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ORIGINAL PAPER

The effect of radial artery reconstruction on the radial forearm donor site: a prospective study

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Abstract The purpose of this study was to evaluate the effect of radial artery reconstruction after radial forearm flap elevation and to study whether a vein graft can stay patent in this position. Ten consecutive oral cancer patients were included in the study. Pre-operative Allen's test was performed, and the flow velocity of both radial and ulnar arteries was recorded using colour Doppler ultrasonography. After flap elevation, the radial artery was reconstructed using the cephalic vein of the donor forearm as a free vein graft. The reconstructed artery was completely covered with surrounding skin, while the actual donor defect was covered with a split thickness skin graft. Colour Doppler ultrasonography was performed at 1–2 weeks and at 6–12 months post-operatively to record long-term patency. Radial artery reconstruction did not prolong the operations. All donor sites healed uneventfully. All of the reconstructed arteries were patent at the post-operative controls. In one patient, graft flow was missing on the first post-operative day but normal in the follow-up. A vein graft can remain patent with a very high success rate after radial artery reconstruction. A negative Allen's test is not an absolute contraindication of a radial forearm flap as radial artery reconstruction can be performed.

Keywords Radial forearm flap · Radial artery · Ulnar artery · Reconstruction · Vein graft

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Introduction

Since its original description in 1981 [1], the use of radial forearm free flap has gained acceptance worldwide. It is one of the most versatile and reliable flaps, especially for reconstruction of head and neck defects. The radial artery is sacrificed during the flap elevation. Because of this, harvesting of the radial artery has been strongly criticised, despite the introduction of several methods apt to minimise donor site morbidity [2–4]. The worse complication with the use of this flap is acute ischaemia of the forearm and hand [5], a complication infrequently seen after radial artery harvesting for coronary artery bypass surgery [6].

Preservation of the donor site is important in the consideration of the donor harvest site. While the literature agrees on the advantages of this flap, which include a thin fatty layer, good pliability, constant anatomy with long vascular pedicle, variability of flap size and versatility of application [5, 7–9], there is less agreement on the functional and aesthetic compromise at the donor site [7, 8, 10, 11].

Furthermore, several studies have reported recently upper extremity haemodynamic changes after radial artery harvest for coronary artery bypass grafting. They did not note hand ischaemia but they identified a reduction in digital perfusion and an increase in ulnar artery flow velocity and diameter with no clinical sequelae or compromise in hand function [12–17].

The aim of this prospective study was to evaluate the effect of radial artery reconstruction after radial forearm flap elevation and to assess the vein graft patency.

Patients and methods

Ten consecutive patients, five men and five women, who were scheduled for a free forearm flap transfer, have been included in this prospective study. Informed consent was given by the patients, and the study was approved by the Ethical Committee of the Töölö Hospital, Helsinki, Finland, where the patients have been operated on.

In all cases, the radial forearm flap was used for repairing head and neck defects after tumour resection, using the facial, the superficial temporal and the superior thyroid artery as recipient artery vessels in end-to-end anastomoses.

The Allen's test was performed pre-operatively in all patients.

Technique

All operations were performed under general anaesthesia, this was maintained with nitrous oxide in oxygen and isoflurane. All patients were given 20 ml/kg (mean, 1,100± 190 ml) of 6% hydroxyethylstarch (PlasmofusinR, Leira, Turku, Finland) and Ringer acetate solution (5,068± 1,720 ml; Ringer steril, Medipolar, Oulu, Finland) in order to maintain stable oxyhemodynamics and to achieve mild hypervolemic hemodilution. Low molecular weight heparin (Dalteparin sodium 2,500 or 5,000 IU subcutaneously) was administered to the patients. The patient's body temperature was kept stable using a warming mattress, by maintaining the ambient temperature at 24°C and by warming the infusion fluids.

During the operation, a two-team approach was used: One team performed the cancer resection and reconstruction, while the other team raised the flap and reconstructed the radial artery. All the radial forearm flaps were harvested and transferred with the same technique by several surgeons. The distal border of the flap was 3–5 cm proximal to the palmar wrist crease, and the radial artery was used for the arterial pedicle of the flap. The cutaneous vein and one of the radial venae comitantes were used as venous pedicles. The interosseous artery system was identified and spared in all cases. The cephalic vein was used as a free graft to replace the radial artery, and the anastomoses were performed by residents using 8–0 intermittent sutures. The reconstructed artery was completely covered with subcutaneous tissue and skin, while the actual donor defect was covered with a split thickness skin graft.

