Journal of Cranio-Maxillo-Facial Surgery 46 (2018) 98–106

Contents lists available at ScienceDirect

Journal of Cranio-Maxillo-Facial Surgery

journal homepage: www.jcmfs.com

3T non-injected phase-contrast MRI sequences for the mapping of the external carotid branches: In vivo radio-anatomical pilot study for feasibility analysis

Jérémie Bettoni [a, b, c, *], Gwénaël Pagé [b, c], Anne-Virginie Salsac [d], Jean-Marc Constans [c, e], Sylvie Testelin [a, c], Bernard Devauchelle [a, c], Olivier Balédent [b, c], Stéphanie Dakpé [a, c]

[a] Maxillo-facial Surgery Department, Centre Hospitalo-Universitaire d'Amiens, Avenue Laennec, 80 000 Amiens, France
[b] BioFlowImage Laboratory, Université de Picardie Jules Verne, Avenue Laennec, 80 000 Amiens, France
[c] Facing Faces Institute, Avenue Laennec, 80 000 Amiens, France
[d] Biomechanics & Bioengineering Laboratory (UMR CNRS 7338), Université de Technologie de Compiègne-CNRS, Sorbonne Universités, CS 60319, 60203 Compiègne, France
[e] Radiology Department, Centre Hospitalo-Universitaire d'Amiens, Avenue Laennec, 80 000 Amiens, France

A R T I C L E I N F O

Article history:
Paper received 8 March 2017
Accepted 11 September 2017
Available online 16 October 2017

Keywords:
Magnetic resonance imagery
External carotid branches
Anatomy
Contrast agent
Phase contrast sequence
Small vessels

A B S T R A C T

An essential stage in head and neck microsurgical reconstruction is the choice of recipient vessels. To make relevant choices, surgeons must rely on accurate imaging techniques. The objective of the study was to examine the feasibility of Phase-Contrast sequences to conduct the pre-operative tests without injection and provide precise radio-anatomical data over the entire vessel region. The challenges were the large velocity range, the lack of contrast, and the large spatial resolution needed to image vessels below 5 mm in diameter.

Thirty-one healthy volunteers were included in an MRI prospective study. The anatomical and morphometrical characteristics of the collaterals of the external carotid artery were determined associating 3D PCA and 2D Cine MRI-PC sequences (average protocole duration time of 49 min ± 4 min). The average diameter was measured to be 2.1 ± 1.4 mm for the superior thyroid artery, 2.2 ± 1.1 mm for the lingual artery, 2.7 ± 1.6 mm for the facial artery, 2.6 ± 1.4 mm for the internal maxillary artery, and 2 ± 1.4 mm for the superficial temporal artery. With a vessel identification success rate of 98%, the study showed for the first time that Phase Contrast MRI allowed non-invasive and non-operator dependent anatomical analyses of small caliber vessels without the use of agent contrast. It also proved that the designed sequences could be used on patients and provided valuable pre-operative information for head and neck surgery.

1. Introduction

With a failure rate ranging from 1% to 10% (Zhang et al., 2015; Pohlenz et al., 2012; Bianchi et al., 2009; Classen and Ward, 2006; Mücke et al., 2016), free flap surgery is essential in head and neck microsurgical reconstruction and relies on the quality of the anastomosis between the flap artery and vein, and the recipient vessels located at the site of the defect. Its success strongly depends on the choice of recipient vessel, the quality of the microsurgical procedure, and a careful clinical monitoring. A challenge that surgeons regularly meet is when patients have vessel-depleted necks, which complicates the procedure (Bozikov and Arnez, 2006; Singh et al., 1999; Ishimaru et al., 2016). Such cases are particularly common in patients who have undergone numerous microsurgical procedures in the head and neck region, as part of the reconstructive process or of previous treatments such as cancer surgery, radiation therapy and vascular embolization.

Kansy et al. (2014) recently illustrated the lack of consensus on vascular preparation in a European study, showing that only 31% of the teams were using preoperative imagery. Only two techniques

* Corresponding author. Maxillo-facial Surgery Department, Centre Hospitalo-Universitaire d'Amiens Avenue Laennec, 80 000 Amiens, France.
E-mail address: Jeremiebettoni@gmail.com (J. Bettoni).

https://doi.org/10.1016/j.jcms.2017.09.005
1010-5182/

are used: Doppler ultrasound and/or CT scan. The issue of Doppler ultrasound is that, despite great advances, it remains operator-dependent, lacks reliability for quantitative anatomical measurements and fails in case of bone interposition. The limitation of CT scan is that it requires the use of a contrast medium. None of them is thus optimal to be used in routine to assess which vessels to use for the anastomosis with a free flap.

Nowadays MRI sequences provide accurate angiographic analysis. Flow MRI without contrast injection relies on phase-contrast MRI sequences (Pelc et al., 1991, 1994; Nayler et al., 1986; Rebergen et al., 1993), that were originally developed for the analysis of aortic flows (Herment et al., 2011; Nayak et al., 2015). It offers the advantage of providing hemodynamic and morphologic information from three-dimensional Phase-Contrast Angiography (3D PCA) and two-dimensional Cine Phase-Contrast (2D Cine PC) Magnetic Resonance Imaging (MRI) sequences in the same non-invasive examination without the injection of a contrast agent. On the one hand, 3D PCA sequences have a sensitivity that can be modulated and adapted to each vessel by choosing the adequate encoding velocity: they offer the possibility to identify vessels with a large range of intraluminal velocities. On the other hand, both geometric and hemodynamic measurements can be obtained during one cardiac cycle from 2D CINE MRI PC sequences. To do so, it is important to position the measurement planes perpendicularly to the vessels and synchronize the measurements with the heart rate.

The objective of the study was to determine the geometrical characteristics of the branches of the external carotid and examine the feasibility of using Phase-Contrast sequences in the head and neck region, a region where the potential recipient vessels have typical diameters between 2 and 6 mm (Shima et al., 1998). A single-center prospective study was conducted to assess whether PC sequences enabled to investigate the branches of the external carotid. This study was approved by the local ethics committee (No. 2013-A00319-36), registered in clinicaltrials.gov (No. NCT02829190), and performed in accordance with the ethical standards of the 1964 Declaration of Helsinki.

2. Materials and methods

2.1. Cohort study

Thirty-one healthy volunteers (Table 1) were included between November 2014 and October 2015 and MRI acquisitions were performed with 3D PCA and 2D Cine PC-MRI sequences. Only one healthy volunteer was excluded following the anatomical acquisitions because of the incidental finding of a benign left parietal lesion.

