SAFE REMOVAL OF THE RADIAL ARTERY FOR MYOCARDIAL REVASCULARIZATION: A DOPPLER STUDY TO PREVENT ISCHEMIC COMPLICATIONS TO THE HAND

Paolo Pola, MD[a]
Michele Serricchio, MD[a]
Roberto Flore, MD[a]
Eric Manasse, MD[b]
Angela Favuzzi, MD[a]
Gian Federico Possati, MD[b]

Radial artery harvesting has recently been reintroduced for myocardial revascularization. Harvesting the radial artery may jeopardize the vascularization of the hand; cautious selection of candidates must therefore be pursued. The study involved 188 consecutive patients. We verified the patency of the upper limb's arteries and the adequacy of the ulnar supply by static and dynamic Doppler evaluations. The use of the radial artery was contraindicated in 14 cases (three for stenosis of the subclavian artery and 11 for inadequate collateralization). One hundred patients were operated on with the radial artery used as a graft; the remaining 74 patients had a different conduit placed. The vascularization of the hand was restudied within 10 days in all patients who underwent operation; in 63 patients, it was studied again at 1 year. The early Doppler examination showed significant increase in blood flow velocities in the ulnar artery, with a flow redistribution in the common digital palmar arteries (decreased in the first and increased in the second and the third). The late Doppler examination showed superimposable findings. No local ischemic complications were observed. We conclude that Doppler study is a useful tool in preoperative screening of candidates for radial artery harvesting for myocardial revascularization. (J Thorac Cardiovasc Surg 1996;112:737-44)

The radial artery (RA) was recently reintroduced as a graft source for coronary artery bypass grafting (CABG).[1,2] Among of the characteristics favoring the use of this vessel are a caliber similar to that of the major coronary arteries, adequate thickness and resistance of the arterial wall, and sufficient length to allow complete myocardial revascularization.[3,4] For reasons of safety, the nondominant arm is used. The entire RA, with satellite veins, is removed from its origin at the level of the brachial artery to the wrist.[5] Circulations of the forearm and hand are acutely deprived of an important artery, with possible ischemic consequences either during the early postoperative period or later. To avoid ischemic complications to the hand, some authors have proposed preliminary evaluation of the palmar circulation by means of an Allen test or a Doppler study.[6,7]

In our opinion, a more nearly complete vascular examination is advisable because of the promising results of this surgical technique. The presence of atherosclerotic lesions of the RA and of the subclavian, axillary, brachial, and ulnar arteries should be explored because patients with ischemic myocardial disease have a higher rate of peripheral vascular disease. It is therefore essential to evaluate the palmar circulation and the adequacy of the blood supply to the hand provided by the ulnar artery. Vascularization of the hand is predominantly ulnar in most subjects, and the RA and ulnar artery are widely anastomosed at the level of the hand by means of the superficial and deep palmar arches, with good hemodynamic compensation should either artery be excluded.[7,8] Anatomic variations (RA predominance, incomplete superficial palmar arch, and malformations of the ulnar artery) may, however, impair appropriate hemodynamic compensation when the RA is removed.[9,10] The aim of this study was to establish objective criteria for safe RA harvesting through assessment of the anatomic integrity of the arteries of the upper limb with Doppler static evaluation and of the adequacy of collat-

From the Departments of Angiology[a] and Cardiac Surgery,[b] Catholic University of the Sacred Heart, Rome, Italy.

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Address for reprints: Paolo Pola, MD, Primario del Servizio di Angiologia, Policlinico A. Gemelli, Università Cattolica del Sacro Cuore, Largo Gemelli 8, 00168 Rome, Italy.

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eral circulation during RA compression (RAC) with a Doppler dynamic test (DDT).

Patients and methods

Between January 1993 and June 1995, 188 consecutive patients (152 male and 36 female) among those admitted at the Catholic University of Rome for isolated CABG were included in this study. The mean age was 57.9 years (range 39 to 76 years). In each patient, the vascularization of the upper nondominant arm was evaluated according to the standard technique by means of continuous wave Doppler equipment (model Dop 2000, Cardioline, Remco Spa, Milano, Italy) equipped with a probe at a frequency emission of 8 MHz.[11, 12] The DDT was performed with the patient's hand only slightly flexed and relaxed. All examinations were performed by three fully trained angiologists of the Angiology Department during the same hospitalization for CABG. The examinations were performed with the patients in the supine position after 10 minutes of rest at a room temperature of 22° to 24° C. Patency of the upper limb arteries was studied by measuring blood flow velocities along the RA and subclavian, axillary, brachial, and ulnar arteries. The following DDT was used: either under basal conditions or during RAC at the wrist, blood flow velocities were measured at the following sites: (1) ulnar artery, at the wrist; (2) superficial palmar branch of the RA (SPA), located along an imaginary line following the proximal segment of the second metacarpal; (3) main artery of the thumb (I ray), located at the base of the thumb on the medial side; (4) second common palmar digital artery (II ray), located between the heads of the second and third metacarpals; and (5) third common palmar digital artery (III ray), located between the heads of the third and forth metacarpals. In each artery, the following Doppler parameters were considered: (1) peak systolic velocity (PSV), expressed in centimeters per second; (2) end-diastolic velocity (EDV), expressed in centimeters per second; and (3) resistance index (RI), derived as (PSV − EDV)/PSV.

