Intraoperative Hemodynamic Evaluation of the Radial and Ulnar Arteries during Free Radial Forearm Flap Procedure

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ABSTRACT

The purpose of this prospective study was to assess the blood flow of the radial and ulnar arteries before and after radial forearm flap raising. Twenty-two patients underwent radial forearm microvascular reconstruction for leg soft tissue defects. Blood flow of the radial, ulnar, and recipient arteries was measured intraoperatively by transit-time and ultrasonic flowmeter. In the in situ radial artery, the mean blood flow was 60.5 ± 47.7 mL/min before, 6.7 ± 4.1 mL/min after raising the flap, and 5.8 ± 2.0 mL/min after end-to-end anastomosis to the recipient artery. In the ulnar artery, the mean blood flow was 60.5 ± 43.3 mL/min before harvesting the radial forearm flap and significantly increased to 85.7 ± 57.9 mL/min after radial artery sacrifice. A significant difference was also found between this value and the value of blood flow in the ulnar and radial arteries pooled together ($p < 0.05$). The vascular resistance in the ulnar artery decreased significantly after the radial artery flap raising (from 2.7 ± 3.1 to 1.9 ± 2.2 peripheral resistance units, $p = 0.010$). The forearm has a conspicuous arterial vascularization not only through the radial and ulnar arteries but also through the interosseous system. The raising of the radial forearm flap increases blood flow and decreases vascular resistance in the ulnar artery.

KEYWORDS: Radial forearm flap, radial artery, ulnar artery, blood flow, hemodynamics

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. However, despite the introduction of several methods to minimize donor site morbidity,[2–4] the radial forearm flap has been strongly criticized as the radial artery is sacrificed during the flap elevation.[5] The worse complication with the use of this flap is acute ischemia of the forearm and hand,[6] a complication infrequently seen after radial artery harvesting for coronary artery bypass surgery.[7] The aim of this prospective study was to assess intraoperative blood flow in the radial forearm flap donor site by measuring the radial and ulnar artery flows during the procedure and analyzing flow changes after the transfer of the flap.

PATIENTS AND METHODS

Twenty-two consecutive patients, 14 men and 8 women with a mean age 56 years (range 37 to 80 years), who

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Received: March 25, 2009. Accepted after revision: August 11, 2009. DOI 10.1055/s-0029-1242135. ISSN 0743-684X.

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 were operated on.

In 20 cases, the radial forearm flap was used for repairing head and neck defects after tumor resection, using the facial, the temporosuperficial, and the superior thyroid vessels as recipient in end-to-end anastomoses. In two cases, the radial forearm microvascular flap was used for lower extremity reconstruction because of a trauma and after resection of a sarcoma. In the latter cases, the artery of the flap was anastomosed end-to-side to the anterior tibial artery. Thirteen patients underwent a simultaneous lateral cervical dissection and 10 patients underwent tracheostomy. The Allen test was preoperatively performed in the first 10 patients.

Technique

All the operations were performed under general anesthesia, which was maintained with nitrous oxide in oxygen and isoflurane. All patients were given 20 mL/kg (mean: 1100 ± 190 mL) of 6% hydroxyethylstarch (PlasmofusinR, Leira, Turku, Finland) and Ringer acetate solution (5068 ± 1720 mL; Ringer steril, Molipolar, Oulu, Finland) to maintain stable oxyhemodynamics and to achieve mild hypervolemic hemodilution. Low-molecular-weight heparin (Dalteparin sodium 2500 or 5000 IU subcutaneously) was administered to the patients. The mean overall (including receiving site) blood loss was 1520 ± 950 mL (range, 200 to 3000 mL). The patients' body temperatures were kept stable by using a warming mattress, maintaining the ambient temperature at 24°C, and warming the infusion fluids.

All the radial forearm flaps were harvested without tourniquet and transferred with the same technique by several surgeons. The distal margin of the flap was 1 cm proximal to the palmar wrist crease. The radial artery, located along the central axis, was used for the arterial pedicle of the flap. A vein of the cutaneous superficial system and one of the radial venae comitantes were used as venous pedicles. Free flap ischemia time was 105 ± 39 minutes. The interosseous artery system was identified and spared in all cases.