Three maxillo-facial patients of the department, planned for a forearm free flap were additionally recruited to demonstrate the clinical relevance of these acquisitions as part of the pre-operative process of recipient vessel choice for a microsurgical reconstructive head and neck procedure.

Clinical cases 1 and 2 were respectively a 54-year-old male and 63-year-old female with *c*T2N0M0 squamous cell carcinoma of oral cavity.Clinical case 3 was a 42-year-old male patient with oropharyngeal radionecrosis. Radiological findings were compared with anatomical exploration during the surgical procedure.

Table 1
Population characteristics.

Population	
Sex	Male (n = 17); Female (n = 14)
Average age (years)	27 (min = 21; max = 55)
Size (cm)	Male: 176 (±12)
	Female: 168 (±10)
Weight (kg)	Male: 79 (±8)
	Female: 61 (±9)
BMI (kg/m^2)	Male: 25.3 (min = 21; max = 28)
	Female: 21.8 (min = 19; max = 25)
Cardiovascular factors	Active smoking: n = 7
	Hypertension: n = 0
	Diabetes: n = 0

2.2. 3-Tesla MRI acquisition procedure

All the acquisitions were obtained on an MRI Research PHILIPS® 3 Tesla (3 T) Achieva TX DSTREAM. To perform the detailed study of the vessels of interest, a new protocol was developed with the use of two types of coils: a 32-element head coil and a microscopic 47-mm diameter coil.

At first, the 32-element head coil (Fig. 1) was used to identify and position the 2D CINE MRI PC measurement planes on the left and right Internal Maxillary Arteries (IMA) and Superficial Temporal Arteries (StempA). Then the 47-mm diameter microscopic coil was positioned near the left and right thyro-lingo-facial bifurcations (Fig. 2) to acquire data in the Facial Arteries, Lingual Arteries and Superior Thyroid Arteries. The procedure includes, for each external carotid, three 3D PCA sequences in order to identify the vessels of interest. Two encoding velocities, one at 10 cm/s (V10) and the other at 30 cm/s (V30), are used in order to obtain morphological acquisitions over a large range of blood flows in the branches of the external carotid. From the 3D PCA acquisition, we positioned a measurement plane perpendicularly to the vessel axis to conduct 2D Cine MRI PC acquisitions in each artery. All the parameters of the MRI sequences (Table 2) were tested and validated on a phantom (Pagé, 2017).

2.3. Data management software

Two software systems were used to analyze the static and kinematic morphological data:

- The Advantage Windows (General Electric®) software for the reconstruction of the 3D PCA sequences in the 3 planes (axial, coronal and sagittal) and the fusion of the V10 and V30 sequences (Fig. 3). It enabled the identification of the external carotid collateral branches and the positioning of the 2D Cine PC-MRI sequences.
- The software developed by Balédent et al. (2001) that is used to extract the vessel cross-section from the 2D Cine PC-MRI sequences (Fig. 4) and determine the geometrical characteristics of the vessels (minimum, maximum and mean diameter) during the cardiac cycle. For an accurate measurement of the vascular sections during the cardiac cycle, an automatic active contour segmentation based on the Vector Flow gradient algorithm (Xu and Prince, 1998) was applied to the 2D Cine PC-MRI sequences.

2.4. Anatomical analysis

For each external carotid tree, five vessels have been studied: the superior thyroid artery (STA), lingual artery (LA), facial artery (FA), internal maxillary artery (IMA) and superficial temporal artery (STempA). These five vessels were chosen owing to their positioning within the actual facial vasculature (Houseman et al., 2000) and frequency of use in head and neck microsurgery (Zhang et al., 2015; Pohlenz et al., 2012; Bianchi et al., 2009; Classen and Ward, 2006; Mücke et al., 2016).

All the 3D PC angiographic acquisitions were analyzed for each healthy volunteer to establish a success rate of artery identification

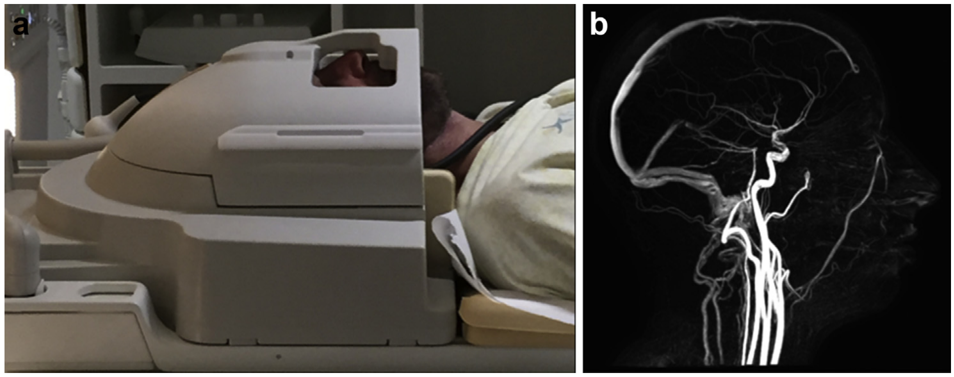

Fig. 1. (a) 32-element head coil, (b) Head and neck 3D PCA acquisition.

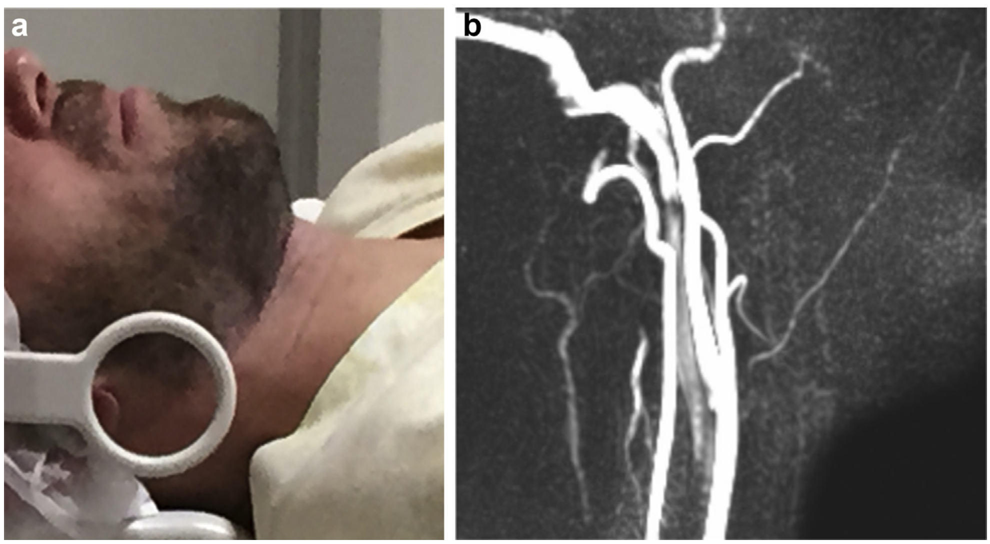

Fig. 2. (a) 47-mm diameter microscopic coil, (b) Thyro-lingo-facial bifurcation 3D PCA acquisition.