Patients without an increase in blood flow velocity at the ulnar artery associated with flow disappearance at the SPA during the RAC were considered unsuitable as candidates for RA harvesting. Among those patients judged to be suitable candidates for RA harvesting, 74 were excluded by the cardiac surgeons for the following reasons: a suitable saphenous vein graft could be found, other arterial conduits (right internal thoracic artery, gastroepiploic artery, inferior epigastric artery) were preferred, or the nondominant arm RA had to be cannulated by the anesthetist for blood-pressure monitoring. One hundred patients underwent myocardial revascularization with the RA. A first clinical examination and a Doppler evaluation were performed 10 days after operation to evaluate the adequacy of the palmar circulation and the presence of ischemic complications. In 63 patients, the same evaluation was repeated 1 year later.

Statistical analysis. Results are expressed as mean values (± standard deviation). The differences between two means were compared with Student's *t* test. The criterion for statistical significance was a *p* value lower than 0.05.

Results

Among the 188 patients considered in this study, three (1.6%) showed an important PSV decrease in all the examined arteries of the upper limb, suggestive of atherosclerotic stenosis of the subclavian artery, and were therefore excluded before any further investigation; the other 185 had normal flow velocities under basal conditions. These 185 patients could be placed into two groups, depending on their response to the DDT: 174 patents (group A; 94.05%) were considered suitable candidates for RA harvesting, and 11 patients (group B; 5.95%) were rejected as candidates because of an inadequate ulnar supply (no increase in blood flow velocity at the ulnar artery associated with flow disappearance at the SPA). Continuous wave Doppler tracings of patients with adequate (group A) and inadequate (group B) compensation are shown in Figs. 1 and 2, respectively.

Table I shows the average values (± standard deviation) of basal Doppler parameters (static evaluation). The two groups showed similar values of PSV, EDV, and RI in all the examined arteries.

Table II summarizes the results obtained during the DDT for each group. Group A had the following findings for PSV: a significant increase at the ulnar artery ($p < 0.0001$), a significant decrease at the I ray and II ray arteries ($p < 0.001$), no changes at the III ray artery, and presence of retrograde flow at the SPA. Group A had the following findings for EDV: a significant increase at the ulnar artery ($p < 0.0001$), a slight reduction at the I ray artery ($p < 0.05$), and no changes at the II ray and III ray arteries. Group A had the following findings for RI: slight reduction at the ulnar artery ($p < 0.05$), slight increase at the I ray artery ($p < 0.05$), and no changes at the II ray and III ray arteries.

Group B showed the following findings for PSV: no increase at the ulnar artery, a significant decrease at the II ray and III ray arteries ($p < 0.0001$), a slight reduction at the III ray artery ($p < 0.05$), and flow disappearance at the SPA. Group B showed the following findings for EDV: no changes at the ulnar artery, a decrease at the I ray and II ray arteries ($p < 0.05$), and a more evident decrease at the III ray artery ($p < 0.001$). Group B showed the following findings for RI: no changes at the ulnar artery and at the I ray artery and a slight increase at the II ray and III ray arteries.

Table III shows the comparison between basal and postoperative (at 10 days and after 1 year) average values of PSV, EDV, and RI in the exam-