Blood Flow Measurement

The Allen test was performed preoperatively 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 color should be restored within 20 seconds; delay beyond this was considered to be pathological. For the purposes of this study, normal results were divided on the basis of the clinical prevalence during the reflow of radial artery, ulnar artery, or no prevalence between them.[8]

Ultrasonic transit-time flowmeter, CardioMed 4000 (Cardiomed AS, Oslo, Norway) was used for intraoperative blood flow measurements (Fig. 1). The probe uses two piezoelectric crystals transmitting a pulsed ultrasonic beam with a frequency of 0.75 to 3.7 MHz, depending on probe size. The diameter of probes used was 2 to 8 mm depending on the vessel size. The blood flow values were recorded after 20 to 30 minutes, waiting for a steady curve of flow. Heart rate and systolic and diastolic arterial pressure were measured simultaneously.

The radial and ulnar arteries were isolated by a 4-cm-long skin incision along the borders of the forearm flap. In the recipient artery, the blood flow value was recorded before the flap was transferred. The last measurement was performed in the flap pedicle after transplantation. All flaps were weighted to adjust blood flow for the weight of the graft.

Statistical Analysis

Statistical analysis has been performed using a SPSS statistical software (SPSS 16.0.1, Chicago, IL). Continuous variables are reported as the mean ± standard deviation. Resistance was calculated by dividing mean systemic arterial pressure by blood flow, and it was

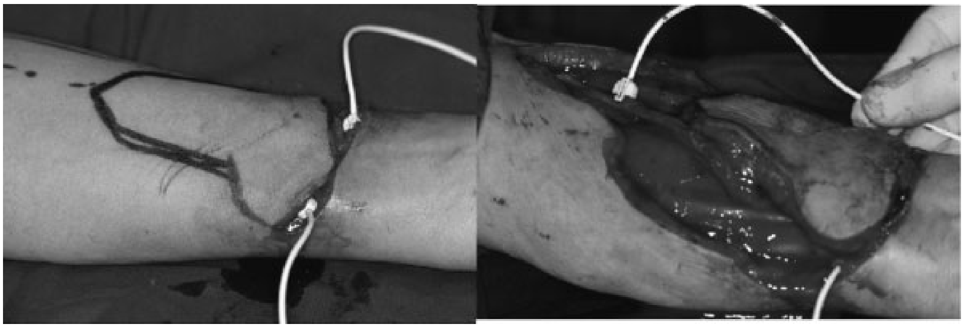

Figure 1 Intraoperative measurement of radial and ulnar artery during radial forearm flap harvesting.

expressed as peripheral resistance units. Wilcoxon test was used to assess the changes in blood flow and resistance in different study intervals. Correlation between continuous variables was estimated by Spearman's test. A $p < 0.005$ was considered as statistically significant.

RESULTS

The Allen test, performed preoperatively in the first 10 patients, showed the radial artery to be dominant in two patients (20%), the ulnar artery in five patients (50%), and no prevalence of reflow was observed in three patients (30%). All flaps were successfully transferred, and no patient developed ischemic complications of the hand.

The mean blood flow of the in situ radial artery as measured intraoperatively by transit-time flowmeter was 60.5 ± 47.7 mL/min. The blood flow in the radial artery after raising the flap was 6.7 ± 4.1 mL/min ($p < 0.0001$ as compared with baseline value) and after anastomosis to the recipient artery it was 5.8 ± 2.0 mL/min (Table 1). The radial artery flow decreased to one-tenth of the initial value when the flap was raised and connected to the arm only by the vascular pedicle. The same value of blood flow was registered when the flap was transplanted to the recipient site. In the recipient artery located in the neck, the blood flow decreased significantly ($p < 0.05$) after anastomosis compared with the initial value in the intact recipient artery.

The mean blood flow of the ulnar artery as measured intraoperatively by transit-time flowmeter was 60.5 ± 43.3 mL/min and significantly increased after harvesting the radial forearm flap to 85.7 ± 57.9 mL/min (Wilcoxon test: $p = 0.002$), but not as much as the sum of the baseline in situ ulnar and radial artery blood flow (121.9 ± 72.0 mL/min; Table 2). The vascular resistance in the ulnar artery decreased after the radial forearm flap raising (from 2.7 ± 3.1 to 1.9 ± 2.2 peripheral resistance units, $p = 0.010$).

Table 3 shows the Allen test results compared with the intraoperative measurements. Transit-time and ultrasound flowmeter evaluation showed that only in one case was the Allen test correct. No significant complication was observed in the early postoperative time. There was no significant correlation between these findings and age, sex, underlying cardiovascular disease, side of harvest of the flap, and duration of flap ischemia.

