Received: 8 June 2018 | Revised: 29 March 2019 | Accepted: 2 April 2019

DOI: 10.1002/hed.25775

ORIGINAL ARTICLE

WILEY

Dual-phase CT angiography for presurgical planning in patients with vessel-depleted neck

Eugenie Du MD[1] | Sagar Patel BS[2] | Benjamin Huang MD, MPH[3] | Samip N. Patel MD[1]

[1]Department of Otolaryngology—Head and Neck Surgery, University of North Carolina at Chapel Hill School of Medicine, Chapel Hill, North Carolina

[2]University of North Carolina at Chapel Hill School of Medicine, Chapel Hill, North Carolina

[3]Department of Radiology, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina

Correspondence
Samip N. Patel, Department of Otolaryngology—Head and Neck Surgery, 170 Manning Drive, Campus Box #7070, Chapel Hill, NC 27599.
Email: samip_patel@med.unc.edu

Abstract

Background: Microvascular reconstruction in vessel-depleted necks is challenging due to limited availability of recipient vessels. We examine the utility of dual-phase CT angiography (CTA), which delineates both arteries and veins, for preoperative planning in such difficult cases.

Methods: Retrospective chart review of a single surgeon from July 2013 to July 2017 in a tertiary referral center was performed. Patient characteristics, operative details, and surgical outcomes were examined.

Results: Thirteen patients met inclusion criteria. The operative plan was changed to a local flap for one patient as a result of imaging; free tissue transfer was performed for the remaining cases with 100% flap survival rate. Average operative time and ischemia time were 524 ± 110 minutes and 153 ± 47 minutes, respectively.

Conclusions: Dual-phase CTA can evaluate potential venous and arterial recipient vessel and guide surgical explorations. As such, it may aid in presurgical planning for microvascular free tissue transfer in vessel-depleted necks.

KEYWORDS

CT angiography, head and neck neoplasms/surgery, microsurgery, reconstructive surgical procedures, surgical flaps/blood supply

1 | INTRODUCTION

In head and neck (H&N) reconstruction, the most challenging and complex cases involve patients who have been previously treated by a combination of prior surgeries and chemoradiotherapy (CRT). Cases involving recurrent disease, second or third primaries, and osteoradionecrosis (ORN) are uniquely difficult surgically for a number of reasons. First, potential recipient vessels for microvascular reconstruction may have been sacrificed in prior surgeries. Furthermore, prior treatments cause distortion of normal tissue planes as well as loss of surgical landmarks making identification of remaining vessels more challenging. Finally, these cases are often referred to tertiary care centers for the expertise of experienced ablative and reconstructive surgeons. As a result, the operative surgeon performing salvage surgery is often not the surgeon who treated the patient initially. Even when detailed operative reports are available, the information conveyed is usually limited.

Patients who have undergone prior neck dissections or free tissue transfers are considered to have vessel-depleted neck anatomy. Often, time consuming and difficult neck explorations at the time of surgery are needed to ensure that adequate vessels are available. A number of papers report using alternative strategies in vessel-depleted necks such as the use of the superficial temporal, transverse cervical, thoracoacromial, external carotid, internal mammary systems, and arteriovenous grafts.[1-4] Knowledge of and familiarity with these nonstandard strategies can increase the likelihood of surgical success intraoperatively. Expert microvascular surgeons

Poster presentation at the American Head and Neck Society meeting at the Combined Otolaryngology Spring Meetings, National Harbor, MD, April 18-22, 2018.

depend on experience, extensive anatomic knowledge and an armamentarium of alternate flaps in approaching these cases. However, there is often little that surgeons can do preoperatively to optimize the patient for successful free tissue transfer from a vessel standpoint.

In our institutional experience, patients under consideration for surgical salvage or revision surgery universally undergo preoperative imaging with CT or MRI. When necessary, single-phase CT or MR angiography (CTA or MRA) can also be performed for evaluation of arterial flow and tumor involvement of vital vessels. While critical and useful, these imaging studies do not evaluate venous vasculature well. Major venous drainage pathways are often sacrificed as part of ablative H&N procedures. In addition, venous thrombosis is the main cause of free tissue transfer failures.[5] As a result, the rate-limiting step in neck explorations in patients with vessel-depleted neck is usually finding adequate recipient veins.

Dual-phase CTA is similar to conventional CTA but obtains a delayed set of images to highlight venous vasculature. It has been described to help delineate arterial and venous collaterals for patients with ischemic stroke.[6,7] It has also been used for the visualization of the portal system for assessment of abdominal pathology.[8-10] We report on the utility of using dual-phase CT imaging for preoperative planning in patients undergoing free tissue transfer with vessel-depleted neck.

