Egyptian Journal of Radiology and Nuclear Medicine

RESEARCH **Open Access**

Preoperative visualization of mammary artery for breast reduction surgery based on computed tomography angiography

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Abstract

Background Macromastia, characterized by an increase in breast size, poses challenges such as elevated body burden and chest oppression, potentially leading to cardiac and pulmonary overload. A crucial aspect of addressing these challenges involves preoperative planning, aiming to acquire detailed images and a 3D model of the internal mammary artery with minimal radiation exposure.

Purpose This study aimed to explore the clinical significance of computed tomography angiography (CTA) of the mammary artery in preoperative planning for breast reduction surgery.

Methods Retrospective analysis was conducted on CT images from 60 patients scheduled for breast reduction surgery in the plastic surgery department. These images were processed using a post-processing workstation to extract internal mammary arteries for subsequent 3D modeling. Radiologists and plastic surgeons collaborated to perform preoperative planning based on the 3D model and associated measurement parameters. Subsequent follow-up examinations occurred 4 to 9 months post-surgery, evaluating necrosis rates and complications of the nipple-areola complex (NAC).

Results A total of 206 blood vessels were reconstructed and extracted in 60 patients, including 156 main arteries and 50 arterioles. There were no instance of NAC necrosis, complications, or infections in the 4–9 months follow-up period.

Conclusions Preoperative Mammary artery CTA emerged as a valuable tool, facilitating a comprehensive understanding of the internal mammary arteries and the primary blood supply in the NAC region. This approach effectively minimizes the risk of NAC supply artery injury during surgery, thereby preserving the functionality of the nipple and areola.

Keyword Macromastia, Breast reduction surgery, Internal mammary artery, Computed tomography angiography

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Background

Macromastia is a medical condition characterized by an abnormal accumulation of glandular, adipose and connective tissues in breasts, resulting in an excessive breast size. This condition imposes an increased burden on the body and can lead to chest oppression, potentially culminating in cardiac and pulmonary overload [1, 2]. As of now, definitive standards for breast hypertrophy remain elusive. In China, surgeons commonly categorize breast sizes based on unilateral volume[3], considering a normal range of 250–350 ml, an excessive size ranging from 350 to 1000 ml, and hypertrophy for volumes exceeding 1000 ml [2]. According to guidelines for plastic surgeons in developing countries, macromastia is defined as an excess of breast tissue greater than 1 (>1) and less than (<2) 2 kg per breast. Gigantomastia, on the other hand, is characterized by a resection weight exceeding 2.0 kg as per the guidelines in developing countries [4]. Whether assessed by volume or weight, preoperative evaluation of macromastosis is feasible.

The precise etiology of breast hypertrophy remains elusive, with genetic factors and environmental stimulus being identified as the potential contributors. In the USA, over 100,000 cases of breast reduction surgeries were performed each year [5]. Although the exact causes of breast reduction surgeries in China have not been statistically evaluated, it would not be a small number considering its large population base.

Presently, breast reduction surgeries are performed worldwide using various techniques, all with the shared objective of eliminating excess glandular and adipose tissue, restoring a natural breast contour, and elevating the position of the nipple and mammary areola while preserving the functional vascular supply to the nipple-areola complex (NAC). Despite the uniformity in surgical goals, preoperative computed tomography angiography (CTA) of internal mammary arteries is not consistently integrated into surgical protocols. The absence of a standardized preoperative CTA scanning protocol for internal mammary arteries in medical institutions has resulted in a lack of comprehensive guidance for surgeons. Several studies have investigated the efficacy of CTA for vascular reconstruction in breast reconstruction [5, 6], In 2017, a plastic surgeon study which utilizing the same patient data, employed CTA for preoperative planning in macromastia cases, was the pioneering study. The study revealed that CTA imaging enabled the definite identification of the dominant source vessels and their branches or perforators supplying the primary blood flow to the NAC tissues in hypertrophic breasts. The study successfully identified both symmetrical and asymmetrical patterns of dominant source vessels supplying blood perfusion to a hypertrophic breast NAC between each individual's breasts. Moreover, the CTA imaging revealed that a small number of hypertrophic breasts had no definitive dominant blood sources for their NAC tissues. Notably, no studies to date have delved into the application of 3D reconstruction in Macromastia surgery, preoperative CTA is essential to help doctors see accurate vascular anatomical information [7]. Despite its recognized significance, the literature lacks a comprehensive discussion on the specific methodology for conducting CTA examinations for macromastia, the subsequent steps for 3D reconstruction, and strategies for optimizing the visual impact of three-dimensional reconstruction.

