Critical review

Preoperative assessment of the perforators of the anterolateral thigh flap: a critical review

S Bai, J Safdar, C Sun*

Abstract
Introduction
The anterolateral thigh flap is gaining widespread popularity as a workhorse in the reconstructive surgery of head and neck defects. The variation of the perforators is still a challenge in preoperative designing. The aim of this critical review is to introduce the current modalities used in perforators’ mapping of the anterolateral thigh flap and evaluate their strengths and weaknesses.

Materials and methods
The Web of Science database was used in this review. This review examined literatures that assess the accuracy, strengths and weaknesses of new techniques used in the preoperative assessment of anterolateral thigh flap perforators. Search terms included ‘anterolateral thigh flap’ in combination with ‘computed tomography angiography’, ‘handheld Doppler’, ‘colour duplex sonography’, ‘computed tomography-guided stereotaxy’ and ‘magnetic resonance angiography’. All literatures were found between 2002 and 2012 in English language.

Results
A total of 20 papers were reviewed according to the refined search. Although the handheld Doppler is non-invasive and portable, it often misidentifies or misses vessels, especially in evaluating small perforators, making this modality unreliable.

Colour duplex sonography provides high spatial resolution of superficial perforators. Computed tomography angiography, computerised tomography-guided stereotaxy and magnetic resonance angiography provide the best three-dimensional images and have become the most advanced modalities used to assess the accurate anatomy of the donor site, of the anterolateral thigh flap.

Conclusion
Given the requirement to improve the outcome of anterolateral thigh flap reconstructive surgery, preoperative assessment of the perforators is essential. The ABC assessment system combined with colour Doppler/computed tomography angiography will facilitate an ideal individual assessment of this perforator flap.

Introduction
Since it was first introduced in 1984 by Song et al., the anterolateral thigh (ALT) flap is known as a versatile flap in reconstructive surgery because of its long vascular pedicle, pliable skin paddle and minimal donor site morbidity. In any case, locating the perforators is a critical step in flap design. In previous studies, three cutaneous perforators of the ALT flap were identified in specific locations named perforators A, B and C from proximal to distal (the ABC system), and the experience seemed to suggest that the ABC system is reliable and can guide flap design without the need for preoperative imaging. As the volume of the perforator flap reconstruction increases, the necessity to obtain the precise localization of the cutaneous perforators becomes much more urgent, and hence, more and more imaging modalities must be introduced. Until now, no adequate formal analyses of the accuracy and feasibility of the modalities used for preoperative imaging of ALT perforators, have been reported. Therefore, the main purpose of this critical review was to elucidate new techniques that have been introduced to locate perforators and to identify their size, origin and the pattern of their course (septocutaneous or myocutaneous). This review was also aimed at evaluating the accuracy, strengths and weaknesses of the modalities used in the preoperative assessment of ALT perforators.

Materials and methods
A literature search was undertaken using the Web of Science database. Topic searches were performed using the following terms: ‘anterolateral thigh flap’ in combination with ‘computed tomography angiography (CTA)’, ‘handheld Doppler’, ‘colour duplex sonography (CDS)’, ‘computerised tomography (CT)-guided stereotaxy’ and ‘magnetic resonance angiography (MRA)’. The number of search results was further reduced by only including studies in the year range 2002–2012 and only those written in English language, after which, a manual filtration for relevance was performed. This retrospective review contains 20 literatures reporting patients who underwent reconstructive surgery with the ALT flap. The modalities used to assess the anatomical vasculature in the donor region can be broadly classified as: (a) CTA (n = 10), (b) colour Doppler sonography (n = 8), (c) CT-guided stereotaxy (n = 1) and (d) MRA (n = 1). The literatures were analysed to assess

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the accuracy and the strengths and weaknesses of these modalities.

**Results**

**CTA**

CTA is a novel technique that has recently been described for the investigation of the anatomy and perfusion of perforator complexes in the axial, coronal and sagittal views in the flap. Owing to the technique of three-dimensional volume and maximum intensity projection, CTA provides insight into vascular variation, including the origin of the perforator from the lateral circumflex artery (ascending, transverse or descending), its course (septocutaneous or myocutaneous), its number and the perforator external diameter. A total of 10 papers were reviewed in which CTA was used in the preoperative assessment of the ALT flap. This review summarises partial literatures describing outcomes from the utilization of CTA for ALT flap harvesting (Table 1).

Schaverien et al. harvested 18 ALT flaps from Western cadavers and performed dynamic and static imaging of perforators and their collateral venae comitantes. Three morphological patterns were evident in the perforators: Type I, where the branches of the perforator course out obliquely through the adipose layer to reach the subdermal plexus, without any components in the subfascial layer (33%); Type II, where the perforator also has branches that course out horizontally to form a suprafascial plexus (17%) and Type III, where the perforators divide into several branches at the suprafascial level, coursing out horizontally before forming the subdermal plexus (50%). With the aid of multidetector CT, Heo et al. conducted skin reconstruction based on an ipsilateral, distally based ALT flap. Liu et al. found that the utility of CTA was associated with a significant reduction in major surgical complications, length of surgery and the need for a secondary debulking procedure in patients with lip or oral commissure involvement.

