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# Hand Doppler flowmetry for surgical planning of pedicled flap in extensive full-thickness scalp reconstruction

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ABSTRACT

Reconstruction of scalp defects can be performed with local flaps for medium to large defects (2–25 $cm^2$) and microvascular free flaps for extensive full-thickness scalp reconstruction greater than 25 $cm^2$. Doppler flowmetry with its ability to exactly mark the course of arteries on the overlying skin, is a useful tool for the surgical planning of large local flaps. In our retrospective study conducted on 38 patients (all patients had malignancies or post-traumatic scalp defects), consisting of 39 total surgical procedures, we studied the impact of doppler ultrasonic flowmetry in the surgical planning for pedicled flaps in extensive full-thickness scalp reconstruction (>25 $cm^2$) by evaluating overall flap survival rate. Nine different types of local flaps were employed in the scalp reconstruction: Superficial temporal artery (STA) pedicled rotation flap, STA pedicled transposition flap, STA islanded flap, bipedicled STA flap, bipedicled fronto-occipital flap, Supraorbital/Supratrochlear artery rotation flap, Supraorbital/Supratrochlear artery transposition flap, Occipital artery (OA) pedicled rotation flap, OA pedicled transposition flap. Before each surgical procedure a hand held doppler Huntleigh Diagnostic flowmeter with a 8 MHz probe was used to identify and follow the course of the arteries. Flap survival rate was 100%. No postoperative complications related to the flap were reported, while in two patients a partial skin graft failure occurred.

## 1. Introduction

Scalp defects can result from several circumstances: traumatic lesions, burns, avulsion injuries or pressure sores, which could require scalp reconstruction [1]. Infected osteoplastic flaps may require wide scalp area removal to complete the primary infection treatment and subsequent reconstruction [2]. Primary and secondary malignancies are the most common occurrences needing for scalp reconstruction. The most common tumors are skin cancers, mostly basal cell and squamous cell carcinomas, that can often involves the galea but may go deeper and infiltrate the calvaria. Less frequent malignancies are malignant meningiomas, soft tissue sarcomas, primary adnexial cancers and secondary malignancies [3].

Different techniques were available for extensive scalp defects reconstruction, however, when the bone is exposed or the hairline compromised, the surgical procedure may be quite challenging [4]. Based upon scalp defect type, the choice of flaps for reconstruction could be local flaps for small to medium full-thickness defects (2–25 $cm^2$), microvascular free flaps (Latissimus dorsi, radial forearm, anterolateral thigh, gracilis, lateral arm, parascapular, rectus abdominis, and omental flap) or Dermal regeneration template plus split-thickness skin grafts (STSG), for extensive full-thickness reconstruction (>25 $cm^2$) [5]. Skin grafts alone may be performed only for partial thickness defects where the pericranium has been spared. Dermal substitutes may be considered useful for extensive full thickness scalp reconstruction, although they require two stage procedure, they are more expensive and leave skin depression in the grafted area [5]. Microvascular surgery is an effective and challenging technique; however, it requires quite extensive human and technical resources. Comorbidity due to microcirculation related pathologies very often contraindicate this reconstructive procedure in

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most of elderly patients. Local pedicled scalp flaps may be considered a useful surgical reconstructive option for many scalp defects as they do not involve the technical complexity and the time related issues of microvascular tissue transfer [6–9]. However the difficulties related to the manual (digital) identification of the vascular axis limit the local flap design extension. The Doppler ultrasound has been widely used as a preoperative examination method for a variety of a axial/perforator flap surgeries [10,11]. To the best of our knowledge this is the first time description of a such devices application for pedicled scalp flap harvesting in extensive full-thickness scalp reconstruction.

The purpose of our study was to determine the effectiveness of doppler ultrasound flowmetry in pedicled flaps planning for extensive scalp reconstruction by evaluating flap survival rate.

## 2. Pertinent anatomy

The scalp is well vascularized by high flow vessels; the superficial temporal and occipital arteries are considered the main blood supply to the scalp. The superficial temporal artery lies within the superficial temporal fascia and divides into the frontal and parietal branch. The posterior scalp is primarily supplied by the occipital arteries. The occipital artery pierces the deep cervical fascia to enter the scalp and divides into three branches: the vertical branch, the horizontal branch and the descending cutaneous branch. The supraorbital vessels reach the forehead through the supraorbital foramen in the middle part of the superior orbital border. The supratrochlear vessels reach the skin of the forehead through the medial part of the superior orbital border. The supratrochlear and supraorbital veins drain the anterior region of the scalp. Nine different types of superficial temporal vein (STV) drainage can be found in the literature with differences described in the arrangement of the affluent of the STV [12,13]. The occipital vein terminates in the suboccipital venous plexus.