The objective of this study was to investigate a preoperative planning examination solution that is both safe and cost-effective, while providing comprehensive preoperative planning images and a 3D model of the internal mammary artery. The emphasis was on minimizing radiation exposure to patients during the imaging process.

Methods

Patients' characteristics

A total of 60 patients who underwent breast reduction surgery for breast hypertrophy from Xijing Hospital, Air Force Military Medical University and Xi`an DaXing Hospital between May 2018 and July 2021 were included. The subjects included in study all met the criteria for Macromastia [4].

The inclusion criteria were: female; Clinical symptoms occurred for excessive size/weight of breast; No contrast agent or drug allergy history, or other CTA examination-related contraindications; the exclusion criteria: < 15 years old or > 65 years old; underwent breast surgery before; Breast cancer or tumor. Before CTA, all patients signed the informed consent for the contrast agent, and assured that they did not have any contraindications to CTA. All patients' thyroid glands were covered with a lead shield (Lead shield is a protective barrier made of lead that is designed to absorb harmful radiation) for protection. Details of patients' characteristics are found in Table 1.

CTA acquisition

All CTA scans were performed on Siemens SOMATOM Definition Flash CT (Xijing Hospital, Air Force Military Medical University) or Canon Aquilion ONE GENESIS Edition CT scanner (Xi`an DaXing Hospital). All scanning protocols refer to the coronary artery scanning guidelines [8]. All CT images were post-processed on a dedicated workstation (virtea, v4.11 Canon MEDICAL SYSTEMS Co., Ltd). The scanning parameters were as follows:

Table 1 Patient information

Item	Value
Cases (*n*)	*n* = 60
Age	15–62(36.2 ± 2.1)
Mean BMI	25.2 ± 1.9
Breast ptosis (cm)	5.5 ± 0.35
chest circumference(cm)	115.2 ± 13.6

Table 2 Parameters setting of the two scanners

Parameters	Xijing hospital, air force military medical university	Xi`an DaXing hospital
Scanner	Siemens SOMATOM Definition Flash	Canon Aquilion ONE 320/GENESIS Edition
Tube voltage	100 kV	
Tube current	300 mA	
Collimator	320×0.5	
Pitch	0.8	
Rotation rate of tube	0.35R/s	0.5R/s
Matrix	256×256	512×512
FC	10.5	12.5
Slice thickness	0.625 mm×0.625 mm	
Position	Prone position(head in, feet out)	
Contrast agent manufacture	GE VISPAQUE 320 mg I/ml	
Dosage of contrast agent	0.8 ml/KG, 50–85 ml	
Flow rate of contrast agent	4.5–5.5 ml/s	
Concentration of contrast agent	370 mg/L	320 mg/L
Scanning phase	Arterial and venous phase	Continuous scanning on arterial phase
Reconstruction algorithm	FLESH FBV	AIDR 3D

100kVp tube voltage, 300 mA tube current, pitch 0.8, reconstruction matrix 512×512, reconstruction kernel was FC=12.5. slice thickness and slice gap 0.5 mm, FOV=500 mm (Table 2).

The contrast agent (GE Healthcare Ireland Limited, VISPAQUE 320 mg I/ml, Injection) was given based on body weight at the standard of 0.8 ml/kg with the flow rate of 4.5–5.5 ml/s and a range of 50–85 ml [9, 10]. Patients were scanned under prone position (head in and feet out).

