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EXPERIMENTAL

Pork Belly: A Simulation Training Model for Intramuscular Perforator Dissection

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Background: Free tissue transfer has evolved from muscle flaps to fasciocutaneous flaps. Dissection of the intramuscular course of feeding vessels is technically challenging. Simulation-based microsurgery skills acquisition is moving toward nonliving training models. Living porcine model or human cadavers are currently cost-ineffective methods for the early learning curve in teaching intramuscular dissection. The aim of this study was to validate an inexpensive ex vivo porcine model simulating harvest of the deep inferior epigastric artery perforator (DIEAP) flap, specifically including perforator intramuscular dissection.

Methods: An initial needs analysis and anatomical dissections (characteristics of vascular anatomy) established the necessity and surgical design (step-by-step) of the ex vivo DIEAP flap harvesting model. A pilot study utilizing objective assessment methodology (time to complete flap raising and hand motion analysis) demonstrated the surgeons' performance. A detailed feedback questionnaire was used to assess the participants' perception of this model.

Results: Fifty-seven participants completed the initial needs analysis. Fifteen pork bellies were dissected and the vascular anatomical characteristics of the inferior epigastric vessels are presented. Eight surgeons performed the step-by-step flap design demonstrating construct validity in flap raising and intramuscular dissection. All surgeons completed the ex vivo DIEAP harvesting and they recommend this model as the first step in training for intramuscular dissection.

Conclusions: The pork belly simulation is a cheap, easy, ethically considerate, and high-fidelity simulation model for intramuscular dissection for the DIEAP free flap. This study guides future validation trials to explore if the absence of physiological blood flow affects skills acquisition in the intramuscular dissection learning curve. The pork belly could be the first step in perforators dissection before progressing to the in vivo porcine model. *(Plast Reconstr Surg Glob Open 2018;6:e1674; doi: 10.1097/GOX.0000000000001674; Published online 14 February 2018.)*

INTRODUCTION

Muscle-sparing fasciocutaneous free flaps have evolved from pedicled musculocutaneous flaps in parallel with advances in microsurgery to become the "workhorse" flaps in plastic and reconstructive surgery. Dissection of intramuscular perforators is technically challenging. Successful harvest of workhorse flaps, such as the anterolateral flap through the vastus lateralis muscle[1] and the deep inferior epigastric perforator (DIEAP flap through the rectus abdominis muscle[2] requires the operating surgeon to be expertly proficient in intramuscular dissection of the vascular pedicle).[3] Microdissection occasionally requires supermicrosurgical skill set for the dissection of very small calibre perforator vessels.[4]

Skills acquisition in microsurgery training is associated with a steep learning curve,[5] necessitating competency-based, hierarchical training, including microdissection, microvascular anastomosis, flap raising, and more recently perforator dissection. Plastic surgery residencies increasingly introduce microsurgery training with simulation sessions. The current trend in simulation training is toward models that address the ethical principles

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Received for publication March 20, 2017; accepted December 21, 2017.

DOI: 10.1097/GOX.0000000000001674

Disclosure: *The authors have no financial interest to declare in relation to the content of this article. The Article Processing Charge was paid for by the authors.*

of the replacement, reduction, and refinement (3Rs) of live animal use and which are cost-effective.[6] A number of training courses use the living porcine model or human cadavers to teach intramuscular dissection, but these are expensive.