Blood flow measurement

Allen's test was performed pre-operatively on the donor hand. The examiner applied simultaneous digital compression of the radial and ulnar arteries, while the hand was alternately opened and closed to exsanguinate it. The hand was then opened to a relaxed, neutral position before release of the ulnar arterial compression. The hand colour should be restored within 20 seconds, delay beyond this being considered to be pathological [15].

Duplex ultrasonography and colour Doppler ultrasonography (Toshiba SSA-270A, Toshiba Corporation, Tokyo, Japan) were done by a radiologist using a 7.5-MHz linear array transducer. Colour Doppler ultrasonography was used to assess the ulnar artery and its course and pulsed Doppler was used to measure angle-corrected arterial peak flow velocity. The peak flow velocity of the ulnar artery was measured at three points: at the wrist, midforearm and the elbow. Both brachial arteries were also measured as controls. Each artery flow velocity (centimetre per second) and vessel diameter (millimetre) were taken and later averaged.

The patency of the reconstructed arteries was followed using a pencil Doppler on the first, third and fifth post-operative day. Colour Doppler ultrasonography was performed pre-operatively, at 1–2 weeks post-operatively before the patient was released and at 6–12 months post-operatively (mean 9 months) to record long-term patency.

Statistical analysis

Statistical analysis was performed using SPSS statistical software (SPSS 16.0.1, Chicago, IL 60606, USA). Continuous variables are reported as the mean ± standard deviation. The pulsatility index was calculated by dividing the difference of the maximum velocity and minimum blood flow velocity by the mean blood flow velocity.

Non-parametric tests for small samples were used for statistical analysis. Wilcoxon's test signed rank (matched pairs) test is a paired test and was used to compare the operated and non-operated hands. A $p<0.05$ was considered as statistically significant.

Results

Systolic arterial blood pressure, heart rate and oxygen saturation were stable during all the operations. Pre-operative Allen's test was judged to be dominant on the radial artery side in two patients (20%), in the ulnar artery in five patients (50%), whilst no prevalence of re-flow was observed in three patients (30%). All flaps were successfully transferred, and no patient developed ischemic complications of the hand. One patient died before reaching 6 month follow-up and was excluded from the study.

All the reconstructed arteries were patent at 2 weeks and 6–12 months post-operatively. In one patient, graft flow was missing on the first post-operative day using a Doppler pencil but then, flow was detected during the follow-up. In this patient, the distal graft presented back-flow at 6-month control.

Colour Doppler ultrasonography measurements performed before the operation showed a mean blood flow velocity of the donor site ulnar artery of 0.83±0.2 cm/s, while it was 0.86±0.25 cm/s in the non-operated control hand (p=0.67). The mean blood flow velocity after 6–12 months post-operatively of the donor site ulnar artery was 0.54±0.18 and 0.55±0.19 cm/s in the non-operated control hand (p=0.78). Pre-operatively, the mean blood flow velocity of the donor site radial artery was 0.88±0.16 cm/s, while it was 0.89±0.19 cm/s in the non-operated control hand (p=0.64). Similarly, the mean blood flow velocity of the vein graft at 6–12 months post-operatively was proximally 0.48±0.23 cm/s, while in the non-operated control hand, the mean radial artery flow velocity was 0.53±0.3 cm/s (p=0.89). The mean blood flow velocity of the vein graft at 6–12 months post-operatively was distally 0.40±0.3 cm/s, while in the non-operated control hand, the mean radial artery flow velocity was 0.53±0.3 cm/s (p=0.33). In addition, Colour Doppler ultrasonography performed pre-operatively showed that mean flow velocity was similar in both arteries (p=0.95, Wilcoxon's signed ranks test, Table 1). After the operation, the maximal flow velocity in the graft was less than in the ulnar artery or the control site.

Pre-operative mean pulsatility index of the ulnar artery was in the donor site 4.8±2.0 and 7.1±6.9 in the non-operated control hand (p=0.37). The mean pulsatility index after 6–12 months post-operatively of the donor site ulnar artery was 11.4±9.3 and 9.1±5.4 in the non-operated control hand (p=0.25). Similarly, the mean pulsatility index pre-operatively of the radial artery was 5.2±2.3 in the donor site and 6.9±4.9 in the control site. The mean pulsatility index after 6–12 months post-operatively of the vein graft proximally was 10.7±6.5 and in the non-operated control hand radial artery was 9.7±9.5 (p=0.33). The mean pulsatility index after 6–12 months post-operatively of the vein graft distally was 8.8±6.6 and in the non-operated control hand radial artery 9.7±9.5 (p=0.67). There were also no differences in pulsatility indexes control sites or arteries (Table 2).