Table 1 Blood Flow as Measured Intraoperatively in the Radial Recipient Arteries during Free Radial Forearm Flap Harvesting

Vessel	Interval	Blood flow (mL/min), Mean ± SD
Radial artery	Isolated	60.5 ± 47.7*
	After raising the flap	6.7 ± 4.1*
	After anastomosis	5.8 ± 2.0
Recipient vessel	Isolated	44.5 ± 33.1

*$p < 0.0001$.
SD, standard deviation.

Table 2 Blood Flow and Resistance Measured Intraoperatively in the Ulnar Artery during Free Radial Forearm Flap Operation

Vessel	Interval	Blood Flow (mL/min), Mean ± SD
Ulnar artery	Isolated	60.5 ± 43.3*
	After harvesting the flap	85.7 ± 57.9*
Ulnar artery resistance	Isolated	2.7 ± 3.1†
	After harvesting the flap	1.9 ± 2.2†
Ulnar + radial arteries	Isolated	121.9 ± 72.0

*$p < 0.002$.
†$p = 0.010$.
SD, standard deviation.

DISCUSSION

Although the radial forearm flap is nowadays widely used, few pathophysiological studies have been conducted on its hemodynamics.[9–12] Hemodynamic parameters such as blood flow and vascular resistance can be intraoperatively measured by the transit-time and ultrasonic flowmeter.[13] The aim of the present investigation was to analyze and quantify intraoperatively the changes in blood flow of the radial and ulnar arteries during radial forearm flap procedure.

The blood supply to the forearm and hand comes from the brachial artery, which divides into the radial and ulnar arteries. In a study of cadaveric upper limbs, McCormack et al[14] 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. The common interosseous artery originates

Table 3 Allen Test Results Compared with the Intraoperative Measurements

Radial Artery Flow (mL/min)	Ulnar Artery Flow (mL/min)	% Difference	Allen Test
214	119	80	U = R
58	16	263	U
125	100	25	U
24	135	82	R
54	55	2	U
39	65	40	U = R
14	19	26	R
83.5	91	8	U
70	75	7	U
79	79	0	U = R

U, ulnar artery; R, radial artery.

from ulnar artery, and it bifurcates into its anterior and posterior branches that communicate at the wrist with the radial and ulnar arteries as well as with the palmar and dorsal arterial arches of the hand.

Harvest of the forearm free flap requires interruption of the radial artery and total reliance on the ulnar artery and palmar arches including the interosseous system to maintain vascular integrity of the hand. In this prospective study, the raising of the radial forearm flap increased markedly the blood flow in the ulnar artery. The mean blood flow of the ulnar artery as measured intraoperatively by transit-time flowmeter was 60.5 ± 43.3 mL/min and significantly increased after harvesting the radial forearm flap to 85.7 ± 57.9 mL/min (Wilcoxon test: $p = 0.002$), but not as much as the sum of the baseline in situ ulnar and radial artery blood flow (121.9 ± 72.0 mL/min; Table 2). Such an increase in blood flow seems to partially compensate for the removal of the radial artery, and this shortfall could be related to an increase of the interosseous system flow.

In a retrospective study, Suominen et al[5] evaluated the donor site morbidity of the radial forearm flap using Doppler ultrasonographic evaluation, and they noticed a significantly increased peak flow velocity in the ulnar arteries on the donor site at the wrist. They compared the donor hand to the contralateral nonoperated side.

In a prospective study, with preoperative and postoperative measurements, Ciria-Lloréns et al,[9] after raising the radial forearm, showed a trend for increased overall forearm flow in the ulnar, posterior interosseous, and anterior interosseus arteries. The anterior interosseus artery showed the greatest increase in blood flow (33%).

The role of the anterior interosseous artery in collateral circulation of the hand has been well recognized also by other authors,[3,15,16] and it has also been shown that excision of the radial artery leads to compensatory changes in the ulnar, posterior interosseus, and anterior interosseus arteries that may in turn guarantee a good vascularization to the hand and may exert a protective effect for potential ischemia.[15] In our intraoperative study, the flow of both anterior and posterior interosseous arteries were not registered as they were not harvested during the operation; dissecting at the origin the ulnar artery and more deeply the interosseous vessels for locating the probe could have impaired the arteries and the vascularization of the hand.