The galea aponeurotica is part of a broad fibromuscular layer that envelops the forehead and scalp and serves as the central tendinous confluence of the occipitalis muscle posteriorly and the frontalis muscle anteriorly. The galea aponeurotica is in continuity with the temporoparietal fascia (superficial temporal fascia). At the level of the ear the superficial temporal vessels are located deep within the subdermal fat on the surface of the temporo-parietal fascia. At 10 cm approximately above the crus helix the vessels take a more superficial course penetrating the subdermal fat. Beneath the galea lies the loose areolar layer, also known as the subaponeurotic layer, subgaleal fascia, or innominate fascia, which is a relatively avascular plane. This layer enables the layers above it (skin, subcutaneous connective tissue, and galea) to slide as a unit over the pericranium. This layer is a safe plane for flap dissection.

## 3. Materials and methods

In this retrospective study 62 patients with extensive scalp defects included in our database from January 2010 to January 2018 were analyzed. Inclusion criteria were patients with post-traumatic or post-oncologic scalp defects who had undergone surgical reconstruction with local pedicled flaps planned with the use of a Doppler flowmetry, and who had a follow-up period of at least one year after surgery. Exclusion criteria consisted of patients with intracranial intradural extension of skin cancers, congenital scalp defects, burn defects, patients with general contraindications to surgery or patients operated with a free flap.

38 patients met the above criteria and were enrolled in the study. Nine different local flaps were performed for reconstruction: Superficial temporal artery (STA) pedicled rotation flap, STA pedicled transposition flap, STA islanded flap, bipedicled STA based flap, bipedicled fronto-occipital flap, Supraorbital/Supratrochlear artery rotation flap or Supraorbital/Supratrochlear artery transposition flap, Occipital artery (OA) pedicled rotation flap, OA pedicled transposition flap.

The flap choice is made on the defect position (anterior, parietal or occipital) must be reconstructed. If the defect is sagittal (middle of the scalp), we prefer to use the bipediced STA-based flap or Bipedicled occipital (OA) and supratrochlear/supraorbital artery-based flap.

Patients' medical histories were collected and risk factors such as diabetes mellitus, smoking, previous surgery, and prior or post-surgical scalp irradiation were evaluated and recorded. Each patient followed a preoperative diagnostic protocol consisting of the following: clinical examination, pre-operative ultrasound imaging [13,14], Computer tomography (CT) scan to establish tumor dimension and its potential extension to the calvaria or to intracranial structures as well as to establish the size of the expected scalp defect) and histology (for tumors only). In malignant tumors when doubts were posed, we performed an intraoperative frozen section biopsies before reconstruction to be sure that the excision margins were negative.

During the follow-up period, each patient underwent clinical examination and imaging exams (US, CT scan) as required by the guidelines for each tumor histology. For each reconstructive procedure patient's age, etiology, defect size and site, type of reconstruction and its vascular supply, flap size, use of skin grafts to close the flap donor site, postoperative flap complications, postoperative donor site complications and final outcome were all evaluated. To estimate the defect size and the flap size, we assumed that the defect to be reconstructed was circular and we calculated the area on the maximum diameter. Postoperative flap complications were divided into major and minor ones. Major flap complications were defined as important tissue loss (total or

**Fig. 1.** Preoperative dopplering.

partial flap necrosis) or wound-healing problems that required an additional operative intervention to obtain wound closure. Minor flap complications included partial flap necrosis, wound dehiscence, hematoma, which were managed with conservative wound care, including bedside debridement and antibiotics. Primary tumor recurrence was recorded during the follow-up period.

## 4. Preoperative dopplering

Patients' scalp was properly shaved to detect the course of the arteries with their proximal and distal branches and to achieve an accurate mapping of possible pedicles[9]. A hand held doppler Huntleigh Diagnostic Doppler (Model No. SD2, manufactured by Huntleigh Healthcare, Cardiff UK, 2010) flowmeter with a 8 MHz probe was used to obtain unidirectional Doppler signals. The frontal branch, the parietal branch, and posterior ramification of STA were all identified and followed in their course. The course of the occipital artery was mapped as well, including the supraorbital and supratrochlear arterial courses when appropriate or needed (Fig. 1).

## 5. Surgical technique

All surgeries were performed under general anesthesia. Infiltration of 2% mepivacaine chlorohydrate with adrenaline 1:100,000 was administered before incision. Skin incision was beveled at an angle parallel to the hair shafts to avoid a linear hairless scar. Patients underwent a one stage surgical procedure, consisting of resection surgery and reconstruction of the residual full-thickness scalp defect.