The vessel diameter measurements after 6–12 months post-operatively showed a significant increase of the mean proximal vein graft diameter compared with the non-operated control hand (3.3±1.27 versus 2.0±0.57 mm, p=0.012, Table 3).

Discussion

Although the radial forearm flap is nowadays widely used, there has been continuing controversy over whether or not the arterial defect that results from the harvesting of the flap contributes significantly to post-operative hand ischemia. The morbidity of the donor site as it relates to non-vascular problems has been widely described [2, 3, 6–17].

Initially, the radial artery reconstruction was recommended as a routine procedure. This practice was since abandoned as it showed that if a pre-operative Allen's test is normal, the hand survives without the radial artery [11].

Also, the long-term patency of a vein graft in radial artery reconstruction has been questioned, and this belief has been based on historical series, but has been attributed to the presence of communicating palmar arches, which theoretically can result in low flow across the anastomosis [18].

In our institution, although the anterolateral thigh flap has become the warhorse in head and neck surgery, we still need to use the radial forearm flap routinely in the intraoral cancer reconstruction, and sometimes, we find an unreliable Allen's test in these predominantly old patients. As the cephalic vein is readily available in radial artery reconstruction after flap elevation, the present investigation was planned in order to analyse and quantify the effect of radial artery reconstruction and to assess the vein graft patency.

The blood supply to the forearm and hand is derived from the brachial artery, which divides into the radial and

Table 1 Mean maximal flow velocity (centimetre per second, mean ± SD) measured pre-operatively and at 6–12 months post-operatively at the radial and ulnar artery and at the vein graft

Vessel	Donor site (cm/s)	Control site (cm/s)	p^a
Ulnar artery pre-operative	0.83±0.2	0.86±0.25	0.67
Radial artery pre-operative	0.88±0.16	0.89±0.19	0.64
Ulnar artery post-operative	0.54±0.18	0.55±0.19	0.78
Vein graft proximally/radial artery	0.48±0.23	0.53±0.3	0.89
Vein graft distally/radial artery	0.40±0.3	0.53±0.3	0.33

[a] Wilcoxon's signed ranks test

Table 2 Mean pulsatility index (mean ± SD) measured pre-operatively and at 6–12 months post-operatively at the radial and ulnar artery and at the vein graft

Vessel	Donor site	Control site	p^a
Ulnar artery pre-operative	4.8±2.0	7.1±6.9	0.37
Radial artery pre-operative	5.2±2.3	6.9±4.9	0.33
Ulnar artery post-operative	11.4±9.3	9.1±5.4	0.25
Vein graft proximally/Radial artery	10.7±6.5	9.7±9.5	0.33
Vein graft distally/Radial artery	8.8±6.6	9.7±9.5	0.67

[a] Wilcoxon's signed ranks test

ulnar arteries. In a study of cadaveric upper limbs, McCormack et al. [19] confirmed the presence of all three arteries in 750 cases. The radial artery terminates in the deep palmar arch and the ulnar artery in the superficial palmar arch. Harvest of the forearm free flap requires interruption of the radial artery, and total reliance on the ulnar system and palmar arches to maintain vascular integrity of the hand. The common interosseous artery originates from radial artery, and it bifurcates into its anterior and posterior branches.

In a previous article, Suominen et al. [15] retrospectively evaluated the donor site morbidity of the radial forearm flap using a Doppler–ultrasonographic system, and they noticed a significantly increased peak flow velocity in the ulnar arteries on the donor site at the wrist, when comparing the donor hand to the contro-lateral non-operated hand.

In 1999, Ciria-Llorens et al. [20] showed a trend for increased overall forearm flow in the ulnar, posterior interosseous and anterior interosseous arteries, with pre- and post-operative measurements, after raising the radial forearm. The greatest increase in blood flow, over 33%, was showed by the anterior interosseous artery.

More recently, Yanagisawa et al. [16] studied the haemodynamic changes in the fingers after free radial forearm flap transfer prospectively measuring skin perfusion pressure, which is used clinically in detecting vascular lesions. They observed that harvesting the free radial forearm flap reduces skin perfusion in the finger of the donor hand and may lead to the re-distribution of blood flow to the fingers, with residual ulnar artery still supplying more blood to finger I than finger V.