Scanning and reconstruction procedures

After removing the underwear, a soft rubber patch was affixed to the mammary areola. Patients lie prostrate on the custom-made foam holder (Fig. 1) to let breast naturally hang. The contrast agent was injected in the right elbow vein, and mid and late arterial phase scanning were performed for data collecting and thin-slice reconstruction. The holder was designed and made independently, and the relevant patent had been applied.

Data processing and VR modeling

Firstly, VT (Vessel tools) software in the VITREA workstation was applied to extract and mark internal breast arteries. Tissues (adipose tissue and some glands) with CT value lower than 20HU were removed by preset CT threshold [11, 12]. The general route of internal breast arteries was identified, then arteries and glands were separated manually by dissecting vessels and surrounding glandular tissues to obtain the model of arterial vessels (Figs. 2, 3).

Fig. 1 Holder for internal mammary artery CTA scanning. The use of holder during CTA scanning focuses the patient's breast and provides more realistic visualization of blood vessels

Secondly, threshold value was reset and related rubber patch was extracted on NAC to obtain the model of NAC. Then breast contour for reconstruction was

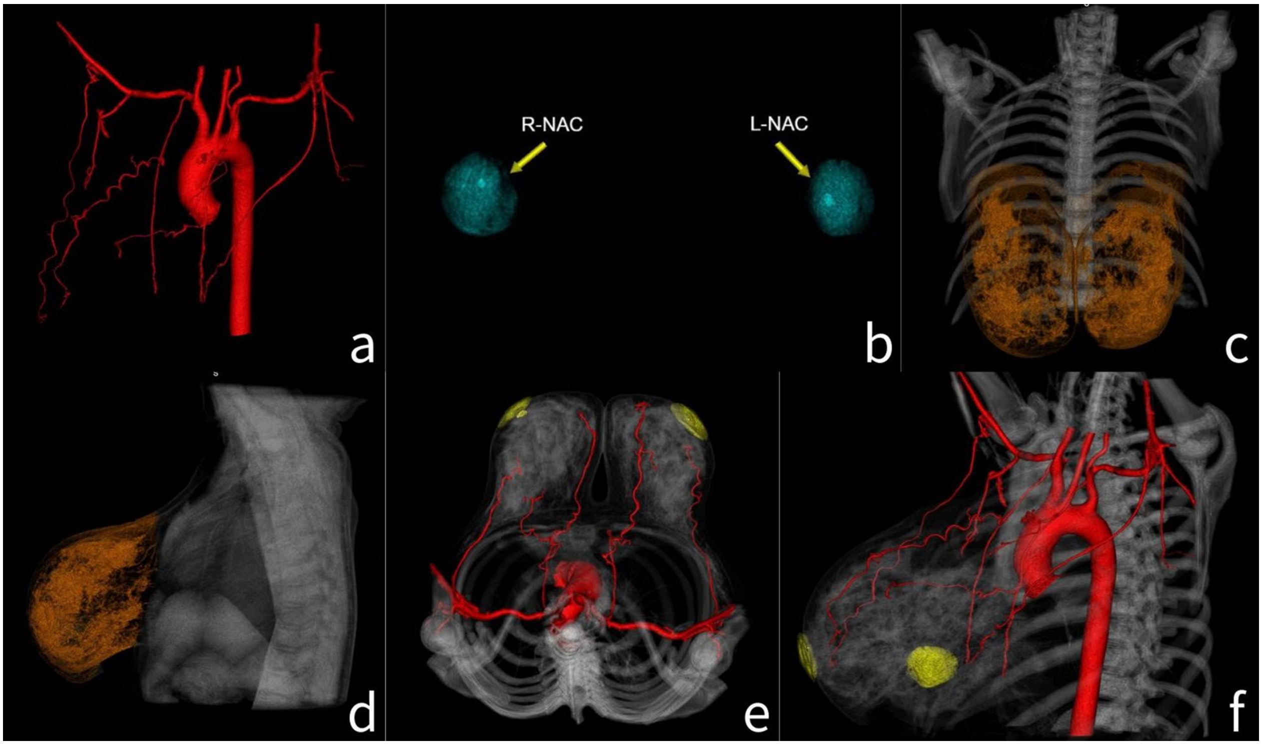

Fig. 2 **a**–**f** Female, 47 years old, with enlarged breasts volume is 2557.21 ml. **a** Blood vessel dissection model, Bone and other soft tissues were removed. **b** manual dissection model of NAC, NAC regions were manually segmented and extracted in ture proportion. **c**–**d** Breast contour model, Breast tissue and contours were extracted and displayed alongside the bone, displays were performed in the sagittal and coronal views. **e**–**f** Complete 3D reconstructed images, fused images of breast contour, NAC, blood vessels, and bone were displayed in axial and sagittal views