Table 2
Parameters of the 3D PCA and 2D Cine PC-MRI sequences.

	3D PCA sequence	3D PCA sequence	2D Cine-PC sequence	2D Cine-PC sequence
	32 head coil	47 mm coil	32 head coil	47 mm coil
TE/TR (ms)	3/5	3/5	13/8	13/8
Spatial resolution (mm^3)	0.5 × 0.5 × 1	0.6 × 0.6 × 1.2	0.5 × 0.5 × 3	0.15 × 0.15 × 2
FOV (mm^2)	240 × 240	140 × 140	120 × 120	50 × 50
Encoding velocities (cm/s)	30	30 and 10	between 30 and 45	between 25 and 45
Number of frames per cardiac cycle	1	1	16	16

and provide a descriptive analysis based on the mapping of the branches of the external carotid artery. Morphometric analysis of the 2D Cine PC-MRI sequences provided the time-average diameter and section of the vessels of interest.

2.5. Statistical analysis

The main objective of the study being to assess the feasibility of MRI flow sequences in head and neck anatomical analysis, we recorded and calculated: (1) the mean duration of the protocol for the entire mapping of the head and neck vessels, (2) the identification success rate for each artery with the two 3D PCA sequences (V30 and V10 encoding velocity), (3) the types of anatomic variations of the external carotid branches, and (4) the mean morphometric vessel section area which required a statistical analysis with a Student's *t*-test.

3. Results

3.1. Acquisition protocol time

The average duration of the complete protocol was 49 min ± 4 min for each volunteer (Fig. 5), which included the analysis of the right and left vasculatures stemming from the external carotids using both the 3D PCA and 2D CINE MRI PC sequences. For single external carotid vasculature, the average duration was 14 min 20 s for the vessel identification and 12 min 40 s ± 3 min for the morphometric analysis.

3.2. Artery identification success rate

Sixty external carotid arteries were studied and 294 arteries of interest were identified with a success rate of 98% (Fig. 5). Only 3

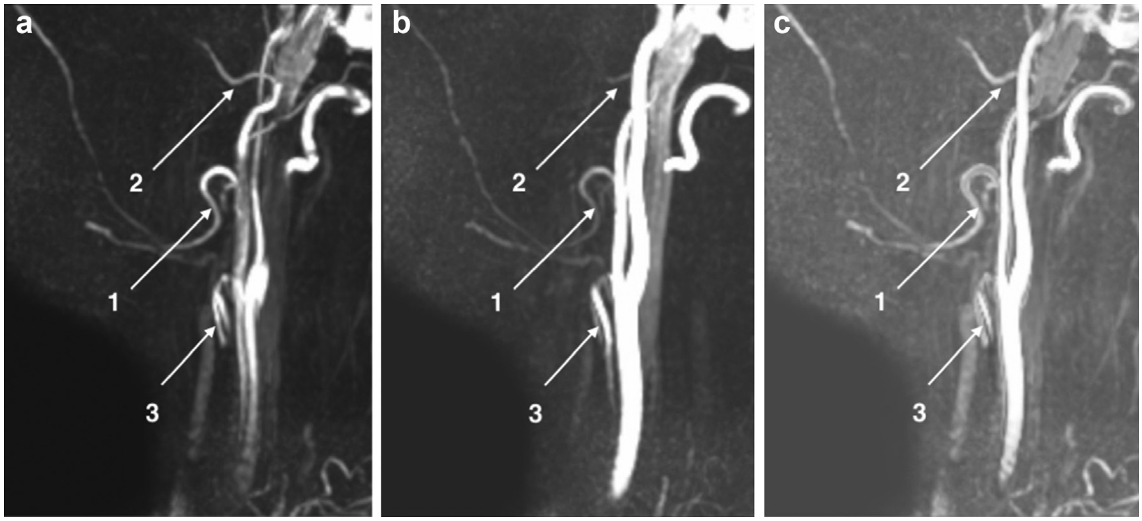

Fig. 3. 3D Reconstructions in Maximal Intensity Projection (MIP) of 3D PCA sequences: identification of the facial (1), internal maxillary (2) and superior thyroid (3) arteries. (a) Encoding velocity of 30 cm/s (V30). (b) Encoding velocity of 10 cm/s (V10). (c) Fusion of V10 and V30 sequences.