CTA has achieved non-invasive vascular imaging with high spatial and temporal resolution. Theoretically, the advantage of using CTA over Doppler ultrasonography is that the perforators can be directly visualised. Hence, CTA can be used in the identification of the appropriate type of perforator for ALT flap reconstructive surgery. With the aid of CTA, if surgeons can locate an appropriate septocutaneous perforator as the dominant perforating vasculature of the flap, they can avoid a tedious intramuscular dissection, making the procedure simple and straight forward. In difficult cases, especially for through-and-through defects, a single ALT flap with two skin paddles can be designed preoperatively, reducing surgery time.

However, mapping of perforators is easier for obese patients because the vessel is demonstrated more prominently in the fatty tissue than in the muscle. Mapping may be problematic in relatively small perforators with weak signal intensities. The detectable perforator calibre is limited to greater than 1 mm in diameter. In addition, an important point to be discussed with the patient is the amount of radiation exposure.

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Number of patients/flaps</th>
<th>Perforators present on CTA</th>
<th>Perforators present (intraoperative)</th>
<th>Number of septocutaneous perforators (intraoperative)</th>
<th>Number of myocutaneous perforators (intraoperative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rozen et al.5</td>
<td>2008</td>
<td>2</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Ribuffo et al.6</td>
<td>2009</td>
<td>9 (6 underwent surgery)</td>
<td>43</td>
<td>27 (exclude 3 patients)</td>
<td>3/43</td>
<td>40/43</td>
</tr>
<tr>
<td>Kim et al.7</td>
<td>2010</td>
<td>139 (limbs)</td>
<td>317</td>
<td>321</td>
<td>37/317</td>
<td>280/317</td>
</tr>
<tr>
<td>Chen et al.8</td>
<td>2010</td>
<td>32</td>
<td>64 (exclude 20 dissatisfied perforators)</td>
<td>77</td>
<td>Null</td>
<td>Null</td>
</tr>
<tr>
<td>Chiu et al.9</td>
<td>2011</td>
<td>9</td>
<td>23</td>
<td>22</td>
<td>Null</td>
<td>Null</td>
</tr>
<tr>
<td>Garvey et al.10</td>
<td>2011</td>
<td>16</td>
<td>40</td>
<td>54</td>
<td>Null</td>
<td>Null</td>
</tr>
<tr>
<td>Yang et al.11</td>
<td>2012</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>5/16</td>
<td>11/16</td>
</tr>
</tbody>
</table>

ALT, anterolateral thigh; CTA, computed tomography angiography.

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exposure, which is equivalent to three times the annual exposure to natural radiation. Also noteworthy, are the side effects that include contrast medium allergy and potential carcinogenic effects.

**Doppler ultrasonography**

Since the report by Taylor et al.15, preoperative Doppler examination has become a ubiquitous facility in most hospitals because of its moderate cost, non-invasive nature and portability. Ultrasound is a perfect choice to assess superficial structures in detail because it provides a high spatial resolution and has the ability to map vessels using duplex examination. Unfortunately, the handheld acoustic Doppler often misidentifies or misses vessels, especially in the evaluation of small perforators, making this modality unreliable. On the other hand, improvements in this modality have permitted the scanning of superficial depths below the skin level with a high sensitivity for detecting vessels as small as 0.2 mm in diameter16,17 (hence called the ‘power Doppler’17). It has been used in the widespread preoperative evaluation of donor and recipient source vessels. A total of eight papers were reviewed, in which colour Doppler sonography was used in the preoperative assessment of the ALT flap and its positive predictive value was reviewed (Table 2).

CDS with a high-frequency transducer enables the anatomical analysis of vascular flow as well as the measurement of blood flow velocity. Studies comparing vessel diameter measured on CTA, MRA and ultrasound, have repeatedly shown that size estimations based on cross-sectional imaging (CTA/MRA) are less accurate than those based on ultrasound21. Patel et al.20 concluded that colour Doppler was particularly useful in identifying patients with clinically asymptomatic infragenual peripheral arterial disease, in whom elevation of the ALT flap might be unsuccessful. CDS provides a non-invasive, without exposure to radiation, repetitive and accurate preoperative assessment of the perforator flap and overcomes the difficulties of anatomical variation seen in cutaneous perforators.

This modality requires both scanning skills and a detailed knowledge of surgery, especially on thin and atrophic thighs because the excessive pressure exerted by the transducer can interrupt the blood flow of the perforators, resulting in missing signals of the smaller perforators21. However, in actual practice, the identification of minor perforators that are smaller than 0.5 mm cannot be considered reliable24. In a previous study, probabilities with the Doppler device decreased with an increasing body mass index25. However, Shaw et al.26 found that this association, in their series, produced a more U-shaped curve which reflected the higher rates of false positives in lean patients with thin thighs.