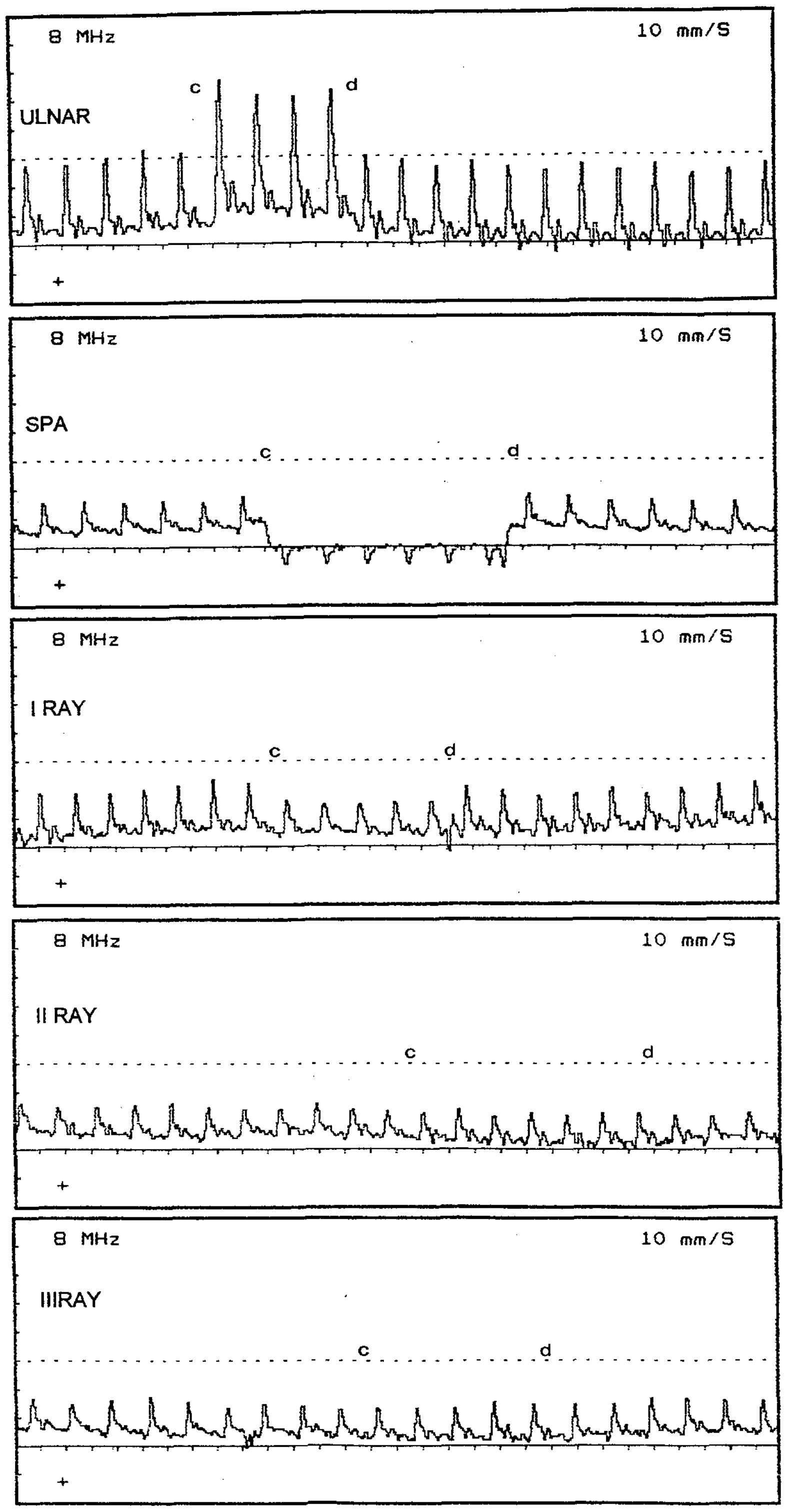

Fig. 1. Doppler tracings of a patient with adequate ulnar supply during DDT. *c,* RAC; *d,* RA decompression.