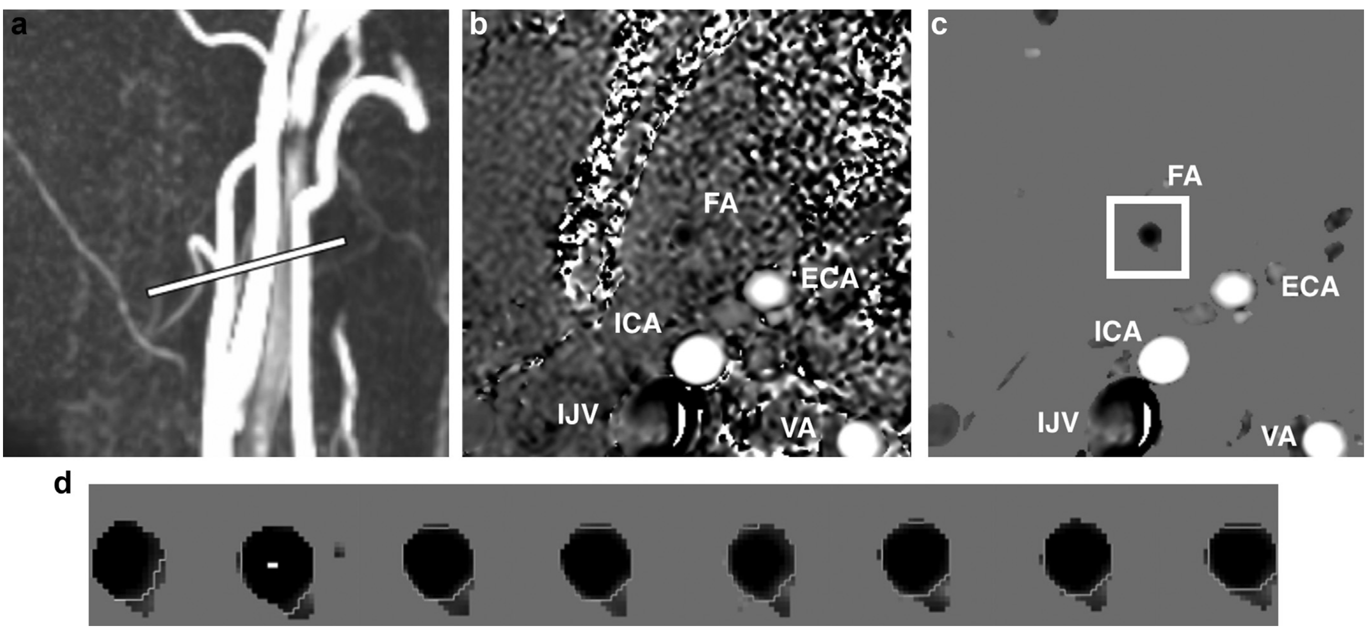

Fig. 4. Determination of the vessel cross-section from the 2D Cine-MRI PC images of the facial artery: (a) Positioning of the cutting plane on the 3D PCA acquisition, (b) 2D CINE MRI PC acquisition with and without filter in order to diminish the background noise and optimize vessel identification: FA (Facial Artery), ECA (External Carotid Artery), ICA (Internal Carotid Artery), VA (Vertebral Artery) and IJV (Internal Jugular Veinous), (d) Evolution of the facial artery cross-section over a half cardiac cycle.

superior thyroid arteries, 1 lingual artery and 2 superficial temporal arteries could not be identified.

3.3. Anatomical variations

We identified three anatomical variations in the thyro-linguo-facial bifurcation (Fig. 6, Video 1) with the following frequencies: separated arterial origins for each of the lingual, facial and thyroid arteries (76.6%), linguo-facial trunk associated with a separate origin of the superior thyroid artery (21.6%), and thyroid-linguo-facial trunk (1.6%).

Supplementary video related to this article can be found at https://doi.org/10.1016/j.jcms.2017.09.005.

Four origin types were identified for the superior thyroid artery: the common carotid artery (9%), the carotid bifurcation (56%), the external carotid artery (33%), and the facial artery (2%).

3.4. Morphometric analysis of the vessel diameter and cross-sections

The average diameter (and cross-section) of the arteries of interest were (Fig. 7): 2.2 ± 1.4 mm (3.5 ± 1.5 mm^2) for the superior thyroid artery, 2.2 ± 1.1 mm (3.7 ± 1 mm^2) for the lingual artery, 2.7 ± 1.6 mm (5.8 ± 2 mm^2) for the facial artery, 2.6 ± 1.4 mm (5.5 ± 1.6 mm^2) for the internal maxillary artery, and 2 ± 1.4 mm (3.2 ± 1.5 mm^2) for the superficial temporal artery.

The comparison of the average diameter between all the arteries of interest ($p < 0.05$ *Student test*) indicates that the arteries can be subdivided into two groups, the internal facial and maxillary arteries being in the group of the "larger calibre" arteries, and the lingual thyroid and superficial temporal arteries being in the "smaller calibre" group.

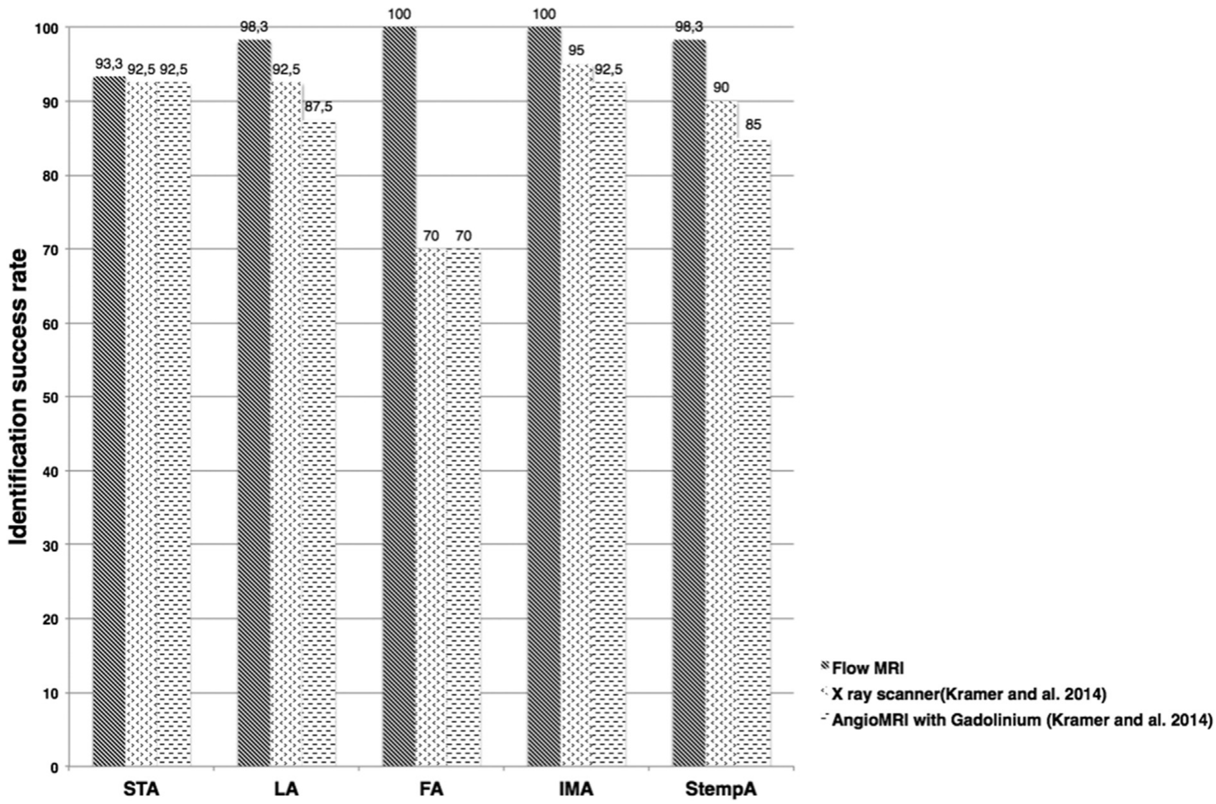

Fig. 5. Comparison of the identification success rate of Flow MRI with angio-CT and angio-MRI for the superior thyroid artery (STA), lingual artery (LA), facial artery (FA), internal maxillary artery (IMA), and superficial temporal artery (STempA).