extracted. The transparency (Density of pseudo color in VR image) of the reconstructed breast contour model was adjusted and was merged with the internal mammary artery model and nipple marking model of NAC to obtain the VR model of distribution of internal mammary arteries. Locations of internal mammary arteries to NAC could be clearly shown in the merged model.

Data measurement

Each extracted internal mammary artery was marked and named, respectively. The end diameter of each perforating vessel near the marker in the NAC area was measured by an associate chief physician. The source of each perforating vessel to obtain the end diameter and origin artery of the supplying artery in the NAC area were traced and recorded. Then, raw data of the two phases were imported into the ORS 3.0 version engineering software (Object Research Systems ORS Inc) for breast volume measuring.

To obtain the complete 3D data of breasts by dissecting adipose tissue and some glands based on preset CT threshold value and removing the muscle and bones (including breastbone, pectoralis major, ribs, clavicle, etc.). Bilateral breast volume was calculated with the automatic calculation tool of ORS 3.0 software, and relevant data were recorded.

Preoperative planning

Patients were asked to stand erect. The plastic surgeon cooperated with the radiologist to mark the distribution and position of internal mammary arteries of the NAC area on patients' body surface based on reconstructed images. Then the breast meridians were measured, the midclavicular line to the nipple, the distance from sternal notch to the nipple, and the distance from the mid sternal line to the nipple on the patient's body surface were drawn.

Results

Follow-up results

All patients were followed up with the time of 4 to 9 months for observation and complications recording. Each patient was followed up at least once, and the necrosis rate and complications of the NAC area were recorded and counted. No NAC necrosis or complications such as fat liquefaction, infection, and hematoma were found in follow-up. Five patients initiated breastfeeding 3 to