2 | PATIENTS AND METHODS

2.1 | Patient selection

Patients were identified for inclusion in this case series in the following fashion. All patients enrolled in a H&N reconstruction were queried to identify those who underwent free tissue transfer with senior author (S.N.P) from July 2013 to July 2017. Institutional Review Board approval was obtained. Each patient's electronic medical record was scanned to identify those who underwent a CTA prior to surgery. These patients were selected for a more thorough chart review. Patient characteristics, operative details, and surgical outcomes were extracted. Patients met criteria for vessel-depleted neck if they had undergone one or more previous major neck surgeries such as neck dissection, local flap reconstruction, or free tissue transfer. The indications for imaging and preoperative notes were reviewed to ensure that a dual-phase CTA was obtained for presurgical planning purposes. Statistical analysis was performed using STATA version 15.0 (Stata Corporation, College Station, Texas).

2.2 | Dual-phase CTA

Dual-phase CTA examinations were performed on a multislice (64 or 128 channel) CT scanner, with images acquired from the aortic arch to the skull base at 0.6 mm collimation following intravenous injection of 75 cc of iodinated contrast (Omnipaque 350) at a rate of 4-5 cc/second, followed by 50 cc saline bolus. A bolus tracking technique used to trigger arterial phase imaging with the threshold set at 100 HU at the level of the aortic arch. Automatic exposure control techniques were used to modulate radiation dose with the reference voltage and current set to 120 kV and 200 mAs, respectively. Approximately 45 seconds after the arterial phase image set was acquired, a second delayed image set was obtained using similar acquisition settings in order to better visualize venous structures. Images were reconstructed for viewing at 1-1.5 mm slice thickness in the axial, sagittal, and coronal planes.

3 | RESULTS

Sixteen patients with vessel-depleted necks were identified as having undergone CTAs in preparation for free tissue transfer. Upon careful review, three patients were excluded as they received standard CTAs for other purposes. Thirteen patients were included in this study; details regarding their clinical features and operative course are described in Tables 1 and 2. All patients had undergone prior major neck surgeries with an average of 2.8 prior head and neck procedures. Eleven (85%) underwent prior neck dissection (6 bilateral, 5 unilateral), 10 (77%) had either prior radiation or CRT, and 7 (54%) had undergone prior free tissue transfers. The indication for surgery was ORN in four cases, osteomyelitis in one, persistent fistula in three, tumor recurrence in two, and trauma in three. All trauma cases were previously operated on by another surgeon or surgeons at initial presentation.

In two cases, a free tissue transfer was not performed despite potential recipient vessels identified with dual-phase CTA preoperatively. One case (patient 10) was aborted as tumor was found to be unresectable at the time of operation. In the other case (patient 5), patient presented with persistent pharyngotracheal fistula after total laryngopharyngectomy, bilateral neck dissection, ALT free flap for hypopharynx cancer followed by pectorals myogenous flap for postoperative pharyngocutaneous fistula. Given extensive surgical history and feasibility of a less morbid regional deltopectoral flap, a free flap was avoided in this situation and served as a backup option. In the remaining 11 cases, free tissue transfer was performed with 100% flap survival rate with a mean length of otolaryngology follow-up of 375 days. There was one complication of partial loss of split thickness skin graft (STSG) involving the donor site. The average surgery length was 531 ± 118 minutes, and the average ischemia time was

TABLE 1 Patient characteristics

Patient	Sex	Age	Number of prior H&N surgeries	Prior neck dissection?	Prior RT or CRT?	Prior local flap?	Prior free Flap?	Indication for surgery
1	M	72	5	Bilateral	Y	N	Y	ORN
2	M	58	1	Bilateral	Y	N	N	ORN
3	M	68	3	None	Y	Y	N	Osteomyelitis
4	M	67	3	Unilateral	Y	N	Y	ORN
5	M	61	3	Bilateral	Y	Y	Y	Fistula
6	F	53	3	Unilateral	Y	N	Y	ORN
7	M	15	1	None	N	N	N	Trauma
8	M	28	4	Bilateral	N	N	Y	Trauma
9	M	27	3	Unilateral	N	N	Y	Trauma
10	M	73	2	Bilateral	Y	N	Y	Recurrence
11	M	50	3	Unilateral	Y	N	N	Fistula
12	M	61	2	Unilateral	Y	N	N	Fistula
13	F	81	3	Bilateral	Y	N	N	Recurrence

Abbreviations: CRT, chemoradiation therapy; F, female; H&N, head and neck; M, male; ORN, osteoradionecrosis; RT, radiation therapy.