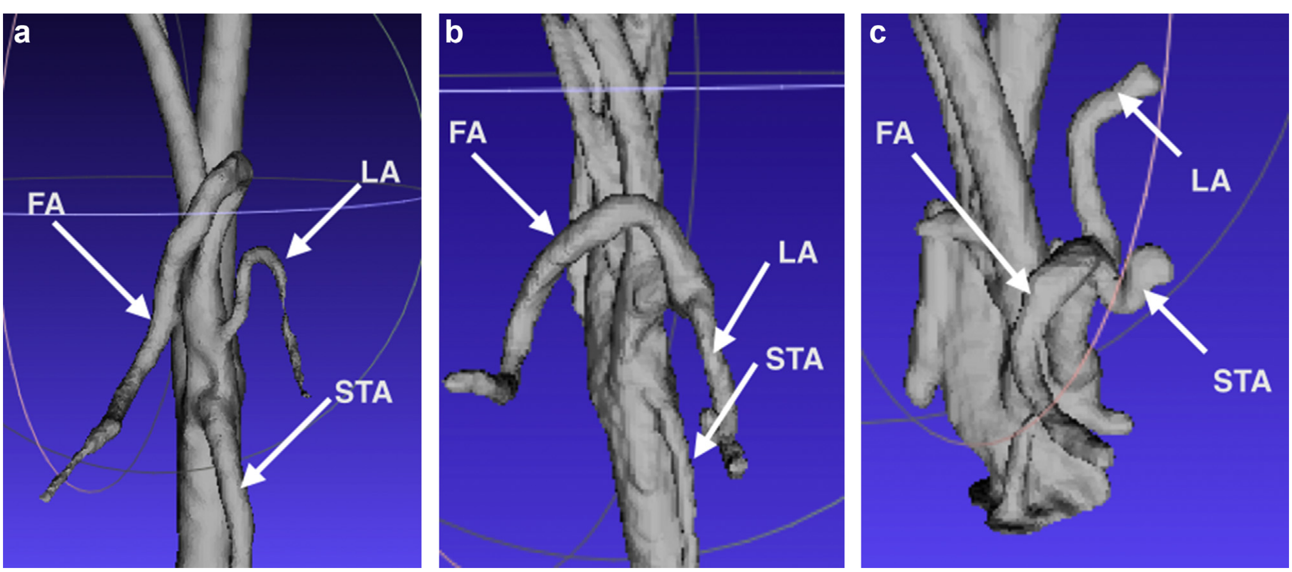

Fig. 6. 3D geometrical reconstruction obtained with the ITK-snap software, showing the variation of the thyro-lingo-facial bifurcation. (a) Separeted origins, (b) Lingo-facial truck, (c) Thyro-lingo-facial truck.

3.5. Clinical results

Fig. 8 provides an overview of the MRI acquisitions of the external carotid for the three patients as compared to the clinical surgical assessment during the procedure. For patients 1 and 2, the superior thyroid artery could not be identified on the pre-operative MRI examination, suggesting a non-functional artery that is not adequate for anastomosis. For patient 3, the MRI examination showed larger morphometric values for the lingual artery than the values in the healthy population. The surgical exploration during the procedure confirmed these preoperative results, i.e. a non-functional vascularisation in the superior thyroid arteries of the three patients that could not guarantee an efficient anastomosis, and an adequate functional vascularisation in the lingual artery in patient 3.

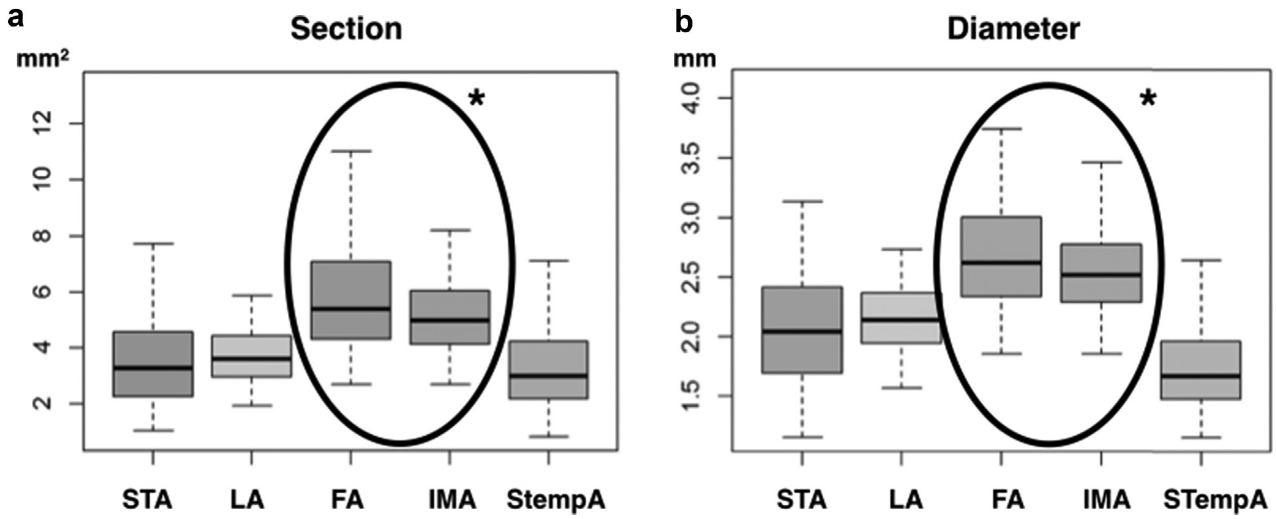

Fig. 7. Box plots of the cross-sections (a) and diameters (b) of the vessels of interest. * large calibre vessels (*Student's test* $p < 0.05$).

