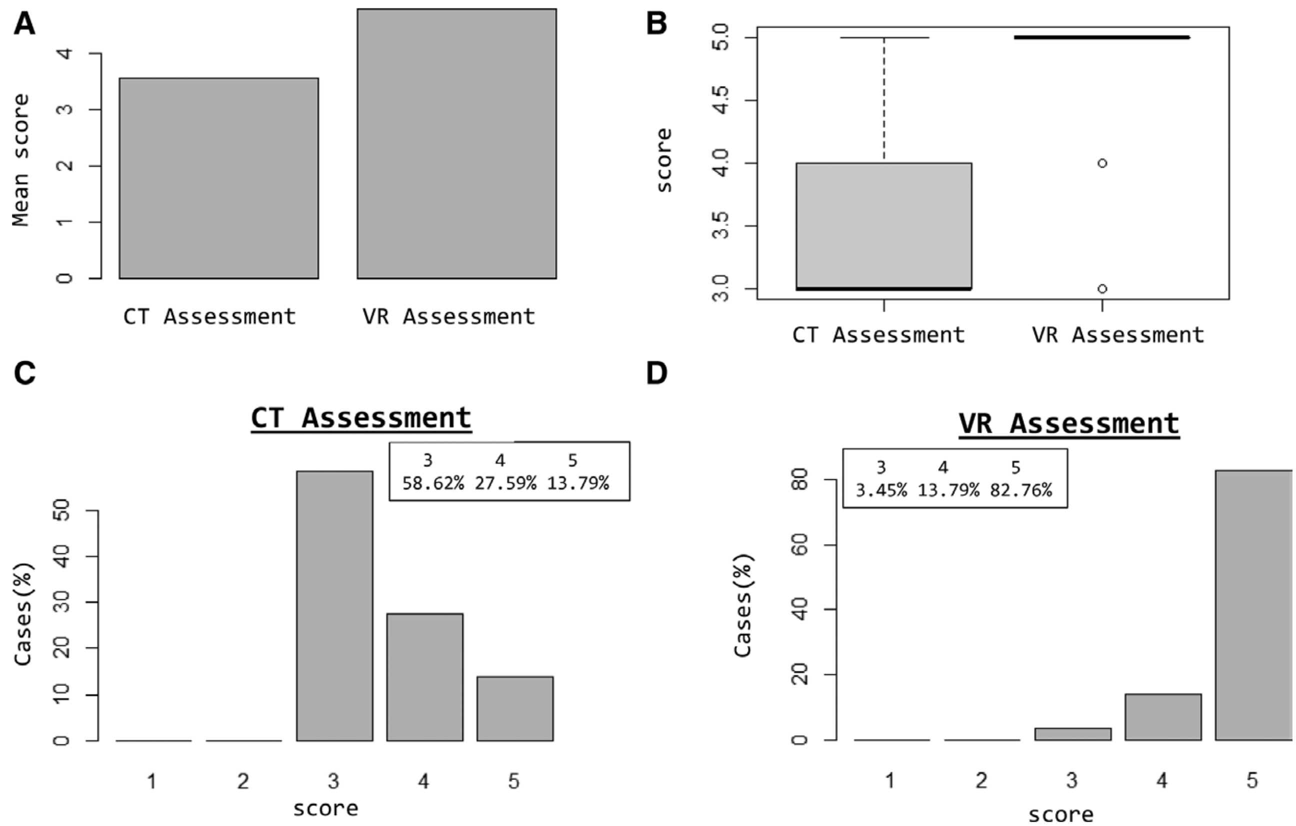

Fig. 3. Surgeons evaluated each modality according to ease of use and data interpretation. A, Mean scores evaluating the ability of the CT versus VR to assess the target artery. B, Histograms show the ratings for each imaging method. C and D, Ratings for CT and VR as a function of the relative percentage of cases.