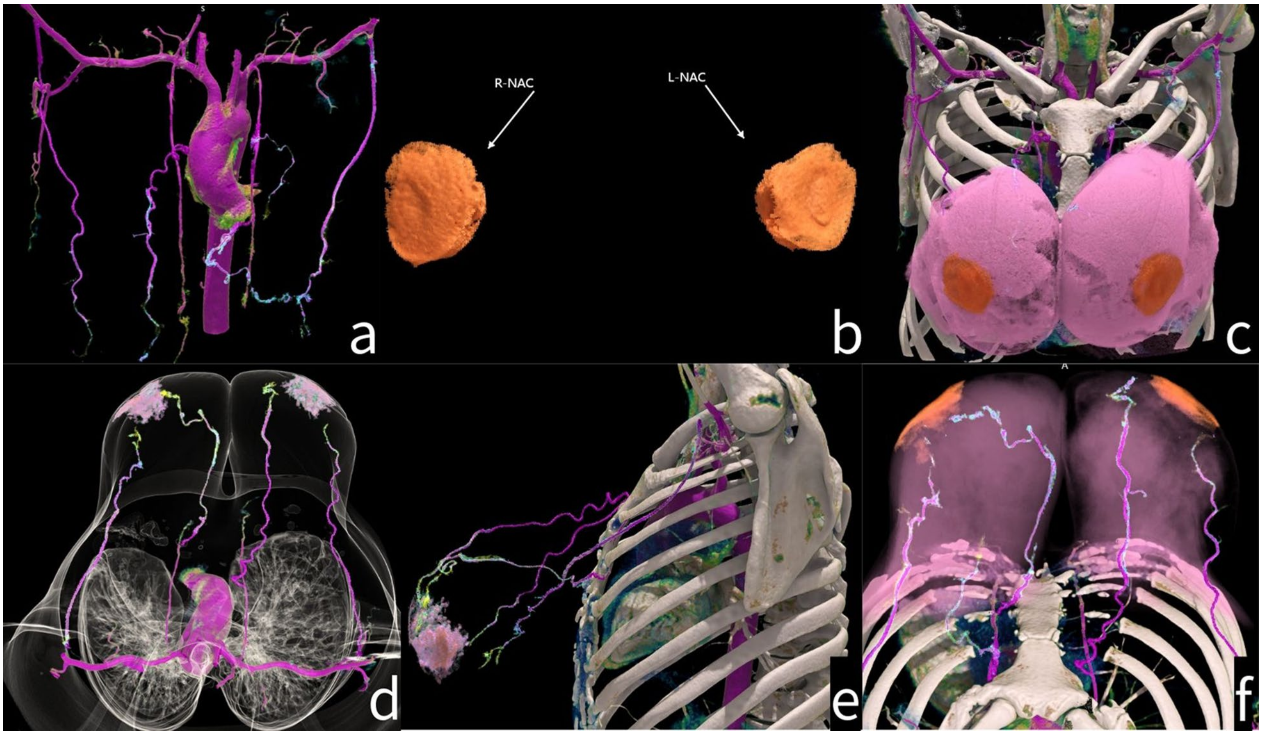

Fig. 3 **a–f** Female, 33 years old, with enlarged breasts volume is 2333.10 ml **a** Blood vessel dissection model, Bone and other soft tissues were removed. **b** manual dissection model of NAC, NAC regions were manually segmented and extracted in ture proportion. **c** Breast contour and NAC model, Breast tissue and contours were extracted and displayed alongside the bone, displays were performed in the coronal views. **d** Fused images of breast contour clearing, blood vessels and NAC, After removal of the bone, the relationship between the artery and the NAC was clearer in this patient. **e** Fused images of bone, blood vessels and NAC, after removal the breast, the relationship between blood artery, NAC and bone was clearer. **f** Complete 3D reconstructed images, fused images of breast contour, NAC, blood vessels, and bone were displayed in axial and sagittal views

Table 3 Postoperative follow-up results

Item	Value & range
Cases	60
Mean volume of unilateral breast before surgery (ml)	585.2 ± 24.3
Mean volume of unilateral breast after surgery (ml)	361.2 ± 11.9
Fat liquefaction	0 (0/60, 0%)
Infection	0 (0/60, 0%)
Hematoma	0 (0/60, 0%)
NAC discomfortableness in breastfeeding	1 (1/5, 20%)
NAC necrosis	0 (0/60, 0%)
Other complications	0 (0/60, 0%)

6 months after their surgeries, only 1 case of uncomfortableness occurred (20%). See Table 3.

Internal mammary artery measuring results

A total of 206 internal mammary arteries supplying blood to the NAC area were reconstructed in 60 patients (105 arteries on the right side and 101 on the left side, 156 main arteries and 50 arterioles). Among them, 116 perforating branches of the internal thoracic artery (56.3%), 42 branches of the lateral thoracic artery (20.3%), 20 branches of the thoracoacromial artery (9.7%), 16 branches of the brachial artery, and 12 branches of axillary artery (4.9%) were reconstructed. No other artery origin was found.

In the breast blood supply pattern, 42 patients (70%) were bilateral symmetry and 18 patients (30%) were asymmetrical.

The origins of internal mammary arteries and blood supply patterns were also statistically analyzed in the plastic surgery study of Hui ZHENG [12] in May 2018. No significant difference was found in the origin of the internal mammary artery between this study and Hui Zheng's study ($P > 0.05$). A significant study on the symmetry of blood supply patterns was found between the two studies ($P < 0.05$). Significant specificity and differentiation could be found on the blood supply symmetry of the internal mammary artery in a patient with breast hypertrophy (Table 4).