4. Discussion

The present study is a radio-anatomical descriptive, morphometric investigation of the external carotid branches by phase-contrast MRI sequences. They confirm the feasibility of PC-MRI to acquire data in vessels of diameter below 5 mm without contrast injection.

The MRI protocol and PC-MRI sequences that are used have been previously defined in an *in vitro* experimental study conducted in a bifurcated vessel phantom. Having optimized the sequences for the exploration of subcentimetric vessels (Pagé, 2017), we presently apply them to the acquisition of the complex anatomy of the head and neck vasculature. This region was chosen to test *in vivo* the feasibility of this new sequence dedicated to small vessels.

The originality of the current imaging procedure is to resort to two complementary coils: a 32-head coil and a 47-mm microscopic coil. Both coils are indeed necessary to guarantee the spatial accuracy required for vessels as small as those of the head and neck region, while providing acquisitions on the entire region. The 32-head coil allows for accurate measurements of the superficial temporal and internal maxillary arteries, but does not cover the neck region: it is thus not appropriate to acquire images in this region. The 47-mm microscopic coil, positioned near the neck vessels, provides a 'zoom effect' and a high spatial resolution (0.15×0.15 mm^2 vs 0.5×0.5 mm^2 for the 32-head coil - Table 2).

The other originality of the procedure is the use of two encoding velocities. It allows for a maximum signal recovery over a wide range of blood velocity. It enables to both identify vessels with high velocity flows like the facial artery and vessels with low velocity flows like the lingual artery. Thanks to the double velocity encoding, very high identification success rates have been obtained using 3D PCA sequences without the use of contrast agent, which is one of its very large advantage over other techniques such as CT-scan or Angio-MRI (Fig. 6 – Kramer et al., 2014).

The present results are consistent with the literature both in terms of the anatomical variations of the thyroid-lingo-facial junction (Tables 3 and 4) and of the vascular morphometry measurements. The present study indeed confirms the observations by Mata et al. (2012), Zumre et al. (2005) and Shima et al. (1998), who found, through dissection, a frequency of 75–80% of separated trunck, 20% of linguo-facial trunk and less than 5% of thyro-linguo-facial or thyro-lingual trunk.

The morphometric study has provided measurements (Table 5) that are in the same range as the dissection work by Shima et al. (1998) or the CT scan study by Tan et al. (2007). The great advantage of *in vivo* MRI acquisitions is that they provide the value of the vessel cross-section in the measurement plane at 16 instants of time within one cardiac cycle, and thus information on the vessel deformation over time. The data are thus much richer than in the case of anatomical dissection, for which measurements are done on dissected vessels or vessel casts (great variability being found on the results depending on whether the cadavers are formoled, fresh or injected during preparation), or CT scan, which provides results at one instant of time only. MRI sequences provide information on not only the variability over time of the vessel cross-section, but also on interindividual variability, which explains why the standard deviations are larger than for the other 2 methods.

The study proves that it is possible to integrate MRI imaging within the clinical preoperative process. With the present MRI protocol, we assessed the vessel branches of healthy patients to collect the morphometric values before any treatment, and demonstrated the interest of these MRI acquisitions in three maxillo-facial patients. Having obtained a high rate of artery identification in the healthy population, the absence of specific vessels on the MRI measurements suggests that these vessels have a very small caliber and/or a much lower velocity than the normal value.

The duration of the protocole may seem disabilating, but, one must keep in mind that the present duration time of about 50 min corresponds to a complete protocole that acquires both external carotid vasculatures, i.e. a total of 10 arteries. A possibility to shorten the acquisition is to limit the number of vessels examined: depending on the surgeon's point of interest, only one external carotid or one thyro-linguo-facial trunk may be imaged. Another possibility will be to use accelerated image reconstruction techniques such as the sensitivity encoding technique (SENSE) (Pruessmann et al., 1999), generalized auto-calibrating partially parallel acquisitions (k-t GRAPPA) (Jung et al., 2011), and Principal Component Analysis (PCA), known as k-t PCA (Pedersen et al., 2009). They could reduce the duration time of 2D sequences to more than half.

Another major limitation of MRI, despite its large potential, is its accessibility. The lack of accessibility will greatly limit its use in the near future for preoperative tests: one cannot foresee a