The flap was outlined adjacent to the defect respecting the dopplered arterial course. The pedicle was visualized and prepared. No attempt was made to visualize or include venous branches in the pedicle. The venous drainage of the flap was sustained by the perivascular fascial network for the islanded STA flaps. A fascial extension around the artery of 2–3 cm was maintained. This could assure an adequate venous drainage through the venous network of the temporal region. The flap, including skin and galea, was elevated over the pericranium and moved to fill the defect without tension. The pericranium was left intact to potentially receive a Split-thickness skin grafts (STSG). If needed, the donor site was covered with a STSG [15]. One or more Penrose drains were placed under the flap to avoid blood collection and pedicle compression.

### 5.1. *Superficial temporal artery (STA) pedicled rotation or transposition based flap*

After the ablation surgery was completed, the recipient defect was converted in a triangular area. The flap was outlined adjacent to the defect in rotation flaps, but also distant to the defect for transposition flaps. The shape of the rotation flap was an arc of circle, the radius being equal to the diameter of the wound.

The main arteries were checked by Doppler ultrasonography and marked on the skin.

The dissection was then carried through at the level of the avascular subgaleal plane. The width of the skin pedicle was 4–6 cm large at the base of the transposition flap, to preserve the superficial temporal artery and veins. Care was given to avoid damage to the STV branches which usually course posterior to the artery and in a more superficial plane above the TPF.

The flap was then elevated and positioned to fill the defect (Fig. 2a and b).

For STA islanded flap the arteries were checked by Doppler ultrasound and marked on the skin.

The skin paddle was centered on the pedicle [16]. The flap size was large enough to allow its edges to comfortably reach and inset into the defect. The length of the STA before entering the flap was calculated to reach the defect with ease. The skin was incised and lifted all around the flap. A fascial extension of 2 cm on each side around the artery was maintained. This assured an adequate venous drainage through the venous network around the STA. Care was given to free as much as possible the subcutaneous pedicle at the temporal level. The flap was then transferred to the defect site (Fig. 3a and b).

### 5.2. *Occipital artery (OA) pedicled rotation or transposition based flap*

The flap was designed adjacent to the defect respecting the occipital artery; this was checked by Doppler ultrasonography and marked on the skin accordingly.

The margins of the flap were incised down to the pericranium. The flap was raised in the avascular subgaleal plane. The occipital vessels were respected at their occipital muscle level emergency. The flap was moved to fill the defect. When needed, the donor site was covered with a split-thickness skin graft harvested either from the upper anterior or lateral thigh [17,18] (Fig. 4a and b).

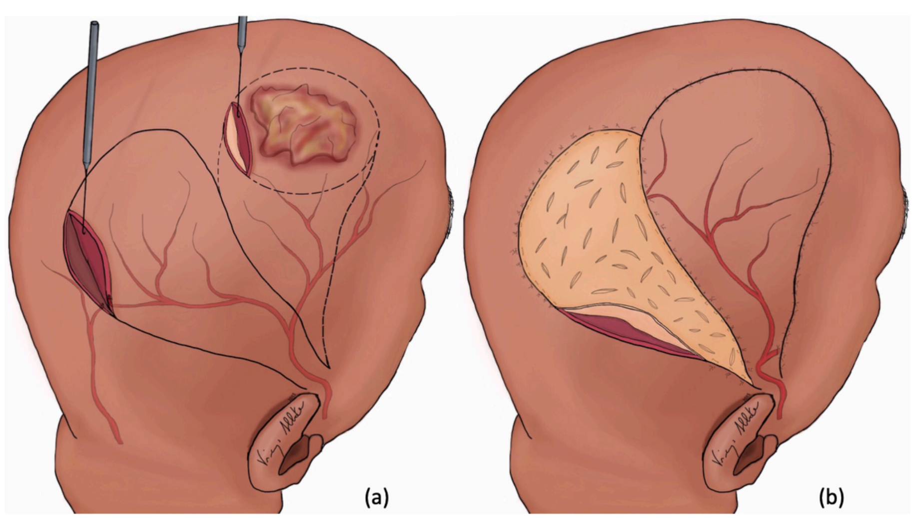


**Fig. 2.** STA based rotation flap scheme: a) Tumor resection and flap harvesting; b) Flap rotation and insetting to fill the full-thickness scalp defect. Split-thickness skin grafts (STSG) on place to cover the donor site.