An ideal simulation would limit live animal use, and be inexpensive to allow practical and repeated access. It would have high levels of validity. There is a clear gap for a nonliving simulation model that includes intramuscular perforator dissection. The pig provides an excellent in vivo model for dissection of a flap analogous to the human (DIEAP) flap, but has no flap closely analogous to the anterolateral. In this study, we explore an ex vivo porcine DIEAP simulation model.[7]

METHODS

Targeted Needs Assessment

An initial targeted needs analysis engaged undergraduate and postgraduate candidate to our microsurgery simulation laboratory. Participants from all levels of training attended the course, including medical students, foundation trainees, core surgical trainees, and specialty trainees. The needs analysis consisted of an exhaustive list of 39 focused questions to gauge the attendees' previous microsurgical experience and to establish what their attitudes toward simulation models were. Responses were scaled using a typical 5-level Likert scale.[8] Two questions focused on the development of the ex vivo pork belly dissection model: (1) regarding perforator dissection, whether "simulations should develop to include simulation of vessel access and flap raising, rather than just microvascular anastomosis" and (2) addressing the attendees' attitudes toward the ethical principle of 3Rs in simulation models, whether "simulations should develop to include biological nonliving animal models, for example, chicken limbs, pig legs, etc."

Surgical Design

A fresh pork belly, weighing approximately 9 kilograms, was purchased for 2 USD per kilogram, from the local butcher (Fig. 1). Using a permanent marker pen, the border of a hemi-DIEAP flap was outlined and the expected course of the underlying vessels (Fig. 2). Meticulous intramuscular dissection of the DIEAPs was possible, and analogous to the in vivo porcine training experience. Anatomical dissections investigated the following; the total number of perforators, and the number of perforators leading to the DIE (deep inferior epigastric) and SIE (superficial inferior epigastric) vessels, the number of branches requiring ligation during intramuscular dissection, all vessels calibers (perforators, SIE, and DIE), length of pedicle and internal mammary vessels characteristics. The microvascular anatomy of the pork belly and its perforators was further investigated to establish anatomical consistency. A submillimeter scale (Crownjun Microscale) was used to measure the calibers of the perforators and a surgical ruler to measure the pedicle length (Fig. 3). Results were entered and analyzed using Microsoft Excel software (version 15.25).

Characterizing the Porcine Microvascular Anatomy

Fifteen hemi-pork bellies (Fig. 1) were dissected to identify the vascular tree of the deep (inferior and superior) epigastric artery and vein, and their intramuscular courses and the patterns of their muscle branches. All specimens were assessed for anatomical variations in the perforator patterns (medial and lateral) for both the superior (s) and inferior (i) vascular pedicles. The internal mammary vessels were also dissected to examine the feasibility of performing a (iDIEA/V or sDIE arterial or venous) to Internal Mammary artery or vein (IMA/V) anastomosis. A step-by-step Hierarchical Task Analysis (HTA) was constructed to reflect the key technical components of a hemi-DIEAP free flap simulated harvest.

Pilot Exposure of Surgeons

A pilot study exposed expert microsurgeons, resident surgeons in training, and novice surgeons to this hemi-DIEAP free flap simulation model to establish reliability outcomes. All participants watched a short demonstration video outlining the hemi-DIEAP free flap harvesting simulation exercise. An objective assessment of the participants' performance during those steps could allow quantification including time to complete flap raising (T), Hand Motion Analysis (HTA) outputs (total movements and total path-length of 4 sensors placed on each index finger tip and dorsum of each hand. The potential of DIEA/V-to-IMA/V anastomosis was investigated and outcomes are assessed using the anastomosis lapse index score[9] and presented. Hand Motion Analysis (HTA) (DextrousMD, Inition, London, United Kingdom) provided total time, path length, and the number of movements, and these were analyzed using SPSS 16.0 and a Student's t test with a P value < 0.05 as statistically significant (Table 2). A feedback questionnaire, using a Likert-type scale, evaluated the participants' perception of the ethical purpose, level of fidelity, reliability, and level of validity of this model.

RESULTS

Targeted Needs Assessment

Fifty-seven candidates, from 2014 to 2016, across different specialties; plastic and reconstructive surgery, general surgery, neurosurgery, and oral and maxillofacial surgery completed the focused questionnaire. Thirty-one respondents (54%) indicated that they "strongly agree" with Q1 statement and none of the attendees reported that they "strongly disagree." Other responses included "moderately agree" (n = 19; 33%), "neutral" (n = 5; 9%) and "moderately disagree" (n = 2; 4%). Thirty-one responders (54%) indicated that they "strongly agree" with Q2. Other responses included "moderately agree" (n = 16; 28%), "neutral" (n = 6; 11%), "moderately disagree" (n = 2; 4%) and "strongly disagree" (n = 2; 4%).