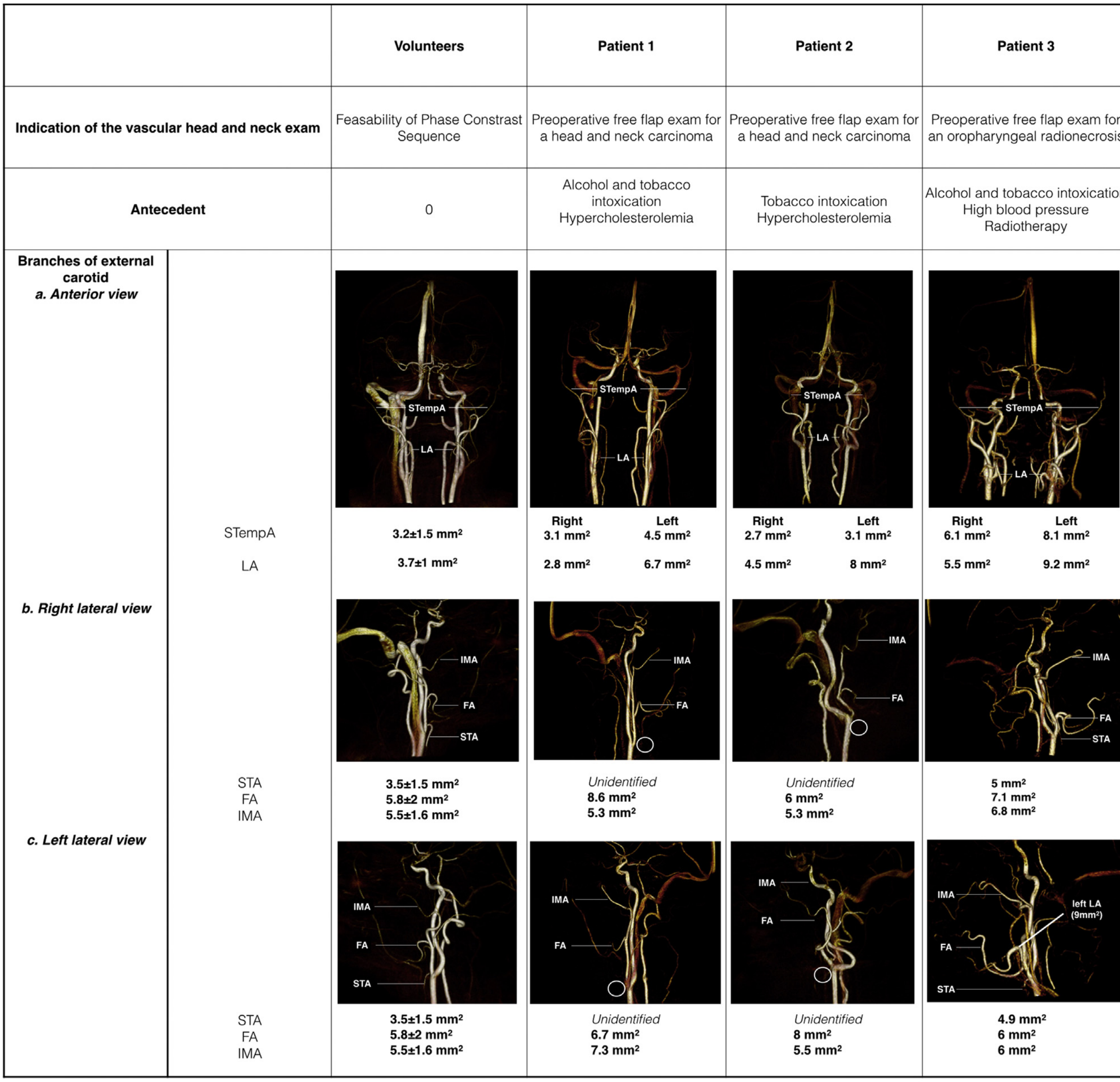

Fig. 8. 3D reconstruction of the external carotid branches from 3D phase Contrast MRI in a healthy volunteer from our cohort study and 3 patients before head and neck reconstructive microsurgery. (a) Anterior view with superior thyroid artery (STempA) and Lingual artery measurements. (b) Lateral view of the right external carotid artery with measurements of the right internal maxillary artery, right facial artery and right superior thyroid artery (STA). The circles show the absence of identification of the right STA for patients 1 and 2. (c) Lateral view of the left external carotid artery with measurements of the left internal maxillary artery, left facial artery and right superior thyroid artery (STA). The circles show the absence of identification of the left STA for patients 1 and 2. For patient 3, the measurements show a dilatation of the right and left lingual arteries.

Table 3
Anatomical variations of the thyro-linguo-facial bifurcation.

Study	Type	% separated trunk	% linguo-facial trunk	%thyro-linguo trunk	% thyro-linguo-facial trunk
Shima et al., 1998	Anatomical (n = 30)	76.6	21.7	1.6	0
Zumre et al., 2005	Anatomical (n = 40)	75	20	2.5	2.5
Ozgur et al., 2008	Anatomical (n = 40)	90	7.5	0	2.5
Mata et al., 2012	Anatomical (n = 36)	78	19.4	0	2.8
Lohan et al., 2007	Radio-anatomical (n = 46)	83	13	4	0
Our study	**Radio-anatomical (n=60)**	**76.6**	**21.6**	**0**	**1.6**

systematization of Phase Contrast sequencing for anatomical exploration prior to free flap procedures. It can still be an excellent alternative for patients having contraindications to contrast agent.

2D CINE MRI sequences are interesting for flow measurement. We are currently evaluating the accuracy of 2D CINE MRI sequences to acquire hemodynamic quantities in vessels of diameter smaller than 5 mm.

Table 4
Anatomical variations of the superior thyroid artery origin.

Study	Type	Common carotid origin	Carotid junction origin	External carotid origin	Facial artery origin
Natsis et al., 2011	Anatomical (n = 50)	12	49	39	0
Mata et al., 2012	Anatomical (n = 36)	3.5	45.3	51.2	0
Zumre et al., 2005	Anatomical (n = 40)	0	70	25	5
Ozgur et al., 2008	Anatomical (n = 40)	35	40	25	0
Our study	**Radio-anatomical (n=60)**	**9**	**56**	**33**	**2**

Table 5
Average diameters of the vessels of interest.

Study	Type	STA	LA	FA	IMA	StempA
Shima et al., 1998	Anatomical (n = 30)	1.9 (±0.5)	1.7 (±0.4)	2 (±0.5)	/	/
Tan et al., 2007	Radio-anatomical (n = 36)	2	/	2.1	/	1.6
Our study	**Radio-anatomical (n=60)**	**2.2 (±1.3)**	**2.2 (±1.3)**	**2.8 (±1.6)**	**2.6 (±1.3)**	**2 (±1.3)**

But one of the main difficult of the application of 2D CINE MRI sequences in the head and neck area is the positioning of the cutting plane on small and sinuous vessels. The development of other sequences like 4D CINE PC MRI (Stankovic et al., 2014) could be an alternative, as the positioning of the cutting plane can then be done during the post-processing.

5. Conclusion

We have shown that it is possible to acquire, with great accuracy, the anatomy of the head and neck vasculature using phase contrast 3D and 2D PCA Cine PC-MRI without the use of contrast agent. This proves the feasibility of the method to provide acquisitions in vessels less than 5 mm in diameter. It shows that, beyond preoperative testing prior to free flap in the head and neck region, PC-MRI will be applicable for the exploration of any small-size vessel, as long as it is not too deep inside the body.

The next step of the project will be to evaluate the feasibility of accurate flow measurements using phase contrast sequences within small vessels. If so, it would open the possibility to acquire complete anatomical and hemodynamic data within the same acquisition and to have a complete pre-operative balance sheet.

Conflict of interest statement

None.

Acknowledgements

We would like to acknowledge the financial support of the Regional Council of Picardy (FlowFace), Fondation Des Gueules Cassées Grant No. (1312004979-1312004980-1312004997), French National Research Agency (Equipex FiGuRes – ANR-10-EQPX-01-01). We would like to thank the Facing Faces Institute, as well as Sophie Potier, Danielle Lembach and Caroline Fournez for their help in the MRI acquisitions.