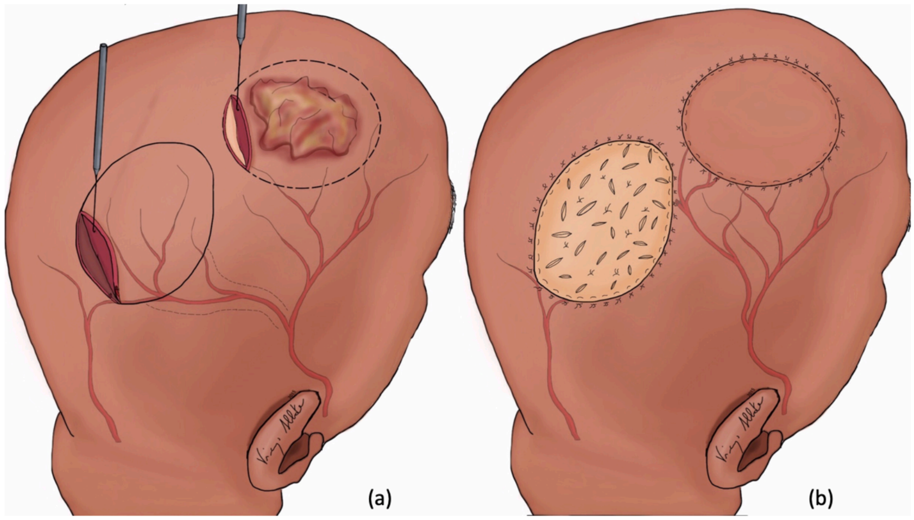


**Fig. 3.** STA based transposition flap scheme: a)Tumor resection and flap harvesting; b) Flap tunneling and insetting to fill the full-thickness scalp defect. Split-thickness skin grafts (STSG) on place to cover the donor site.

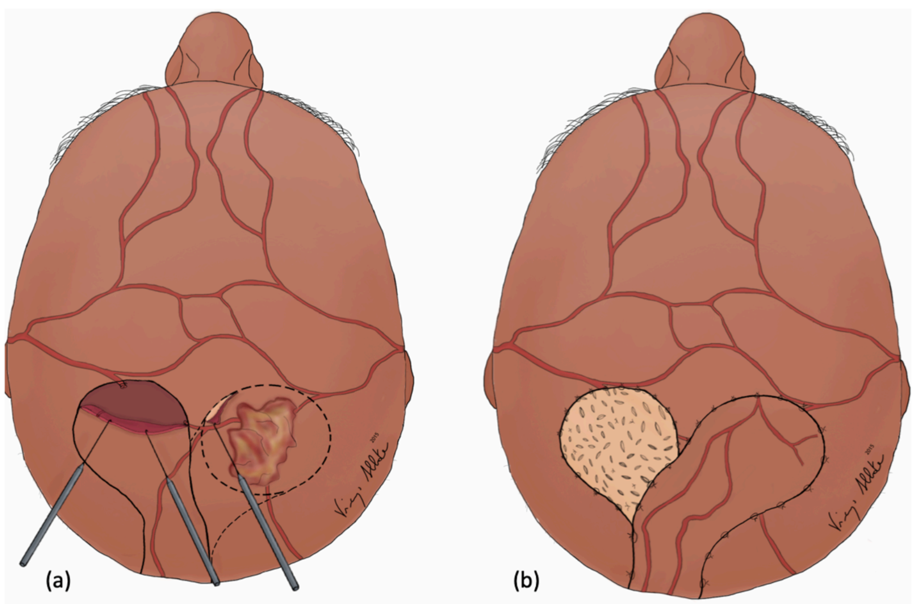


**Fig. 4.** Occipital artery (OA) based rotation flap scheme: a) Tumor resection and flap harvesting; b) Flap rotation and insetting to fill the full-thickness scalp defect. Split-thickness skin grafts (STSG) on place to cover the donor site.

### *5.3. Bipedicled STA based flap (bucket-handle flap)*

After the ablation surgery was completed, a bipedicled STA flap was designed to provide the cutaneous coverage. The incisions were made through two curved lines that started above the ear and cross the entire cranium vault to the other side. The bases of the flap were located in both temporal areas. The flap pedicle was based on both STA and measured 5 cm in width. The dissection was carried out in the avascular subgaleal plane. The flap was then transposed anteriorly, like a bucket-handle movement, to fill the defect. The procedure was always completed with a split-thickness skin graft to cover the large area of denuded pericranium [19,20] (Fig. 5a and b).