TABLE 2 Operative and hospitalization details

Patient	Recipient artery	Recipient vein	Recipient side[a]	Flap	Defect	Flap ischemia time (min)	Length of surgery (min)	LOS
1	Superior Thyroid	IJ		Scapula	Mandible	229	773	9
2	Facial	Facial		Scapula	Mandible	192	549	8
3	Facial	Facial		RFFF	Scalp	N/A	625	20
4	Transverse Cervical	EJ	Ipsilateral	ALTFF	Temporal	105	463	5
5				DP	Hypopharynx			14
6	Facial	Facial with cephalic vein graft	Contralateral	Scapula	Maxillary	108	559	20
7	Facial	Facial		Fibula	Oral cavity	185	530	8
8	Lingual	EJ		RFFF	Mandible	307	362	6
9	Facial	Facial	Contralateral	Fibula	Mandible	180	580	12
10								
11	Facial	Facial	Ipsilateral	RFFF	Nasal	N/A	349	7
12	Superior Thyroid	EJ and IJ	Ipsilateral	Fibula	Maxillary	202	556	7
13	Lingual	IJ		RFFF	Oral cavity	325	493	12

Abbreviations: ALTFF, anterolateral thigh free flap; DP, deltopectoral; EJ, external jugular vein; IJ, internal jugular vein; LOS, length of stay; N/A: not available; RFFF, radial forearm free flap.

[a]In patients with prior unilateral neck dissection, the laterality of the recipient side with respect to previous unilateral neck dissection is listed.

153 ± 48 minutes. The superior thyroid (two cases), facial (six cases), lingual (two cases), and transverse cervical (one case) were used as recipient arteries. The common facial (six cases, one with a cephalic vein graft), internal jugular (IJ; three cases), and external jugular (EJ; three cases) were used as recipient veins. The following two cases illustrate the potential utility of dual-phase CTAs in our clinical practice.

4 | CASE REPORTS

4.1 | Case A

The patient is a young male with a history of depression and self-inflicted gunshot wound. The initial injury resulted in extensive soft tissue and bony injury to the midface and mandible. He had undergone numerous surgical procedures, most notably, a failed osteocutaneous fibula free flap from

the right lower extremity, from another surgeon, and subsequent successful osteocutaneous fibula free flap from the left lower extremity by our team. Operative reports were available for both free tissue transfers. The operative report for the first free tissue transfer attempt states that microvascular anastomosis was attempted using the left facial artery and vein, as well as the left superior thyroid artery but tissue transfer was unsuccessful. The operative report for the successful fibula free flap notes that free tissue transfer was achieved using the right facial artery and vein. It also was noted that the carotid artery on the right side was explored and the superior thyroid and lingual arteries were identified and preserved. The patient is now seen with significant microstomia and oral incompetence.

The surgical plan was for a radial forearm free flap with palmaris tendon to reconstruct the lower lip. A preoperative dual-phase CTA was obtained that demonstrated patency of the right lingual and superior thyroid arteries, right IJ vein, left lingual artery, as well as the left EJ vein (Figure 1). Intraoperatively, a limited exploration of the left neck was performed, and successful microvascular anastomosis was achieved using the left lingual artery and left EJ vein as recipient vessels. Patient had no postoperative complications and was discharged from the hospital on postoperative day 8 tolerating a puree diet by mouth.

4.2 | Case B

Patient is an elderly female with a history of prior stroke and a T1N1M0 squamous cell carcinoma of the right buccal mucosa. Initial treatment 3 years before presentation was surgical resection including neck dissection followed by adjuvant CRT. She subsequently recurred a year later and underwent a second surgery to address the primary site. She recurred again 6 months later and underwent bilateral modified radical neck dissection and wide local resection including infrastructural maxillectomy. At this time, she was reconstructed with an obturator and an STSG as patient was initially hesitant to undergo a free tissue transfer. All surgical treatment up to this point was under the care of another surgeon. Patient presented with severe trismus and gastrostomy-tube dependence. Physical examination and in-office biopsy was difficult due to her severe trismus but was also concerning for tumor recurrence. Surgical plan was a coronoidectomy to release the densely fibrotic mandible, wide local resection, and resurfacing of buccal and palate region, and a radial forearm free flap. Only the operative report from the most recent surgery was available. It made note of sacrifice of bilateral facial veins, preservation of bilateral facial arteries, and no specific mention of any other vascular structure. A preoperative dual-phase CTA was obtained that demonstrated patency of multiple arteries bilaterally as well as bilateral IJ veins (Figure 2). Intraoperatively, a thorough