References

Balédent O, Henry-Feugeas MC, Idy-Peretti I: Cerebrospinal fluid dynamics and relation with blood flow : a magnetic resonance study with semiautomated cerebrospinal fluid segmentation. Invest Radiol 36: 368–377, Jul 2001
Bianchi B, Copelli C, Ferrari S, Ferri A, Sesenna E: Free flaps : outcommes and complications in head and neck reconstructions. J Craniomaxillofac Surg 37: 438–442, 2009
Bozikov K, Arnez ZM: Factors predicting free flap complications in head and neck reconstruction. J Plast Reconstr Aesthet Surg 59: 737–742, 2006
Classen DA, Ward H: Complications in a consecutives series of 250 free flap operations. Ann Plast Surg 56: 557–561, May 2006
Herment A, Lefort M, Kachenoura N, De Cesare A, Taviani V, Graves MJ, et al: Automated estimation of aortic strain from steady-state free-precession and phase contrast PR images. Magn Reson Med 65: 986–993, 2011
Houseman ND, Taylor GI, Pan WR: The angiosomes of the head and neck: anatomic study and clinical applications. Plast Reconstr Surg 105: 2287–2313, 2000
Ishimaru M, Ono S, Suzuki S, Matsui H, Fushimi K, Yasunaga H: Risk factors for free flap failure in 2,846 patients with head and neck cancer : a national database study in Japan. J Oral Maxiloofacial Surg 74: 1265–1270, 2016
Jung B, Stalder AF, Bauer S, Markl M: On the undersampling strategies to accelerate time-resolved 3D imaging using k-t-GRAPPA. Magn Reson Med 66: 966–975, 2011
Kansy K, Mueller AA, Mücke T, Kopp J-B, Koersgen F, Wolff KD, et al: For Microsurgical Reconstruction: microsurgical reconstruction of the head and neck - currents concepts of maxillofacial surgery in Europe. J Craniomaxillofac Surg 42: 1610–1613, 2014
Kramer M, Schwab SA, Nkenke E, Eller A, Kammerer F, May M, et al: Whole body magnetic resonance angiography and computed tomography angiography in the vascular mapping of head and neck: and intraindividual comparison. Head and Face Medecine 10: 16, 2014
Lohan DG, Bakhordarian F, Saleh R, Krishnam M, Salamon N, Ruehm SG, et al: MR angiography at 3T for assessment of the external carotid artery system. AJR Am J Roentgenol 189: 1088–1094, 2007
Mata JR, Mata FR, Souza MC, Nishija H, Ferreira T: A : arrangement and prevalence of branches in the external carotid artery in humans. Ital J Anat Embryol 117: 65–74, 2012
Mücke T, Ritschi LM, Roth M, Güll FD, Rau A, Grill S, et al: Predictors of free flap loss in the head and neck region : a four-years retrospective study with 451 microvascular transplants at a single center. J Craniomaxillofac Surg 44: 1292–1298, 2016
Natsis K, Raikos A, Foundos I, Noussios G, Lazaridis N, Njau SN: Superior thyroid artery origin in Caucasian Greeks : a new classification proposal and review of the literature. Clin Anat 24: 699–705, 2011
Nayak KS, Nielsen JF, Bernstein MA, Markl M, D Gatehouse P, M Botnar R, et al: Cardiovascular magnetic resonance phase contrast imaging. J Cardiovasc Magn Reson 17: 71, 2015
Nayler GL, Firmin DN, Longmore DB: Blood flow imaging by cine magnetic resonance. J Comput Assist Tomogr 10: 715–722, Sep-Oct 1986
Ozgur Z, Govsa F, Ozgur T: Assessment of origin characteristics of the front branches of the external carotid artery. J Craniomaxillofac Surg 19: 1159–1166, 2008
Pagé G: Blood flow quantification and characterization in the cervico-facial vasculature tree using flow MRI:evaluation and applications. Université de Picardie Jules Verne, PhD, 2017
Pedersen H, Kozerke S, Ringgaard S, Nehrke K, Kim WY: k-t PCA: temporally constrained k-t BLAST reconstruction using principal component analysis. Magn Reson Med 62: 706–716, 2009
Pelc NJ, Herlkens RJ, Shimakawa A, Enzmann DR: Phase contrast cine magnetic resonance imaging. Magn Reson Q 7: 229–254, Oct 1991
Pelc NJ, Sommer FG, Li KC, Brosnan TJ, Herlkens RJ, Enzmann DR: Quantitative magnetic resonance flow imaging. Magn Reson Q 10: 125–147, Sep 1994
Pohlenz P, Klatt J, Schön G, Blessmann M, Li L, Schmelzle R: Microvascular free flaps in head and neck surgery: complications and outcome of 1000 flaps. Int J Oral Maxillofac Surg 41: 739–743, 2012
Pruessmann KP, Weiger M, Scheidegger MB, Boesiger P: SENSE: sensitivity encoding for fast MRI. Magn Reson Med 42: 952–962, 1999
Rebergen SA, van der Wall EE, Doornbos J, de Roos A: Magnetic resonance measurement of velocity and flow: technique, validation, and cardiovascular applications. Am Heart J 126: 1439–1456, 1993
Shima H, von Luedinhausen M, Ohno K, Michi K: Anatomy of microvascular anastomosis in the neck. Plast Reconstr Surg 101: 33–41, 1998

Singh B, Cordeiro PG, Santamaria E, Shaha AR, Plister DG, Shah JP: Factors associated with complications in microvascular reconstruction of head and neck defects. Plast Reconstruct Surg 103: 403–411, Feb 1999
Stankovic Z, Allen BD, Garcia J, Jarvis KB, Markl M: 4D flow imaging with MRI. Cardiavasc Diagn Ther: 173–192, 2014 Apr
Tan O, Kantarci M, Parmaksizoglu D, Uyanik Y, Durur I: Determination of the recipient vessels in the head and neck using multislice spiral computed tomography angiography before free flap surgery : a preliminary study. J Craniofac Surg 18: 1284–1289, Nov 2007
Xu C, Prince JL: Snakes, shapes, and gradient vector flow. IEEE Trans Image Process 7: 359–369, 1998
Zhang C, Sun H, Xu L, Ji T, He Y, Yang W, et al: Microsurgical free flap reconstructions of the head and neck region : shanghai experience of 34 years and 4640 flaps. Int J Oral Maxillofac Surg 44: 675–684, 2015
Zumre O, Salbacak A, Çiçekcibasi AE, Tuncer I, Seker M: Investigation of the bifurcation level of the common carotid artery and variations of the branches of the external carotid artery in human foetuses. Ann Anat 187: 361–369, 2005