### *5.4. Bipedicled occipital (OA) and supratrochlear/supraorbital artery based flap*

The fronto-occipital scalp flap received its blood supply from the frontal vessels (supraorbital and supratrochlear arteries) and occipital vessels (occipital artery). The flap had two bases located in the frontal area and in the occipital area of the same side of the head and therefore extended over all the cranial vault. After the skin and galea incision by blunt dissection, the galea was then separated from the subgaleal layer in the avascular plane. The flap, which was wider in the central part and thinner at the pedicle bases, was then elevated and transposed to the recipient site similar to the movement of a bucket-handle from the vertex to the lateral side of the skull, forming redundant frontal and occipital dog ears. A split-thickness skin graft harvested either from the upper anterior or lateral thigh provided the cutaneous coverage of the pericranium at the flap donor site [21](Fig. 6a and b).

### *5.5. Supraorbital/Supratrochlear artery rotation or transposition based flap*

The Supraorbital and Supratrochlear arteries were detected by

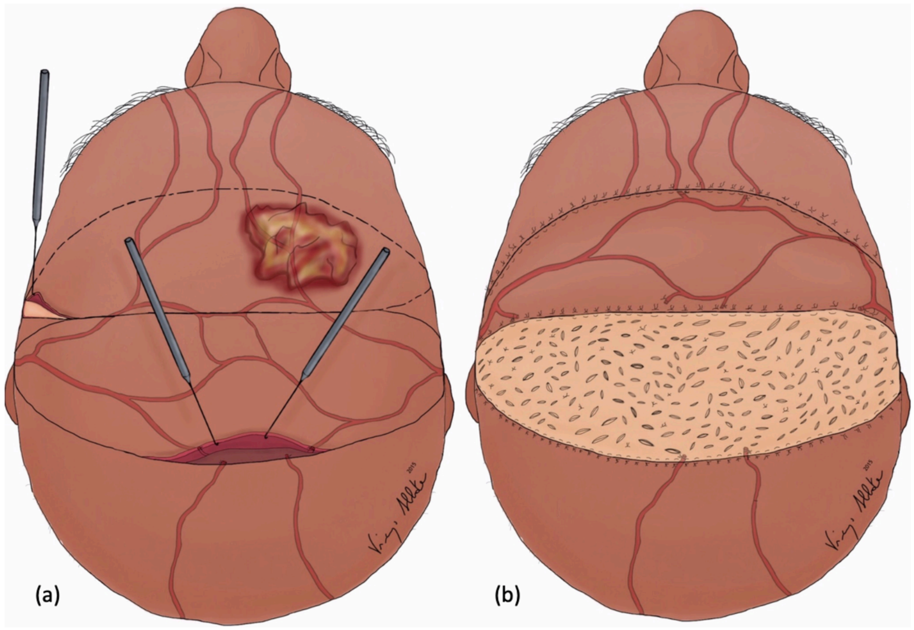


**Fig. 5.** Bipedicled STA based flap scheme (bucket-handle flap: a) Tumor resection and flap harvesting; b) Flap rotation and insetting to fill the full-thickness scalp defect. Split-thickness skin grafts (STSG) on place to cover the donor site.

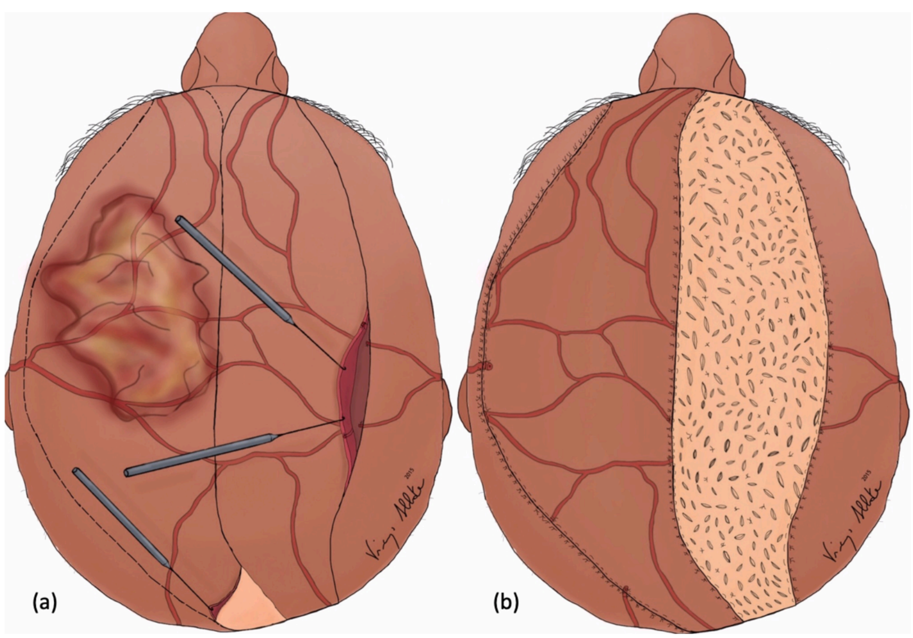


**Fig. 6.** Bipedicled flap scheme, based on the occipital artery (OA) and the supratrochlear/supraorbital artery: a) Tumor resection and flap harvesting; b) Flap rotation and insetting to fill the full-thickness scalp defect. Split-thickness skin grafts (STSG) on place to cover the donor site.