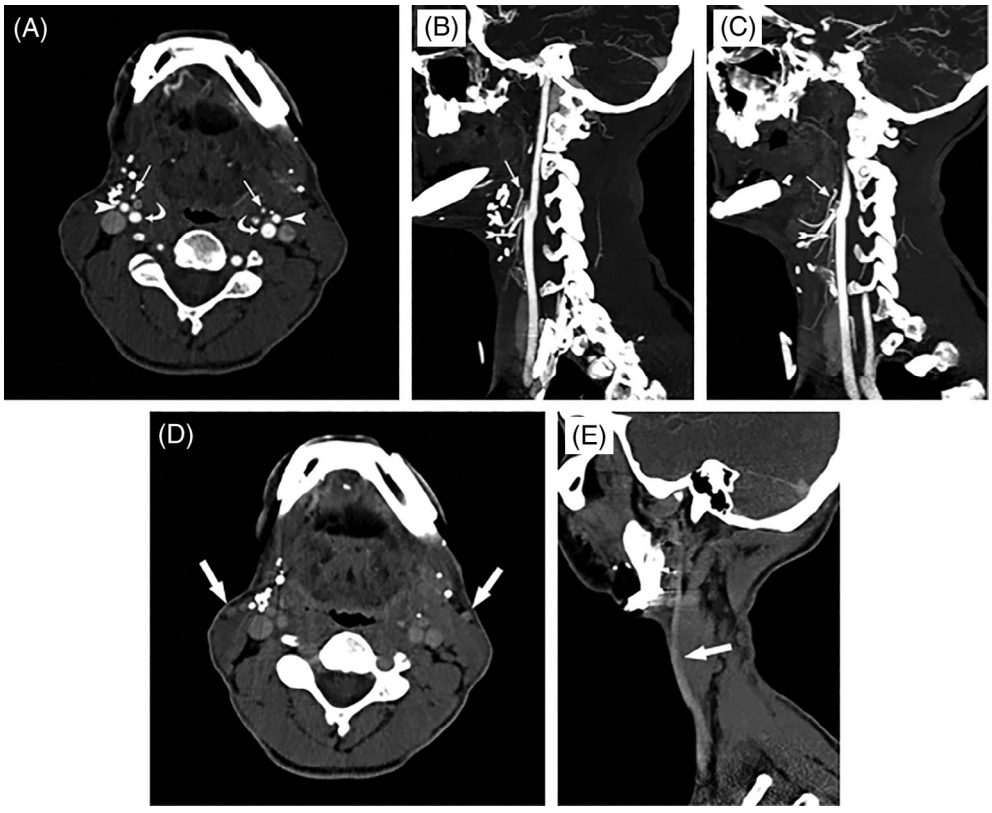

FIGURE 1 Arterial and venous phase of the dual-phase CTA for case A. Axial arterial phase image (A) and the right (B) and left (C) parasagittal thick maximum intensity projection (MIP) arterial phase images demonstrate patency of both lingual arteries (thin straight arrows in A-C) and superior thyroid arteries (hatched arrows in B and C). Axial (D) and left parasagittal (E) delayed phase images demonstrate patency with contrast opacification of the external jugular (EJ) veins (thick arrows in D and E). Opacification of the EJ veins is not evident on the arterial phase images (curved arrows in A: internal carotid arteries, arrowheads in A: external carotid arteries)

right-sided neck exploration was performed with careful identification and preservation of the IJ vein, common carotid artery, superior thyroid artery, and lingual artery. Successful microvascular anastomosis was achieved using the right lingual artery and an end-to-side anastomosis to the IJ vein. The patient who had an uncomplicated postoperative course was discharged to a skilled nursing facility on her preoperative tube feed regimen on postoperative day 8. Her trismus was significantly improved with surgery, and she was able to tolerate a puree diet by mouth starting 6 weeks after surgery.

5 | DISCUSSION

A vessel-depleted neck due to prior surgical treatments is of particular challenge to reconstructive surgeons. Advancements of ablative techniques and adjuvant CRT has simultaneously broadened treatment options for head and neck cancer care and increased the complexity of cases. In tertiary referral centers, it is becoming more common for patients to presenting with late treatment effects of radiation such as ORN, multiply recurrent tumors, or second primaries. In these cases, the need for healthy, vascularized tissue provided by microvascular reconstruction grows at the same time as the availability of donor vessels in the neck decreases. Existing literature attempts to address this issue by providing surgical techniques and alternative vessel options.[1-3,11-20] To our knowledge, no techniques have been described to help in the preoperative planning phase to help maximize the odds of free flap success and minimize operative time and surgeon anxiety in this patient population.