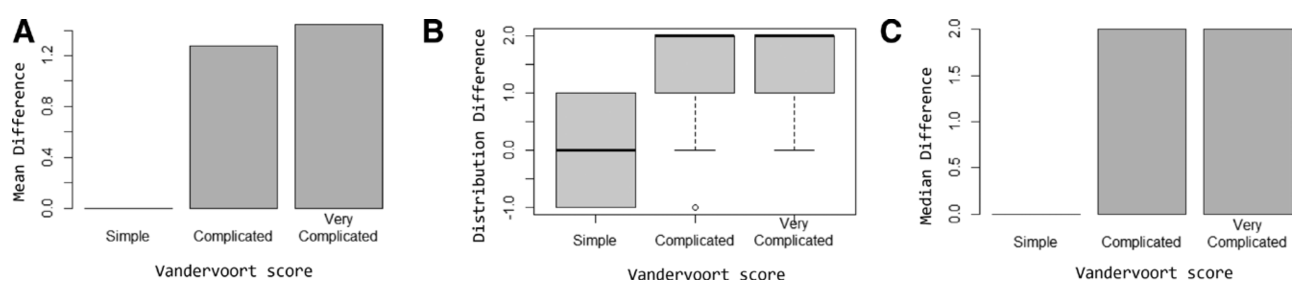

Fig. 4. Difference = $VR_{score} - CT_{score}$. No correlation was observed between the level of complexity of the perforators and the selected imaging method. A, Mean difference for the degree of complexity. B, Distribution of differences. C, Median of differences for the degree of complexity.

DISCUSSION

The use of novel technologies and VR has recently been explored in the field of breast reconstruction.[18–23] According to a systematic review published in May 2020, VR is likely to reduce the duration of surgery, improve outcomes, and enhance accuracy.[24] Our study was designed to determine whether VR can assist surgeons in preoperative planning and to what extent VR provides additional information that cannot be obtained from CTA alone.

In this study, in 96.55% of the cases, the surgeons rated the accessibility of new information by the VR as 3 or better (48.28% chose the maximal evaluation score of 5). This may have been confounded by their ability to examine the patients' data twice, first as a CTA scan, and then as a stereoscopic 3D model. Nevertheless, it supports the finding that stereoscopic 3D information is more intuitive and easily understood and remembered. In terms of the clarity and usability of the images obtained by both CTA and VR, in most cases, the VR model was preferred. Of the participating surgeons, 72.4% rated the VR 3D model as having maximum similarity to reality, with a median rating that was significantly higher than 3, with no significant difference between the surgeons' ratings and the levels of perforator anatomical course or complexity.

No correlation was observed, though, between the level of complexity of the perforators and the selected

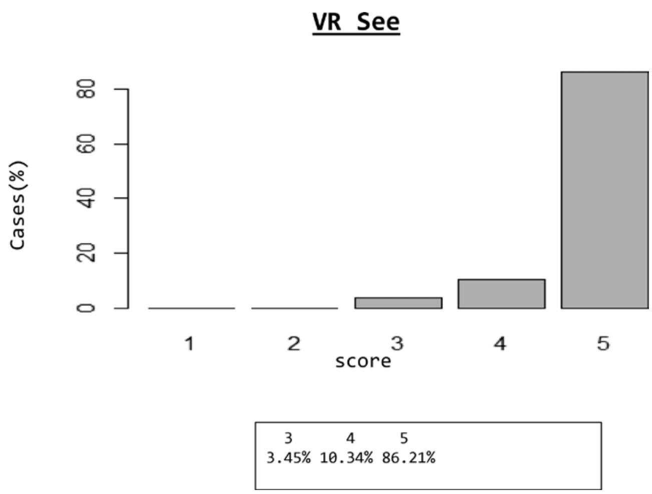

Fig. 5. Percentage of surgeons interested in viewing the VR model in subsequent procedures.