Doppler ultrasonography and marked on the skin. A rotation or transposition flap was designed to provide the cutaneous coverage, based on the doppplered vessels. The flap was marked in the frontal region as a standard skin pedicled flap based anteriorly on the supraorbital and supratrochlear arteries. The margins of the flap were incised; the flap was raised in the avascular subgaleal plane. It was then transferred to the defect more often as transposition flap. If needed, the donor site was covered with a split-thickness skin graft harvested either from the upper anterior or lateral thigh [22] (Fig. 7a and b).

## 6. Results

Our series consisted of 38 patients, 21 male and 17 female. Mean age was 66,8 years (ranging from 54 to 89 years). 39 total surgical procedures were performed as in one patient a local recurrence of SCC took place requiring a second operation. Defects were the result of skin cancer resections (infiltrating basal cell carcinoma = 4 patients; recurrent basal cell carcinoma = 2 patients; squamous cell carcinoma (SCC) = 10 patients; recurrent squamous cell carcinoma = 8 patients; cutaneous metastasis from SCC = 2 patients; malignant melanoma = 3 patients; fibrosarcoma = 1 patient; Merkel cell carcinoma = 1 patient; cutaneous

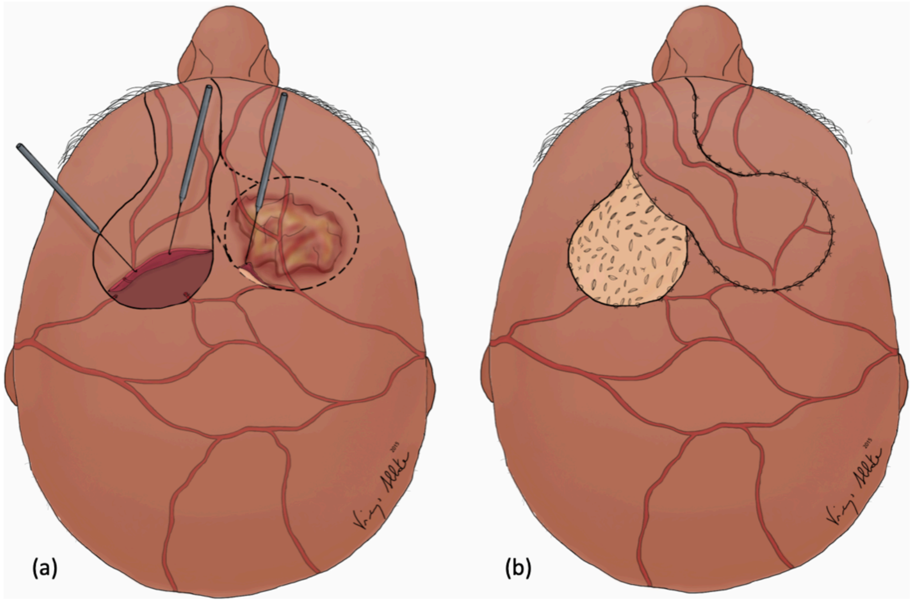


**Fig. 7.** Supraorbital/Supratrochlear artery transposition flap scheme: a)Tumor resection and flap harvesting; b) Flap rotation and insetting to fill the full-thickness scalp defect. Split-thickness skin grafts (STSG) on place to cover the donor site.


**Fig. 8.** Extensive full-thickness scalp reconstruction (496 $cm^2$) left fronto-temporal region malignancy recurrence. (a–b) Preoperative dopplering for right STA based transposition flap planning; (c) Intraoperative view after flap insetting; (d) Follow up at 3 months.