Characteristics of the Porcine Microvascular Anatomy

Anatomical dissections demonstrated that the vascular anatomy is completely relevant to clinical practice and is easily reproducible. The average number of perforators in each dissected flap were 3.3 (2–5), and 2.1 (1–3) perfo-

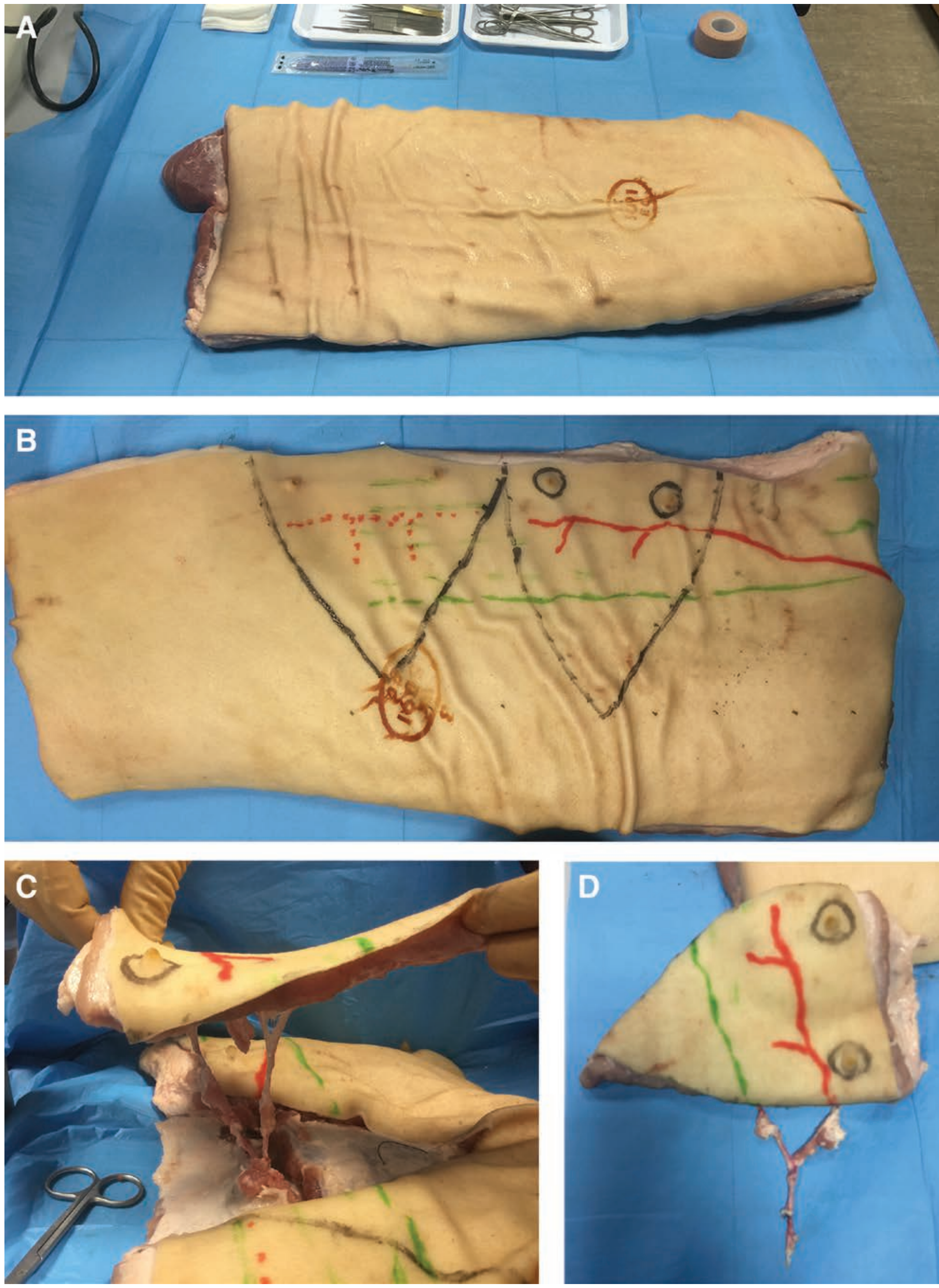

Fig. 1. Photographs of the pork belly and underlying vessels. The pork belly (A). Horizontal semielipti- cal skin markings for the porcine semi-DIEAP flap, along with the expected course of the deep inferior epigastric pedicle (B). Flap elevation and intramuscular dissection of pedicle (C). Successful flap harvesting demonstrating the 2 perforators and the pedicle length (D).

rators were leading to the DIE pedicle. The average number of intramuscular branches identified were 2.7 (1–5) to reach an average pedicle length of 10.7 (7–14) cm. The average caliber of the dominant perforator was 0.2 (0.2–0.4) mm; the DIEA was 1.4 (1.2–1.6) mm, the DIE venae comitantes was 1.7 (1.4–2.0) mm, and the SIE was 2.0 (1.8–2.3) mm. The calibers of internal mammary vessels were measured above 5 mm in all dissections; therefore, recipient end-to-end anastomosis was not optimal to be performed due to vessels caliber discrepancy.

Pilot Exposure of Surgeons

Eight participants performed this DIEAP simulation exercise: 2 medical students and 2 junior residents without clinical microsurgical experience (group A), and 2 senior residents and 2 consultant microsurgeons (group B). There was a statistically significant difference between the 2 groups: the total time taken by group A (81 ± 7 minutes) was significantly less than group B (200 ± 75 minutes), $P = 0.02$; the total number of hand movements for group A (58,389 ± 12,765 mm) was significantly more than group