According to our results, the pedicle flow dropped significantly after anastomosis, likely because of the small size of the flap, although the flow was high in both donor radial and recipient arteries. In a previous study,[10] we showed that blood flow in a free flap does not depend on the recipient artery blood flow; the microvascular transplant promotes the recipient artery flow depending on the free flap tissue component. It has been shown that vascular resistance to blood flow in the free radial forearm flap is higher than in the free musculocutaneous flap,[17] and subsequently blood flow through this fasciocutaneous flap is lower compared with muscular free flaps in which blood flow increases after anastomosis because of reduced vascular resistance due to denervation.[18]

In our study, the radial artery flow after raising is about the same as the radial artery flow after anastomosis (6.7 versus 5.8 mL/min), and this means that the vascular resistance in a fasciocutaneous flap is already reduced when the flap is harvested and the artery cutting does not increase the flow. Probably the sympathetic afferences in the vessel wall do not play an important role in the vessel caliber regulation, at least immediately after anastomosing.

Ikizler et al[12] noticed, after removal of the radial artery for coronary bypass, a significantly longer Allen test refill delay 1 week after surgery, but no statistical difference was observed at 6 months after the operation. A compensatory mechanism characterized by an increase in blood flow of the digital arteries in the long-term analysis was found. The authors supposed that prolonged capillary refill during the Allen test, even if harvesting of radial artery is deemed safe, might be an indicator for potential hypoperfusion-related complications after radial artery removal in patients with systemic vascular diseases.

Harvesting the radial forearm flap may cause more circulatory disturbances in radial than ulnar fingers.[19] In a recent prospective study, Yanagisawa et al[20] measured skin perfusion pressure to assess changes in circulatory dynamics in the donor hand, assuming that it is clinically more reliable in detecting the circulatory changes in the skin than plethysmography and Doppler ultrasonography. They observed reduced skin perfusion in the fingers of the donor arm and redistribution of blood flow to the fingers, with residually more blood to finger I than to finger V. They hypothesized the presence of an autoregulating mechanism in the fingers controlling the blood flow, but without considering the forearm arterial interosseous system.

To the best of our knowledge, only two cases of donor site hand vascular complications after radial artery removal for coronary bypass graft were shown by Jones and O'Brien[6] and Nunoo-Mensah.[21] Donor hand ischemia occurred despite a preoperative satisfactory Allen test, showing that this test was not predictive of postoperative donor hand vascularization, at least in patients with systemic vascular disease in whom ischemic complication can occur postoperatively.

We registered the Allen test preoperatively and not intraoperatively only in the first 10 patients because of the contradictory results observed during the intraoperative instrumental measurements (Table 3). In our short series of patients, the Allen test results were not confirmed by intraoperative blood flow measurements in all the cases except one (n = 10) in which the refill delay was the same for radial and ulnar arteries (showing a similar role of both arteries in hand vascularization); in addition, the transit-time intraoperative value of blood flow in the radial and ulnar artery was the same. Interestingly, two patients showed radial dominance on the Allen test, but they both had higher ulnar blood flow during the intraoperative measurements (135 mL/min versus 24 mL/min and 19 mL/min versus 14 mL/min; Table 3). On the light of these observations and according to recent larger studies,[22,23] preoperative Allen test results were not considered afterward.

These findings suggest that the Allen test cannot be used for showing the prevalence of the radial or ulnar artery in the vascularization of the hand as this vascularization is very dynamic not only through the radial and ulnar arteries but also through the interosseous system. The Allen test seems not to be predictive of donor site hand complications except for showing whether there is patency of the arterial connections between the superficial and palmar arches, which are essential for good vascularization of the donor site hand.

CONCLUSIONS

The raising of the radial forearm flap increases blood flow and decreases the resistance in the ulnar artery. These blood flow changes seem to partially compensate for the removal of the radial artery. The interosseous system likely plays a major compensatory role.

The radial forearm flap needs little blood flow to survive and behaves as a vascular shunt. According to our results, the Allen test seems to not be reliable for preoperative planning of the radial forearm flap harvesting, except for showing patency of the connections between the radial and ulnar artery at the wrist through the superficial and deep palmar arches.

ACKNOWLEDGMENTS

Presented at the 12th European Conference of Scientists and Plastic Surgeons (ECSAPS), Bern, Switzerland, September 12 and 13, 2008.

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