linfoma = 1 patient; multiple meningiomas = 1 patient), or craniectomy sequelae (= 5 patients). Mean defect size was 97 cm2, mean flap dimension was 189,5 $cm^2$. The largest scalp defect was of 350 $cm^2$ and was reconstructed with a **transposition** STA flap of 496 $cm^2$ (Fig. 8a,b,c, d). Scalp defects were located in the following regions: frontal region (5 patients), fronto-orbital region (3 patients), fronto-temporal or fronto-parietal region (3 patients), temporal region (7 patients); temporo-parietal region (6 patients), parietal region (3 patients), vertex region (6 patients), occipital region (3 patients) and auricular or pre-auricolar region (2 patients). The above stated defects were reconstructed with different local flaps: STA-based transposition or rotation flaps (16 patients), STA-based island flaps (6 patients), STA-based bipedicled flaps ("bucket-handle" flap) (3 patients), Fronto-Occipital bipedicled flaps (2 patients), Supraorbital/Supratrochlear artery based rotation or transposition flaps (9 patients), Occipital artery (OA) based rotation or transposition flaps (3 patients) (Table 1). One reported patient had a recurrence of the primary tumor and underwent a second stage surgery. The first stage surgery included a rotation STA based flap to reconstruct a 59,5 $cm^2$ defect in the left temporo-parietal region; the second stage surgery included a bipedicled right Fronto-Occipital flap to reconstruct the recurrent SCC post resection defect of 171 $cm^2$ in the left parietal region. Flap survival rate was 100%. No postoperative major or minor complications related to the flap were reported, while in two patients a partial skin graft failure occurred (Table 2). We found no problems with regard to the healing of surgical wounds. During the follow-up period local recurrence of the primary tumor was reported in 5 patients (see Fig. 9).

## 7. Discussion

Several algorithms for the choice of scalp reconstruction have been proposed in literature which are based either on location, size, and etiology of the defect, quality of tissue and/or wound environment, exposed structures, and hairline distortion [4,23–25].

Local flaps provide "like with like" and therefore are the preferable method for closure of scalp defects in non-irradiated patients and for defects that cannot be primarily closed [4].

In addition to the consideration of "like with like", from the cosmetic point of view other parameters for the reconstruction of the scalp, that is the maintenance of an adequate hairline and the limitation of the alopecia and the appearance of the scar with aesthetically positioned incisions and attention to hair growth patterns.

These flaps are considered relatively safe with a low major complication rates (3,4%) [25] and are considered an optimal surgical option in head and neck, especially in elderly patients who cannot undergo prolonged surgical procedures [26].

If tissue quality is poor due to prior irradiation, presence of infections, prior surgery and local options are unavailable, then free tissue transfer is the best treatment option [27,28].

Radical surgical resection remains the gold standard for this type of disease and most often leads to good results.

Additional treatments such as irradiation, chemotherapy and

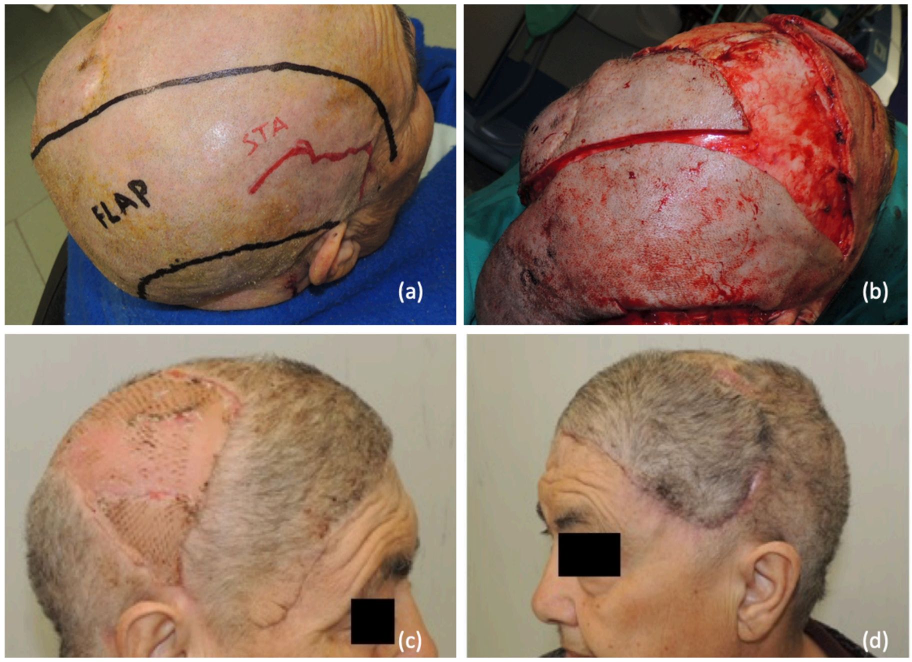


**Fig. 9.** Bipedicled STA rotation flap: (a) Preoperative drawing; (b) Intraoperative image of the flap; (c–d) Follow up at 3 months.