Table 4 Origin of internal mammary artery & Blood supply pattern

Item	2018 study (Hui ZHENG's study) (%)	2021 study (This study) (%)	*P*-value
Number of patients	60	60	N/A
Number of vessels	163	206	N/A
From internal thoracic artery (internal mammary artery)	81 (49.6)	116 (56.3)	0.2063
From lateral thoracic artery	46 (28.2)	42 (20.3)	0.08
From thoracoacromial artery	22 (13.5)	20 (9.7)	0.2558
From brachial artery	7 (4.3)	16 (7.7)	0.1712
From axillary artery	7 (4.3)	12 (5.8)	0.5093
Other artery	0 (0)	0 (0)	1
Symmetry	27 (45)	42 (70)	0.0058
Asymmetry	33 (55)	18 (30)	0.0058

Discussion

The importance of assessing the internal mammary artery before surgery

Breast reduction surgery stands as one of the most prevalent breast plastic procedures. In China, such surgeries have traditionally relied on prior experience and anatomical knowledge of breast blood supply in normal individuals, lacking specific information on the internal mammary artery. Notably, the blood supply origins of internal breast arteries in the NAC area exhibit high specificity. While existing studies typically highlight perforating vessels of the internal thoracic artery as primary blood supply sources, it is crucial to recognize the lateral thoracic artery, thoracoacromial artery, brachial artery, and axillary artery as additional sources [13–15]

Furthermore, the abnormal hyperplasia of gland and fat in patients with breast hypertrophy deviates from the distribution of internal mammary arteries and blood supply origin seen in normal individuals. The asymmetry in the blood supply of bilateral breasts poses a challenge, as the dissection of gland and adipose tissue on one side may be well-executed, but potential blood supply vessel issues could arise on the other side [16].

Internationally, several studies have reported functional loss or even necrosis of the nipple-areola complex resulting from injuries in the NAC area during breast reduction surgery based on past experiences of breast gland resection [6, 17]. These findings underscore the need for a comprehensive understanding of the specificities of blood supply in the context of breast hypertrophy to enhance surgical outcomes and minimize complications.

Disadvantages of different examinations in assessing internal mammary artery

To prevent injury to feeding arteries in the NAC area during surgery, numerous studies have been conducted. For instance, Başaran, in a 2011 study, utilized Doppler angiography to map blood vessel distribution before surgery [13]. Similar approaches have been employed in preoperative planning. However, utilizing ultrasonic examination to locate internal mammary arteries proves challenging in patients with breast hypertrophy due to the substantial breast volume, requiring skilled ultrasound technicians. Moreover, ultrasonic examination results lack the capability to generate 3D reconstructed images for detailed pre-surgical observation, unlike CTA [14].

Breast MRI is another option for internal mammary artery scanning [15]. Yet, it has drawbacks, including extended scanning times, contraindications for certain metal implants, and pronounced venous artifacts that hinder clear observation. In comparison, CTA offers faster scanning, superior contrast resolution, and enhanced 3D reconstruction capabilities, making it the preferred choice for internal mammary artery examination.

Comparison with the preliminary study for CTA scanning in internal mammary artery

In referencing Hui Zheng's 2018 study [12], conducted by the same research group at XiJing Hospital, we observed a notable gap in detailing parameters for CTA scanning and the demonstration of 3D reconstruction techniques. Our study addressed this by reviewing the original data and scanning parameter settings of 60 patients from Hui Zheng's research. By optimizing the collection time, adjusting the contrast agent amount, and incorporating a new post-processing software for vascular segmentation and extraction, we significantly enhanced the detection rate of blood supply vessels. This improvement underscores the importance of refining scanning protocols and utilizing advanced post-processing tools for more accurate and comprehensive vascular assessments.