The use of preoperative imaging to map vascular anatomy of free flap donor regions has been described in the literature.[21-24] In particular, CTA or MRA have been used in the preoperative planning of the fibular free flap and perforator flaps such as deep inferior epigastric artery perforatory or anterolateral thigh flaps.[21,22,25] In a review of various methods for vascular mapping of flaps, Smit et al concluded that in flaps with highly variable donor site vasculature, CTA and

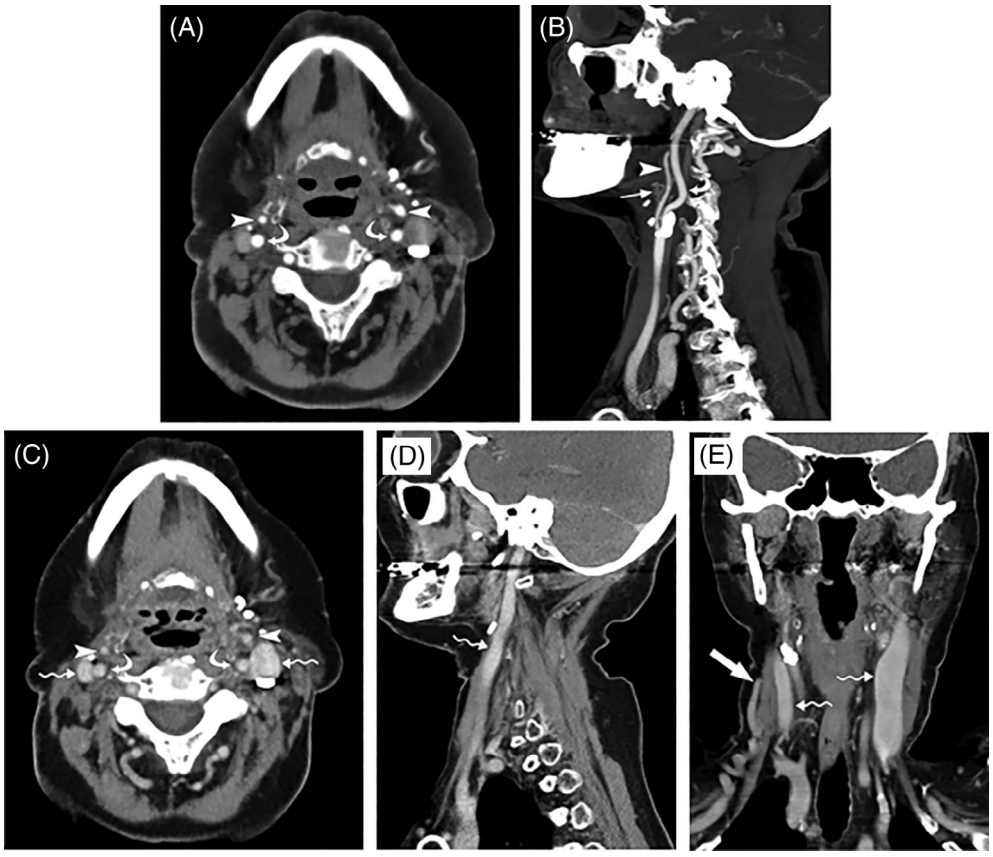

FIGURE 2 Arterial and venous phases of dual-phase CTA for case B. Axial arterial phase image (A) demonstrates patency of bilateral internal carotid arteries (ICA, curved arrows) and bilateral external carotid arteries (ECA, arrowheads). Right parasagittal thick MIP arterial phase image (B) demonstrates patency of the right lingual artery (thin straight arrow) in additional to normal opacification of the right ICA (curved arrow) and ECA (arrowhead). Axial delayed phase image (C) demonstrates contrast filling of both internal jugular (IJ) veins (wavy arrows), with patency of the right IJ vein confirmed on a parasagittal delayed phase image (D). Coronal delayed phase image (E) demonstrates patency of only the lower half of the right external jugular (EJ) vein (thick arrow). Portions of both patent IJ veins (wavy arrows) can be seen. The left EJ vein and proximal right EJ vein were not visible on any of the delayed phase images

MRA may be beneficial in facilitating vessel identification.[25] The theoretical benefit of preoperative angiography for these donor sites is to enable more precise identification and facilitate selection of appropriate perforators to decrease operative time. Here, we apply the same principle by mapping the vasculature of vessel-depleted necks in which the vascular anatomy has been significantly altered by prior treatment as a way to further improve preoperative surgical planning.