**CT-guided stereotaxy**

CT-guided stereotactic navigational systems are relatively advanced in imaging technology, utilising software manipulation of the image data from a CT study to allow extremely accurate preoperative or intraoperative anatomical localisation27. Rozen et al.5 applied CT-guided stereotaxy, for perforator mapping, in two patients undergoing ALT flap reconstruction. The preoperative findings obtained from CT-guided stereotaxy showed a high correspondence with

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Number of patients/flaps</th>
<th>Perforators present on colour Doppler sonography</th>
<th>Perforators present (intraoperative)</th>
<th>Positive predictive value (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iida et al.18</td>
<td>2002</td>
<td>17</td>
<td>48</td>
<td>50</td>
<td>95.8</td>
</tr>
<tr>
<td>Tsukino et al.19</td>
<td>2004</td>
<td>10</td>
<td>15</td>
<td>15</td>
<td>100</td>
</tr>
<tr>
<td>Patel et al.20</td>
<td>2010</td>
<td>14</td>
<td>48</td>
<td>43</td>
<td>89.5</td>
</tr>
<tr>
<td>Ensat et al.21</td>
<td>2012</td>
<td>13</td>
<td>30</td>
<td>30*</td>
<td>96.7</td>
</tr>
<tr>
<td>Ulatowski et al.22</td>
<td>2012</td>
<td>30 (healthy volunteers)</td>
<td>119</td>
<td>Null</td>
<td>Null</td>
</tr>
</tbody>
</table>

ALT, anterolateral thigh

*All perforators except one was found during flap dissection; one perforator had not been detected with colour Doppler sonography.

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the intraintraoperative findings. The only addition to the scanning protocol was the attachment of fiducial markers to the bony landmarks of the hip and the skin of the thigh. However, the cost involved in the purchase of the unit and the time involved in performing the examination serve as major limitations.

MRA

MRA is one of the most advanced modalities used in obtaining threedimensional views of flap perforator images. MRA has the highest contrast resolution, but the lowest spatial resolution, and involves the highest overall cost. Compared with CTA, MRA has little known deleterious effects and performs high quality vascular imaging, resulting from its unparalleled contrast resolution. At present, advanced factors that aid in the production of high quality MRA images are not yet readily available and further investigation into its accuracy is underway.

Discussion

The aim of this study was to create a contemporary overview of the preoperative mapping methods available for the localisation of perforators of the ALT flap. A serious limitation of the studies discussed in this review is that, the current studies based on the preoperative assessment of perforators of the ALT flap, which differ either in modality or in microvascular application, are mostly large case series and have low levels of evidence. Therefore, it might be difficult to draw concrete conclusions based on the current literatures.

Reviewing the modalities described above in the preoperative assessment of perforators of the ALT flap, a key point should be emphasised: most studies took place in specialised units, but the outcomes might be obtained in less specialised units where advanced assessment methods were unavailable. In other words, the modalities used in locating the perforators, depend on the criteria of the local hospital to a large extent.

CDS exhibits superiority in assessing superficial structures in great detail. However, the largest limitations of CDS include the requirement of skilled personnel to perform the scanning and the low reproducibility of the procedure because of its real-life dynamics. Also, as the volume of reconstruction increases, the requirement to obtain a higher spatial resolution of the surgical-site anatomy becomes much more urgent. There is considerable evidence to suggest that the handheld Doppler and CDS have been superseded. Modern modalities such as CTA and MRA have been shown to be more accurate, significantly shortening dissection times and reducing both donor morbidity as well as operator stress levels. CTA can provide detailed information regarding the intramuscular course of the perforating vessels as well as the adjacent vessels in the scan field and may hence provide precious incidental findings.

Conclusion

In the pioneering studies, 5.4%–16% of patients lacked optimal cutaneous perforators that could be used surgically. Due to anatomical variations of the ALT perforators, preoperative assessment is considered as a very important step. The choice of modality used in detecting the perforators depends on the criteria of the local hospital to a large extent. The ABC assessment system combined with colour Doppler/CTA will facilitate an ideal individual assessment of this perforator flap. The success rate of ALT flap transplantation has reached a plateau: safer and more simplified operations yielding optimal outcomes could be pursued through individualised planning. However, further advancements testing the feasibility of these techniques are warranted in the future.

Abbreviations

ALT, anterolateral thigh; CDS, colour duplex sonography; CT, computerised/computed tomography; CTA, computed tomography angiography; MRA, magnetic resonance angiography.

References

9. Chiu WK, Lin WC, Chen SY, Tzeng WD, Liu SC, Lee TP, et al. Computed tomography angiography imaging for the chimeric anterolateral thigh flap in recon-
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