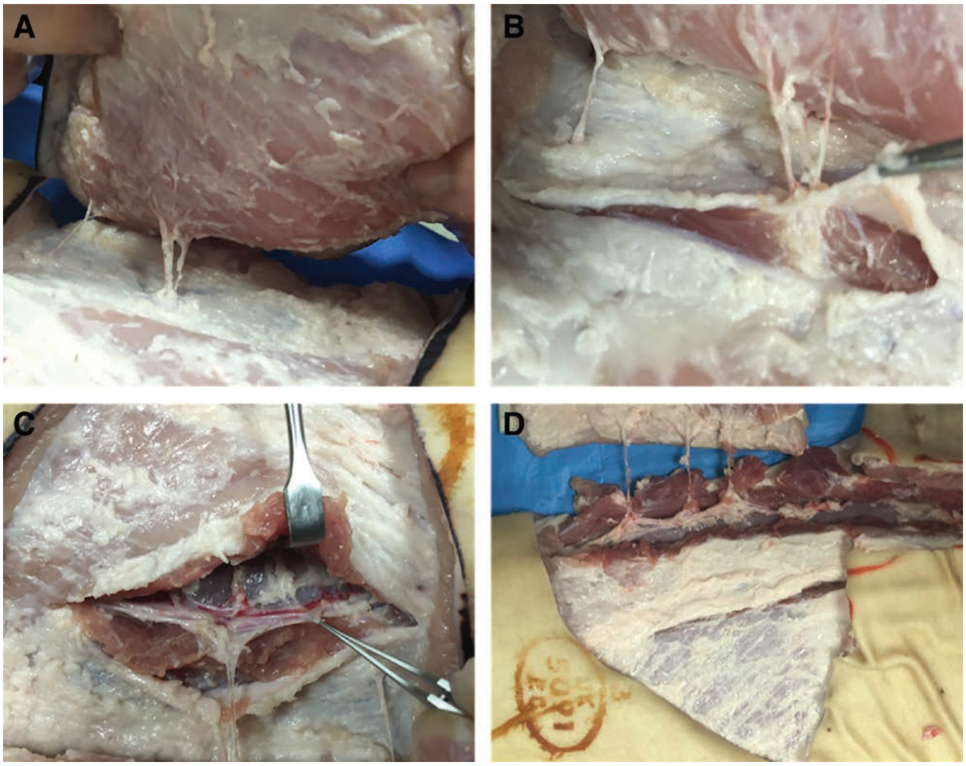

Fig. 2. Photographs of intramuscular dissection. Suprafascial perforators (A). Intramuscular penetration of perforators (B). Intramuscular dissection identifying the origin of the DIE pedicle (C). Multiple perforators in a row originating from the DIE pedicle (D).

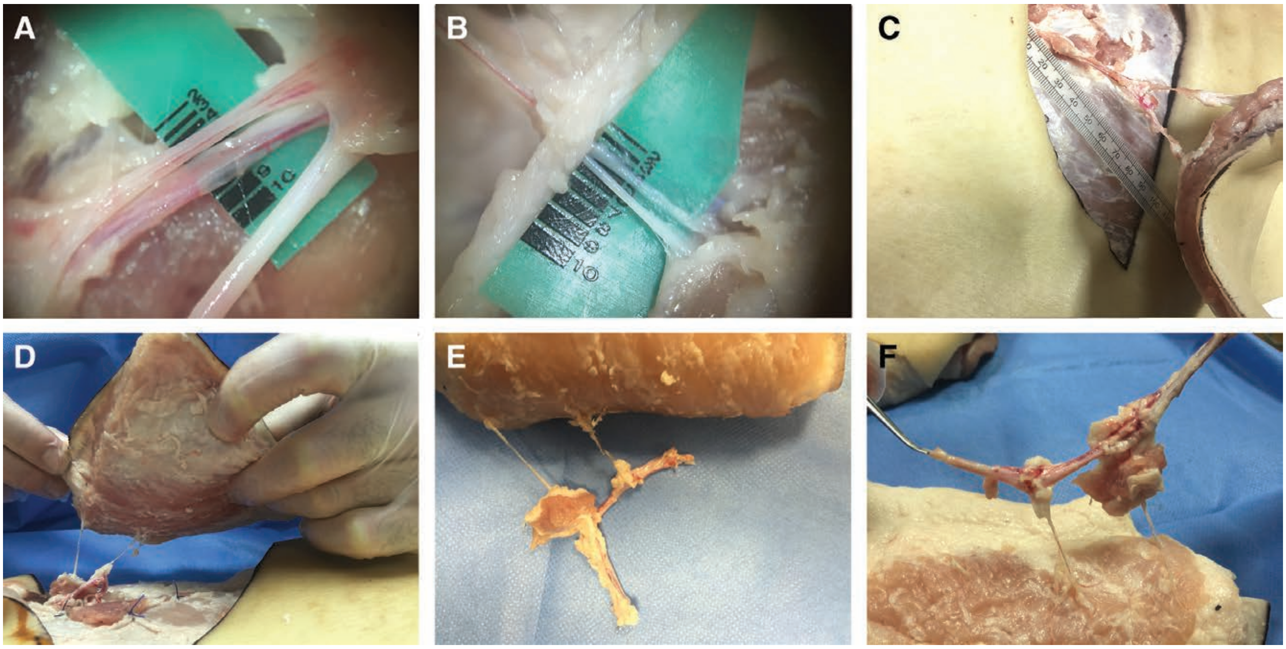

Fig. 3. Photographs of the DIE pedicle. (A) The perforator vessels (B) with a submillimeter scale. The measurement of the pedicle length (C and D). Two perforators leading to the main pedicle demonstrating 2 techniques: small muscle cuff perforator dissection and intramuscular dissection and skeletonizing of the vessel (E and F).