They concluded that compensatory mechanisms are probably mediated by the autonomic nervous system, which increases blood flow in the remaining forearm arteries after excision of the radial artery, in order not to impair the global arterial inflow to the hand.

Several authors [3, 20–22] recognised the role of the anterior interosseous artery in collateral circulation of the hand, this has been well recognised by others, and it has also been shown that excision of the radial artery leads to compensatory changes in the ulnar, posterior interosseous and anterior interosseous arteries and may give a protective effect and reduce the risk of hand ischaemia [21]. According to our results, with the radial artery reconstruction, these compensatory mechanisms have no significantly statistical difference as shown by a maximal flow velocity, pulsatility indexes in both donor and control side.

Recently, Knobloch et al. [23] confirmed that radial artery harvesting for coronary revascularisation does not compromise palmar microcirculation in a long-term evaluation of superficial and deep palmar microcirculation using a laser Doppler spectrophotometry O2C system.

A cut-off level of <67 years of age was identified by microcirculatory monitoring, and they supposed a significant deterioration of palmar microcirculation more likely occurring beyond this age [24].

In a recent study, Kiehn et al. [25] evaluated the long-term patency of seven radial arteries reconstructed after radial forearm flap harvest with a mean follow-up time of 24 months, and no areas of stenosis were detected nor complications from harvest of the vein graft. They noticed in five ultrasound examinations an average of 1 mm larger in diameter of the vein graft compared with native arteries.

In our prospective study, there were 10 consecutive patients with a mean post-operative follow-up time of

Table 3 Mean vessel diameter (millimetre, mean ± SD) measured pre-operatively and at 6–12 months post-operatively at the radial and ulnar artery and at the vein graft

Vessel	Donor site (mm)	Control site (mm)	p^a
Ulnar artery pre-operative	2.0±0.52	2.1±0.61	0.17
Radial artery pre-operative	1.9±0.37	2.2±0.51	0.24
Ulnar artery post-operative	1.9±0.55	2.2±0.54	0.17
Vein graft proximally/radial artery	3.3±1.27	2.0±0.57	0.012
Vein graft distally/radial artery	2.5±1.22	2.0±0.47	0.25

[a] Wilcoxon's signed ranks test

9 months. All of the reconstructed arteries were patent at the post-operative follow up. In one patient, the vein graft flow was missing on the first post-operative day, probably as a result of too tight closure, but it was normal on further follow-up.

In addition, we noticed at 6–12 month post-operatively that the mean vein graft diameter proximally was 1.3 mm larger than the non-operated control side, and this, according to the results of Kiehn et al. [25], was expected as the cephalic vein is larger than the radial artery. The same reason can explain the slower maximal flow velocity in the graft than in the ulnar artery or the control site.

Radial artery reconstruction does not adversely affect the duration of the surgery when resources exist for two surgical teams to work simultaneously. In our management, a two-team approach is used, and the radial flap raising and the anastomosis are usually performed by residents, this does not prolong the operations.

Tight adherence to basic principles of microsurgery can play a role in a high patency rate success in radial artery reconstruction [25]. Meticulous technique and performance of a tension-free anastomosis between vessels of good quality is probably the most important contributing factor.

Finally, the practice of primary reconstruction may be of value for some patients such as those who are at higher risk of trauma, who undertake heavy labour, and those with a disposition to the development of atherosclerosis. The Allen test can be a good and valid screening test for the circulation of the hand. And, although the Allen test seems not to be reliable and a doubt or positive results seems not to be a contraindication of a radial forearm flap, according to our results, reconstructing the radial artery is worthwhile as the vein graft remains patent at least 12 months post-operatively, assuring a good vascularisation to the hand.

Conclusions

The long-term patency of a vein graft in radial artery reconstruction has been questioned in this prospective study, and our results showed that a vein graft can remain patent in this position.

Performing radial artery reconstruction after radial forearm flap harvesting does not affect the duration of the operation when two surgical teams work together.

A meticulous microsurgical technique and tension-free anastomosis are always recommended.

According to our findings, a positive Allen's test is not an absolute contraindication of a radial forearm flap as radial artery reconstruction can be performed with a very high success rate.

Conflict of interest statement There is nothing to disclose in this manuscript.

No commercial associations or disclosures may pose or create any conflict of interest with information presented in this manuscript.

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