In previous analysis of the 2018 study data, we identified that the majority of internal mammary arteries originated from the internal thoracic artery, constituting 49.6%, while the second most common origin was the external thoracic artery, accounting for 28.2%. Previous studies showed limited imaging of terminal internal mammary arteries near the NAC area, but a clear visualization toward the heart. We attribute this to the perceived thinness and slight delay in blood flow, likely due to compression from fatty tissue in patients with macromastia. To address these challenges, our study optimized the collection time and selected the proximal end of the

Table 5 Parameters setting in study 2018 and study 2021

	Study 2018	Study 2021
Monitoring part	Ascending aorta	Left subclavian artery
Scanning-triggering threshold	120Hu	160Hu
Collection time of the first phase	Arterial phase (22–28 s)	Late arterial phase (26–31 s)
Collection time of the second phase	Venous phase (42–48 s)	Late arterial phase (28–33 s)
Dose of contrast agent	70 ml	Contrast agent to body weight: 0.8 ml/KG, 50–85 ml
Number of patients	60	60
Number of detected blood vessels	163	206
Average detected vessels of each patient	2.71	3.43

left subclavian artery as the monitoring vessel, the origin blood vessel of the internal thoracic artery. We set the threshold value at 160Hu, slightly higher than the previous 120Hu, and positioned it above the previously used ascending aorta as the monitoring vessel. To enhance microarteriography [18], late arterial phase data collection was prioritized with a 2-s interval, allowing for adjusted contrast agent amounts based on the contrast agent to body weight ratio (0.8 ml/kg). In addition, we employed the latest Canon Vitrea 4.0 workstation and ORS 1.0 segmentation software for 3D reconstruction, surpassing traditional methods. This approach facilitated more accurate extraction of blood vessels, even with subtle enhancements of thin vessels. As a result, the modified approach demonstrated a 26.3% increase in the detection ratio of vessels, as shown in Table 5.

Limitations

Firstly, the sample size of this study is relatively small. In this study, 42 patients (70%) had symmetrical arterial blood supply to both breasts, compared with 27 patients (45%) in the previous study [18]. A large sample size is needed to provide the distribution of internal mammary arteries in patients with macromastia. Secondly, scan parameters in this study can be further optimized, for example, with special adjustments for each patient's conditions, including body weight, chest size and other autogenous diseases. Thirdly, the post-processing software may further enhance the detection on small vessels in the distal breast. Additional comparative studies on different scanner models are recommended for a more comprehensive understanding of imaging outcomes and technological variations in macromastia preoperative planning.

Conclusions

Preoperative mammary artery computed tomography angiography (CTA) proves beneficial in delineating the territory of internal mammary arteries and identifying the primary blood supply within the nipple-areola complex (NAC) area. This application aids in mitigating the risk of injury to NAC supply arteries during surgery, thereby preserving the functionality of the nipple and areola. The clinical utility of this approach is substantial, underscoring its high value in preoperative planning and surgical interventions.

Acknowledgements
My deepest gratitude goes first and foremost to Professor Yue Qin and Chenggang Yi, for their constant encouragement and guidance. Without their consistent and illuminating instruction, this thesis could not have reached its present form. Second, I would like to express my heartfelt gratitude to Doctor Yinhu Zhu, who led me into the world of medicine. I am also greatly indebted to the of the Xi`an Daxing hospital have instructed and helped me a lotin the past years. I also owe my sincere gratitude to my colleague Jigang Geng and Lei Wang, who gave me their help and time in listening to me and helping me work out my problems during the difficult course of the thesis.

Author contributions
Guarantor of integrity of the entire study: YQ, LW. Study concepts and design: XSL, JGG. Literature research: DJ, YZ. Clinical studies: XL. Experimental studies / data analysis: JG, LW. Statistical analysis: XSL. Manuscript preparation: XSL, LW, and JGG. Manuscript editing: XSL, LW. All authors have read and approved the manuscript.

Funding
This study was not supported by any funding.

Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request. All data generated or analyzed during this study are included in this published article.

Declarations

Ethics approval and consent to participate
Not applicable, because this is a retrospective study.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interest in this section.

Received: 15 August 2023 Accepted: 11 December 2023
Published online: 02 January 2024

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