**Table 1**
Distribution of different flap types.

| Flap Type | No | Defect average (cm2) | Flap average (cm2) |
|---|---|---|---|
| STA-based pedicled rotation or transposition flap | 16 | 102,9 | 183,19 |
| STA-based islanded flap | 6 | 95,5 | 193,3 |
| STA-based bipedicled flap (bucket-handle flap) | 3 | 104,3 | 200,7 |
| Fronto-occipital bipedicled flap | 2 | 76 | 146,5 |
| Supraorbital artery based rotation or transposition flap | 9 | 90,7 | 184,2 |
| Occipital artery based rotation or transposition flap | 3 | 93,6 | 192,5 |

**Table 2**
Patient Information and Postoperative results.

| Patient Information/Outcome | **No of Patients (%)** |
|---|---|
| Patient age Mean/range | 66,8/54-89 |
| Histological typing | 24 (61,5%) |
| • Squamous cell carcinoma | 13(33,3%) |
| • Basal Cell Carcinoma | 2 (5,2%) |
| • Merkel Carcinoma | |
| Microcirculation disorders | 31(81,6%) |
| Uneventful healing | 37 (94,87%) |
| Partial skin graft failure | 2 (5,2%) |
| Total | 39 (100%) |

immunotherapy should be considered as adjuvant therapies or second choice options if surgery is impossible or not desired.

Ibleher et al. [23] described a specific algorithm for oncologic scalp reconstruction and considered a scalp defect from 6 to 8 cm or 4–5 cm at hairline border after oncologic surgery the threshold for using a local scalp flap. Desai et al. [4] proposed an algorithm that included scalp defect size, defect location, radiation history and hairline distortion. They recommended the use of local flaps for small defects (less than $9\ cm^2$) in the fronto-temporo-parietal and occipital area with hairline distortion, and for medium defects (between 9 and $30\ cm^2$) in the fronto-temporo-parietal and occipital area with no radiation history and no hairline distortion [4]. Beasley et al. [27] proposed a staging system for forehead and scalp defects based only on the location and size of the defect, considering local flaps feasible for forehead defects of less than $50\ cm^2$ and scalp defects less than $200\ cm^{2.}$ Newman et al. considered defect size and the presence of good or poor local tissues in choosing a surgical technique allowing for the use of local flaps even for large defects (more than $50\ cm^2$) but with the preliminary condition of good local tissue [25]. Lesavoy et al. [8] presented a series of 10 patients with full-thickness scalp defects that were reconstructed with local pedicled flaps. The average defect area was of $241\ cm^2$ even reaching defects of $450\ cm^2$.

In our experience it is possible to use local scalp flaps and split-thickness skin grafts (STSG) to reconstruct major full-thickness scalp defects up to $350\ cm^2$. This can be performed more precisely with the use of a doppler in the preoperative planning which allows us to harvest scalp flaps up to $496\ cm^2$ as reported in our study. It must be noted that the use of preoperative Doppler may not be necessary, but we discovered that in this way it was easier to preserve the pedicle by drawing the flap following the pedicle. Hand Doppler flowmetry provides essential preoperative information on vascular anatomy, allow the surgeon to identify the exact position of the flap pedicle allowing for quicker and safer flap harvest [28,29]. One of the advantages of the Doppler system is that it is compact and pocket-size, it can be easily carried and it is really cheap compared to other surgical instruments.

Obviously this type of flaps are not without limits. To the best of our knowledge the main limitation is represented by the hairline distorsion. This complication can lead to psychological problems and therefore to a lowering of the quality of life. We found no such complication in our cohort.

The low rate of major and minor post operative complications obtained and the high flap survival rate (100%) enable us to confirm the benefit of hand doppler in scalp flap planning. Before any type of reconstructive technique, in malignant tumors when doubts arose, we performed an intraoperative frozen section biopsies before reconstruction to be sure that the excision margins were free from pathology. Our study is not without its limitations. Most important is the retrospective nature of the study and the limitations associated with such data, the small number of cases and the non-homogeneous sample for some flaps.

## 8. Conclusions

Scalp reconstruction is a complex field with a variety of surgical options and approaches. Doppler flowmeter is considered a helpful tool in scalp reconstruction flaps. Its application enable the surgeon to standardize the technique and harvest large local flaps ensuring low postoperative complication rates. The encouraging results obtained in our series leave to assume that hand Doppler flowmeter applied for local scalp flaps planning may be a useful method for extensive reconstruction over 350 $cm^2$, well beyond those reported in recent reconstruction algorithms. Larger series will be needed to confirm the results and compare them with previous reports.

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## Declaration of competing interest

The authors do not declare conflict of interest and did not receive any financial support for the study presented in the manuscript.

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