B (33,542 ± 4,140 mm), $P = 0.01$; and the total path length for group A (237,440 ± 57,643 mm) was significantly more than group B (129,057 ± 47,993 mm), $P = 0.028$.

Outcomes from the feedback questionnaire demonstrated that 7 of 8 participants strongly agreed that the pork belly simulation model adequately represents the "dissection skills used in raising the DIEAP flap" and "the intramuscular dissection skills required for the pedicle dissection during the DIEAP flap." Six of 8 participants strongly agreed that they would "recommend courses with nonliving models for trainees before living animal courses for flap raising, especially for DIEAP flap training." All 8 participants strongly agreed with the statement "Learning on this nonliving model is an important first step prior to operating on a living pig DIEAP model, according to the principles of 3Rs."

DISCUSSION

This ex vivo model simulates the surgical steps in raising a DIEAP flap: preparation and marking of the surgical site, perforator identification and selection, intramuscular dissection, and the microvascular anastomosis to the recipient vessels.

The pork belly nonliving training model is inexpensive, reliable, and easily reproducible. It does not require special facilities, such as anesthetic equipment, or extensive institutional experience to set up, compared with the living porcine model. It simulates an important step of a free-flap procedure that follows the principles of free tissue harvest and potentially may include a 2-teams approach to expand from flap harvesting only to nonliving model recipient vessel preparation and microvascular anastomosis. The pork belly used in this simulation model should be purchased under specific requirements: (1) a "long-belly cut" with more than 4 nipples in the cephalocaudal direction; (2) there should be a 2–3 cm skin bridge from the midline laparotomy incision to the nipple line, and more than 15 cm of skin to the lateral margin; (3) a cut should extend from the lowest 4 sternocostal joints to at least 10 cm from the fourth nipple inferiorly. A pork belly cut in this way will include all the anatomical structures in the anterior abdominal wall deep to the peritoneum.

Fresh pork belly vascular anatomy offers pedicles with vessels of variable length with similar characteristics to human vascular anatomy. It provides high face validity tissue dissection, similar to cadaveric or living porcine models and adheres to the principles of 3Rs. Harvest of the DIEAP flap in a living simulation porcine model has been described as unfeasible in a previous laboratory study.[10] However, in our model, we were able to successfully harvest the DIEAP flap in our model by following a step-by-step approach (Tables 1–2). Stefanidis et al.[11] reported that cadavers and living porcine models are comparable with in vivo clinical surgery for surgical trainees. Using a pork belly to simulate intramuscular dissection demonstrated face and construct validity.

The lack of blood flow in such nonliving models reduces the face validity. However, this model allows the trainee to visualize perforator patterns and to identify and to select a suitable perforator during flap harvest. In microvascular anastomosis simulation, nonliving models act as a first step in optimizing technical skills acquisition, according to the principles of 3Rs.[12,13] In this hemi-DIEAP flap model, the lack of blood flow could in some ways be addressed using an infusion pump or latex solution to assist in perforator identification and selection, as demonstrated by Alvernia et al.[14] in their anatomical dissection study of human cadaveric heads following injection with latex. In our experience using colored saline infusion to simulate artificial blood proved insufficient to demonstrate the quality of the anastomotic leaks. When infusion of latex was performed, the anastomotic patency could be established and minor leaks could be easily simulated from the highly cohesive latex fluid.