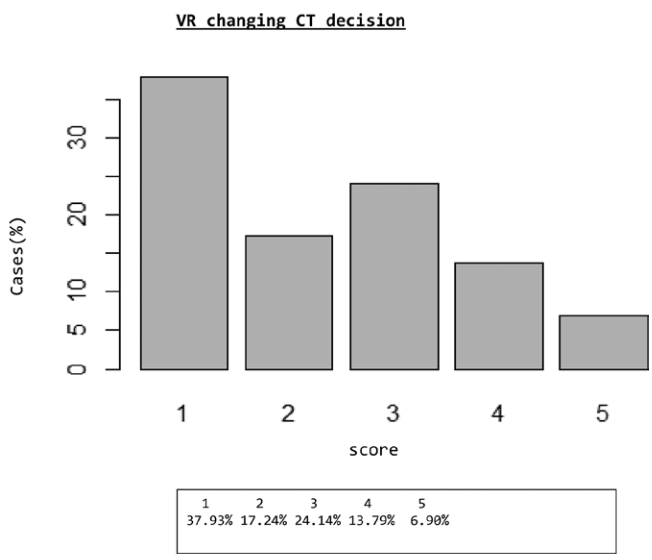

Fig. 6. Viewing a VR 3D model in most cases did not change the decision with respect to the preferred perforator chosen by the CT (either the DIEP flap or the free TRAM flap).

imaging method. The perforators' complexity did not affect the extent to which the 3D model provided additional guidance. The VR served in most cases to confirm decisions that had already been made based on the CTA, and only supported a different clinical decision than the one based on the CTA in a few specific cases (Fig. 7). In other words, in the context of complex perforators, the VR did not show any significant advantage over the CTA. This leads to two main conclusions. The first is further endorsement of the current gold standard, CTA, as a reliable method for planning this type of surgery. The second is that, despite the strength of the CTA method, in four out of the 42 flaps (9.5%), the VR revealed details such as the perforator's exact location, the intramuscular route length, and the perforated split direction toward the abdominal wall that were not obvious in the

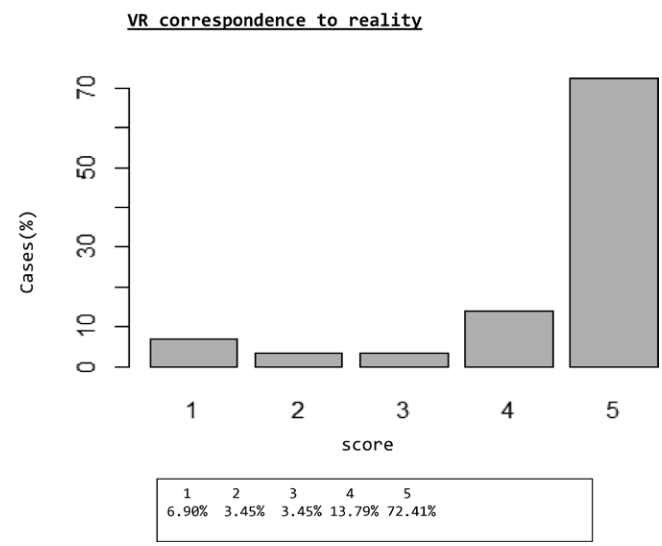

Fig. 7. Accuracy of VR imaging in displaying the location of the perforators. Accuracy was rated as more than 3 out of 5 by 86% of the participants.

standard CTA evaluation and thus allowed for crucial decision-making and changed the surgical approach.

It is known that for a successful anastomosis, several factors must be taken into consideration, such as the number and location of DIEA splits, the intramuscular spread and course, and the point of exit from the fascia. Several factors contribute to an unfavorable anatomy, such as the absence of a dominant vessel, the need for a large amount of muscle tissue to be sacrificed, and the presence of many splits near the flap entrance. Thus, identifying a dominant vessel may be sufficient to perform a DIEP procedure; however, its anatomy within the flap and intramuscular course, which are easier to evaluate using the VR, may play an important role in its use. In the early phases of the study, although automatic segmentation was preferred, it was particularly evident that for very small blood vessels with small diameters, manual segmentation was necessary to maintain the model in alignment with the anatomical course of the vessels.[25] The surgeons' observation was that the VR was able to measure the size and route of the blood vessels with great precision, but their functional caliber and blood flow could not be assessed and determined.