Branches of the external carotid artery system, the transverse cervical artery, dorsal scapular artery, and the internal mammary artery have been previously described as donor arteries for microvascular reconstruction. Even though transverse cervical system is available in the majority of patients, it can be unsuitable in approximately 8% patients. Preoperative assessment with dual-phase CTA is helpful for vessel delineation even when the use of alternative vessels such as transverse cervical system is planned. Some experienced reconstructive surgeons are hesitant to use vessels that are within the field of radiation, but the exact impact of radiation on free flap survival rates is unclear. External beam radiation has been shown to cause changes to the tunica intima of arteries.[26,27] However, although some small case series showed increased arterial related complications,[28] others larger series have not.[11,27] Even with extensive prior treatment and neck procedures, we found in our series of patients that the facial artery, lingual artery, and superior thyroid artery often remain viable donor options. Availability of venous options is even more challenging as both the EJ and IJ system can be compromised or sacrificed during surgery. However, as with other previous series of microvascular reconstruction in challenging vessel-depleted necks, we found that vein grafts were not often necessary.[29] As suggested by Head et al, preferential use of free flaps with long vascular pedicles obviated the need for vein grafts in our case series in all but one patient.[29]

Dual-phase CTAs have been previously described for use in evaluating cerebral, portal, and cardiac vascular systems.[6-9,30-34] The use of evaluating head and neck vasculature, especially in the setting of patients with vessel-depleted neck is novel and, in our case series, appears promising. Since the availability of appropriate donor vessels is often the limiting factor for successful free tissue transfer in vessel-depleted necks, preoperative evaluation with dual-phase CTA can potentially decrease the need for lengthy vessel explorations at the time of surgery. It is difficult to benchmark the operative times in this case series to that of other vessel-depleted neck cases given the absence of published operative times in the literature and the wide variability in pathology and free tissue transfer used. In general, reported operative times for free tissue transfer for H&N reconstruction range from 7 to 12 hours with bony flaps (fibula or scapula) taking 9 to 10 hours in total.[35-39] The average in this case series of 8 hours and 44 minutes falls into that range. We suspect that total operative times of 9 hours are less than what would normally be encountered when dealing with patients with vessel-depleted neck. In our experience, preoperative CTA was helpful in the planning process and allowed us to identify target vessel candidates with high success. Preoperative CTA did not influence the choice of free tissue donor site. However, for one patient, it eliminated a potentially lengthy and ultimately fruitless neck exploration as our operative strategy was changed from a free flap to a rotational flap based on imaging. Given the complexity and stress of these challenging cases, the ability to differentiate candidate vessels from non-candidate ones preoperatively is of great value to reconstructive surgeons. In addition to decreasing operative times, this strategy may also decrease the morbidity of flap failures resulting from poor vessel selection. It may also be possible to use preop CTA to roughly estimate how much donor vessel pedicle length is needed to reach viable neck vessels. The main drawback of this strategy is the cost and radiation exposure associated with the additional imaging. Future studies are needed to assess whether the use of this imaging modality decreases operative times when compared to standard exploration as well as the cost difference between this and other potential preoperative imaging modalities.

This study is limited by its retrospective nature and small sample size. We present this technique to discuss a novel approach, which may be of benefit in a surgically challenging group of patients. Future prospective studies are needed to compare dual-phase CTA imaging to standard CTA or intraoperative neck exploration to see if it truly adds value in terms of decreasing operative time or improving surgical success.

In conclusion, dual-phase CTA imaging allows for evaluation of potential venous recipient candidates in addition to possible arterial recipient vessel. As availability of appropriate veins can be the limiting issues with free tissue transfer in vessel depleted necks, preoperative evaluation of vein viability can decrease the need for multiple vessel explorations at the time of surgery. As such, dual-phase CTA can be helpful in presurgical planning of microvascular free tissue transfer for difficult cases involving patients with vessel-depleted necks.

ORCID

Eugenie Du https://orcid.org/0000-0002-3550-9857

REFERENCE

1. Baj A, Bolzoni A, Torretta S, Pignataro L. Arterial microanastomoses on the reverse flow of the internal carotid artery reverse flow: an extreme solution in free-flap revascularisation. How we do it. *Acta Otorhinolaryngol Ital*. 2014;34:368-371.