Our pilot study demonstrated significant differences in the hand motion analysis outputs of overall time, total number of movements, and total path length for flap raising and harvesting between surgeons of 3 levels of experience, confirming construct validity. Experienced consultant surgeons performed the procedure with a greater economy of hand movements. Participants indicated in their feedback that, of all simulation steps in this model, intramuscular dissection most accurately resembled clinical operating. Subjective assessment of surgical experience using logbooks, direct obser-

Table 1. A step-by step Hierarchical Task Analysis (HTA) Guide for Pork Belly Hemi-DIEAP Flap Harvesting

Step 1: The borders of the flap are delineated, starting from the midline of the abdomen extending to the lateral midline in a hemi-elliptical manner following the expected course of the underlying DIE vessels.
Step 2: Superior and inferior skin incisions of the hemi-DIEAP flap are made with a scalpel (Fig. 2).
Step 3: The incisions are extended deeper, carefully preserving the deep fascia (note: in the porcine model, dissection through an additional layer of panniculus muscle is required).
Step 4: The flap is elevated from the lateral edge of the ellipse medially toward the lateral border of the anterior rectus fascia.
Step 5: Perforators are identified and isolated until the flap is fully elevated from the anterior rectus fascia and is islanded on its perforator branches.
Step 6: A row of perforators leading to the pedicle arises in this dissection plane. Perforators leading to the lateral pedicles should be sacrificed.
Step 7: The SIE artery and veins in the superior and inferior incisions are identified and preserved with a reasonable pedicle length.
Step 8: The anterior rectus fascia is incised vertically. Muscle splitting and dissection 1–2 cm lateral to the perforator-fascia junction, with superior and inferior extensions leading to the direction of the main sDIEAP or iDIEAP.
Step 9: Meticulous intramuscular dissection of the perforators to the DIE artery and DIE veins by careful ligation of site branches.
Step 10: The sDIEAP and/or iDIEAP pedicles are clipped and flap can be transferred.

Table 2. Pork Belly Deep Inferior Epigastric Vascular Anatomy

Modalities Measured		Mean	SD
No. perforators/flap		3.3	1.0
No. perforators leading to the DIEA pedicle/flap		2.1	0.5
No. intramuscular branches identified		2.7	1.1
Caliber of the dominant perforator (mm)		0.5	0.1
Caliber of the nondominant perforators (mm)		0.2	0.1
Caliber of the deep inferior	A	1.4	0.2
epigastric system (mm)	V	1.7	0.1
Caliber of the superficial inferior	S	2.0	0.2
epigastric system (mm)	I	2.0	0.1
Length of the pedicle (cm)		10.7	1.9

A, artery; I, inferior; S, superior; V, vein.

vation, and simulated procedures is highly reliable, but the validity is variable. Using objective methodologies to assess surgical skills provides a quantification of skills acquisition. For example, GRS and HMA have a high reliability and validity, with potential predictive validity.[15,16] Face, content, and construct validities can effectively correlate ex vivo simulation models with specific technique-related clinical outcomes.[17] Furthermore, objective methods of assessment can be used in conjunction with qualitative and quantitative feedback provided by trainees during courses to identify areas of weakness and focus their training accordingly, for example, on intramuscular submillimeter perforator dissection.

There is a paucity of microsurgery training courses that simulate intramuscular dissection, which is a crucial and technically challenging step in perforator free-flap procedures. As with microvascular anastomosis training, the skills of microdissection and especially intramuscular dissection are better learned with a ladder-based curriculum. Early-years training should begin with the use of simple, nonliving models, which are easily reproducible, such as the pork belly. Trainees can then progress to using models with physiological blood flow, such as the porcine living model. Advanced training can be undertaken using cadaveric specimens, to fine tune the human anatomical and operative knowledge base. The proposed ladder-based curriculum for microvascular dissection encourages junior surgeons to improve their anatomical knowledge while acquiring the microsurgical skill set required for perforator free flap dissection in a safe simulation environment, following a systematic educational strategy.

CONCLUSIONS

This model is cheap, easy to set up, ethically considerate, and simulates high-fidelity intramuscular dissection. The outcomes here will guide future validation of nonliving perforator flap models, and exploration of the importance or not of physiological blood flow in intramuscular dissection skills acquisition. It is proposed as the first step during early learning curve training for basic microsurgical skills acquisition before progressing to the in vivo porcine model.

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