The main limitation of the VR technique is the need to remove the headset after finishing the preoperative planning before surgery. Future use of augmented reality (AR) technology may resolve this problem, although it is still not fully accurate for soft tissue body registration. In addition, operating the AR set is difficult, takes time to learn, and requires users to be tech-savvy. As shown in Figure 8B, the surgeons felt subjectively that the surgery was shortened in 55% of cases, though no difference was observed according to the formal documentation and further studies are now being conducted to determine whether VR, in fact, shortens the surgery duration. AR application may facilitate faster flap harvesting in the future; however, accurate registration tools remain to be developed.

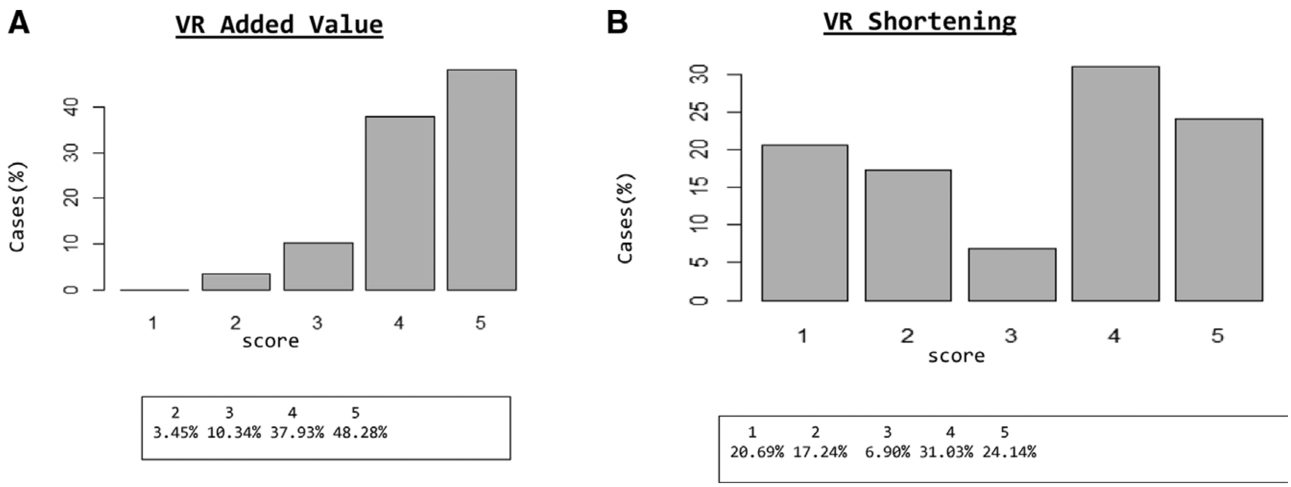

Fig. 8. Surgeons' evaluation regarding procedure time shortening and added value gained after VR preoperative planning. A, In comparison to the CT, VR was rated higher by 86.21% of participants, indicating 3 and above. B, In 55% of cases, the surgeons had the subjective impression that surgery time was shorter when using VR, though the surgical records have not demonstrated this finding.

CONCLUSIONS

Overall, the VR was seen by most of the surgeons as an important complementary tool for future procedures. It was found that in 86.21% of the cases, the surgeon expressed strong interest (a score of 5) in using VR 3D models in the future. VR technology has made significant progress lately and is now readily available, making it possible to generate models in under an hour using various software applications. It provides additional data and can supply surgeons with feedback on preoperative planning with CTA. The results demonstrate the feasibility of VR as an imaging technique for DIEP surgery, and further evaluation is needed to determine which of the imaging techniques provides a better understanding of the anatomy.

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