2. Harris JR, Lueg E, Genden E, Urken ML. The thoracoacromial/-cephalic vascular system for microvascular anastomoses in the vessel-depleted neck. *Arch Otolaryngol Head Neck Surg*. 2002; 128:319-323.
3. Wong KK, Higgins KM, Enepekides DJ. Microvascular reconstruction in the vessel-depleted neck. *Curr Opin Otolaryngol Head Neck Surg*. 2010;18:223-226.
4. Yu P. The transverse cervical vessels as recipient vessels for previously treated head and neck cancer patients. *Plast Reconstr Surg*. 2005;115:1253-1258.
5. Francis DO, Stern RE, Zeitler D, Izzard M, Futran ND. Analysis of free flap viability based on recipient vein selection. *Head Neck*. 2009;31:1354-1359.
6. Park M, Kim KE, Shin NY, et al. Thrombus length discrepancy on dual-phase CT can predict clinical outcome in acute ischemic stroke. *Eur Radiol*. 2016;26:2215-2222.
7. Shin NY, Kim KE, Park M, et al. Dual-phase CT collateral score: a predictor of clinical outcome in patients with acute ischemic stroke. *PLoS One*. 2014;9:e107379.
8. Hickethier T, Iuga AI, Lennartz S, et al. Virtual monoenergetic images from a novel dual-layer spectral detector computed tomography scanner in portal venous phase: adjusted window settings depending on assessment focus are essential for image interpretation. *J Comput Assist Tomogr*. 2018;42(3):350-356.
9. Ko SE, Choi IY, Cha SH, et al. Clinical and radiologic characteristics of pancreatic head carcinoma without main pancreatic duct dilatation: using dual-phase contrast-enhanced CT scan. *Clin Imaging*. 2016;40:548-552.
10. Yamashita K, Sakuramoto S, Mieno H, et al. Preoperative dual-phase 3D CT angiography assessment of the right hepatic artery before gastrectomy. *Surg Today*. 2014;44:1912-1919.
11. Jacobson AS, Eloy JA, Park E, Roman B, Genden EM. Vessel-depleted neck: techniques for achieving microvascular reconstruction. *Head Neck*. 2008;30:201-207.
12. Karle WE, Anand SM, Clain JB, et al. Use of a combined latissimus dorsi scapular free flap revascularized with vein grafting to the internal mammary artery in a vessel-depleted and previously irradiated neck. *Head Neck*. 2013;35:E328-E332.
13. Moubayed SP, Giot JP, Odobescu A, Guertin L, Harris PG, Danino MA. Arteriovenous fistulas for microvascular head and neck reconstruction. *Plast Surg (Oakv)*. 2015;23:167-170.
14. Rosko AJ, Ryan JT, Wizauer EJ, et al. Dorsal scapular artery as a recipient vessel in the vessel-depleted neck during free tissue transfer in head and neck reconstruction. *Head Neck*. 2017;39: E72-E76.
15. Salgarello M, Snider F, Finocchi V, Bussu F, Paludetti G, Almadori G. The Pruitt-Inahara carotid shunt as an assisting tool to anastomose the arterial free flap pedicle to the internal carotid artery in the vessel-depleted neck. *Microsurgery*. 2011;31: 234-236.
16. Schneider DS, McClain L, Robb PK Jr, Rosenthal EL, Wax MK. Use of internal mammary vessels in head and neck microvascular reconstruction. *Arch Otolaryngol Head Neck Surg*. 2012;138: 172-176.
17. Shimizu F, Lin MP, Ellabban M, Evans GR, Cheng MH. Superficial temporal vessels as a reserve recipient site for microvascular head and neck reconstruction in vessel-depleted neck. *Ann Plast Surg*. 2009;62:134-138.
18. Su T, Pirgousis P, Fernandes R. Versatility of supraclavicular artery Island flap in head and neck reconstruction of vessel-depleted and difficult necks. *J Oral Maxillofac Surg*. 2013;71:622-627.
19. Urken ML, Higgins KM, Lee B, Vickery C. Internal mammary artery and vein: recipient vessels for free tissue transfer to the head and neck in the vessel-depleted neck. *Head Neck*. 2006;28: 797-801.
20. Vasilakis V, Patel HD, Chen HC. Head and neck reconstruction using cephalic vein transposition in the vessel-depleted neck. *Microsurgery*. 2009;29:598-602.
21. Chow LC, Napoli A, Klein MB, Chang J, Rubin GD. Vascular mapping of the leg with multi-detector row CT angiography prior to free-flap transplantation. *Radiology*. 2005;237:353-360.
22. Kurlander DE, Brown MS, Iglesias RA, Gulani V, Soltanian HT. Mapping the superficial inferior epigastric system and its connection to the deep system: an MRA analysis. *J Plast Reconstr Aesthet Surg*. 2016;69:221-226.
23. Battaglia S, Maiolo V, Savastio G, et al. Osteomyocutaneous fibular flap harvesting: computer-assisted planning of perforator vessels using computed tomographic angiography scan and cutting guide. *J Craniomaxillofac Surg*. 2017;45:1681-1686.
24. Garvey PB, Chang EI, Selber JC, et al. A prospective study of preoperative computed tomographic angiographic mapping of free fibula osteocutaneous flaps for head and neck reconstruction. *Plast Reconstr Surg*. 2012;130:541e-549e.
25. Smit JM, Klein S, Werker PM. An overview of methods for vascular mapping in the planning of free flaps. *J Plast Reconstr Aesthet Surg*. 2010;63:e674-e682.
26. Konings AW, Smit Sibinga CT, Aarnoudse MW, de Wit SS, Lamberts HB. Initial events in radiation-induced atheromatosis. II. Damage to intimal cells. *Strahlentherapie*. 1978;154:795-800.
27. Mulholland S, Boyd JB, McCabe S, et al. Recipient vessels in head and neck microsurgery: radiation effect and vessel access. *Plast Reconstr Surg*. 1993;92:628-632.
28. Valentino J, Helton WB, Unnikrishnan R, Kudrimoti M, Arnold SM, Gal TJ. Microvascular reconstruction after intra-arterial chemotherapy with concomitant radiation. *Otolaryngol Head Neck Surg*. 2013;149:541-546.
29. Head C, Sercarz JA, Abemayor E, Calcaterra TC, Rawnsley JD, Blackwell KE. Microvascular reconstruction after previous neck dissection. *Arch Otolaryngol Head Neck Surg*. 2002;128:328-331.
30. Chen CY, Tsai TH, Jaw TS, et al. Diagnostic performance of Split-bolus portal venous phase dual-energy CT urography in patients with hematuria. *AJR Am J Roentgenol*. 2016;206:1013-1022.
31. Fujibayashi S, Otsuki B, Kimura H, Tanida S, Masamoto K, Matsuda S. Preoperative assessment of the ureter with dual-phase contrast-enhanced computed tomography for lateral lumbar interbody fusion procedures. *J Orthop Sci*. 2017;22:420-424.
32. Fukuyama N, Kurata A, Kawaguchi N, et al. Two-phase contrast injection protocol for pediatric cardiac computed tomography in children with congenital heart disease. *Pediatr Cardiol*. 2018;39: 518-525.
33. Iacobellis F, Ierardi AM, Mazzei MA, et al. Dual-phase CT for the assessment of acute vascular injuries in high-energy blunt trauma: the imaging findings and management implications. *Br J Radiol*. 2016;89:20150952.
34. Muller K, Datta S, Gehrisch S, et al. The role of dual-phase cone-beam CT in predicting short-term response after Transarterial

chemoembolization for hepatocellular carcinoma. *J Vasc Interv Radiol*. 2017;28:238-245.
35. Dowthwaite SA, Theurer J, Belzile M, et al. Comparison of fibular and scapular osseous free flaps for oromandibular reconstruction: a patient-centered approach to flap selection. *JAMA Otolaryngol Head Neck Surg*. 2013;139:285-292.
36. Gerressen M, Pastaschek CI, Riediger D, et al. Microsurgical free flap reconstructions of head and neck region in 406 cases: a 13-year experience. *J Oral Maxillofac Surg*. 2013;71:628-635.
37. Hanasono MM, Skoracki RJ. Computer-assisted design and rapid prototype modeling in microvascular mandible reconstruction. *Laryngoscope*. 2013;123:597-604.
38. McCrory AL, Magnuson JS. Free tissue transfer versus pedicled flap in head and neck reconstruction. *Laryngoscope*. 2002;112:2161-2165.
39. White LJ, Zhang H, Strickland KF, et al. Factors associated with hospital length of stay following fibular free-tissue reconstruction of Head and neck defects: assessment using the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) criteria. *JAMA Otolaryngol Head Neck Surg*. 2015;141:1052-1058.

How to cite this article: Du E, Patel S, Huang B, Patel SN. Dual-phase CT angiography for presurgical planning in patients with vessel-depleted neck. *Head & Neck*. 2019;41:2929–2936. https://doi.org/10.1002/hed.25775