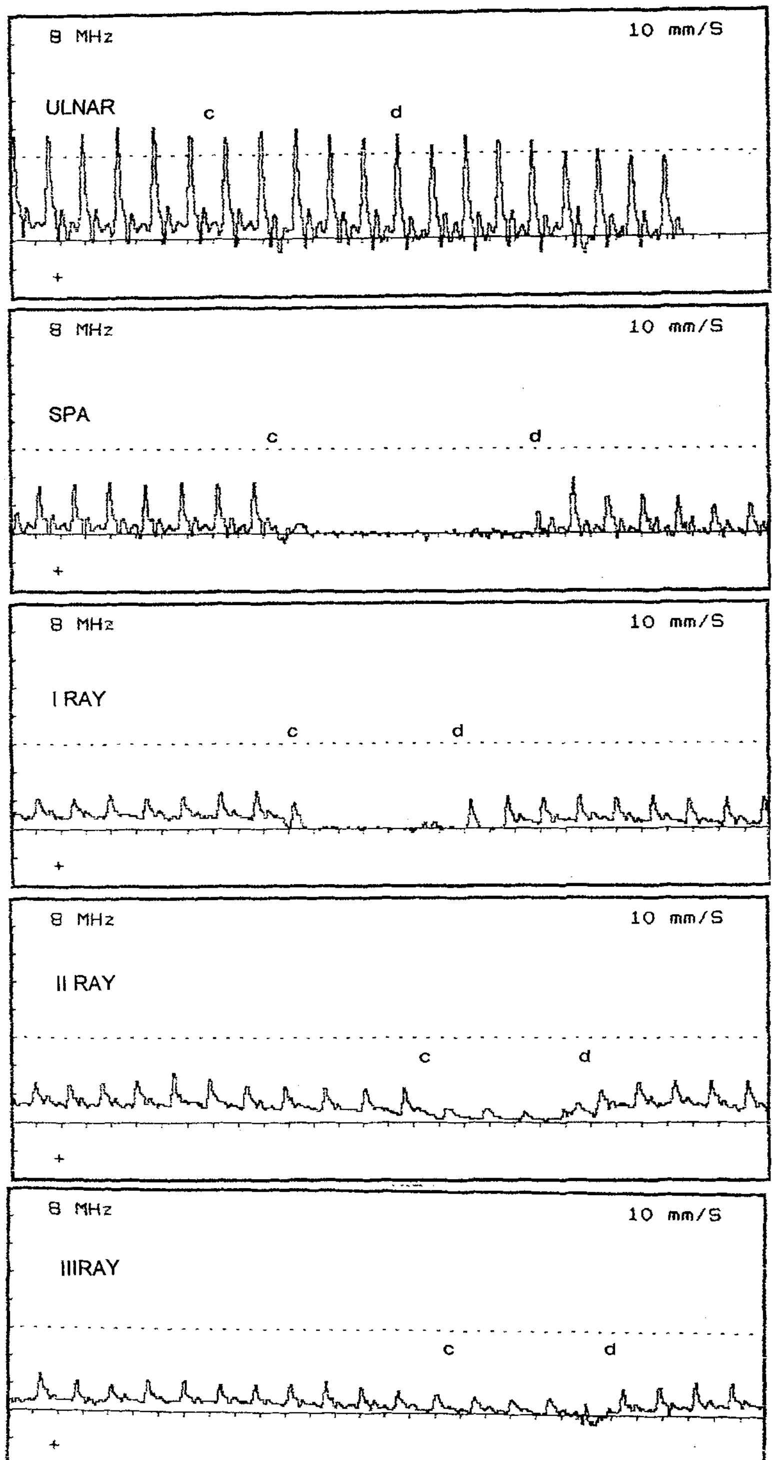

Fig. 2. Doppler tracings of a patient with inadequate ulnar supply during DDT. *c,* RAC; *d,* RA decompression.

ined arteries. After 10 days, we observed significant increases in PSV and EDV at the ulnar artery, with an important reduction in RI ($p < 0.0001$). At the SPA, we observed a reverted flow. At the I ray artery, we observed a slight PSV decrease ($p < 0.05$) and no changes in EDV and RI. At the II ray artery, slight increases in PSV and EDV and a decrease in RI ($p < 0.05$) were noted. We observed slight PSV and EDV increases ($p < 0.05$) and no changes in RI at the III ray artery.

The results at 1 year after the operation showed significant increases in PSV ($p < 0.0001$) and EDV ($p < 0.05$) at the ulnar artery, with a reduction in RI ($p < 0.001$). At the SPA, we observed a reverted flow. At the I ray artery, a slight PSV decrease was observed ($p < 0.05$), with no changes in EDV and RI. No change in PSV, a slight increase in EDV ($p < 0.05$), and a decrease in RI ($p < 0.0001$) were observed at the II ray artery. At the III ray artery, we observed slight PSV and EDV increases ($p < 0.05$), with a decrease in RI ($p < 0.0001$).

Table IV shows the comparison between flow values obtained during DDT and at 1 year follow-up. At the ulnar artery and at the SPA, no significant differences in PSV, EDV, and RI were seen. At the I ray artery, a higher PSV ($p < 0.0001$), a higher EDV ($p < 0.0001$), and a lower RI ($p < 0.0001$) were seen at 1 year. A higher PSV ($p < 0.0001$), a higher EDV ($p < 0.001$), and a lower RI ($p < 0.0001$) were also seen at 1 year at the II ray artery. At the III ray artery, we similarly observed increased PSV ($p < 0.0001$), increased EDV ($p < 0.0001$), and decreased RI ($p < 0.0001$) at 1 year.

Clinically, no ischemic complications of the hand were found, either in the immediate postoperative phase or after 1 year.

Table I. *PSV, EDV, and RI in examined arteries under basal conditions, in the patients considered suitable for RA (group A) and in those rejected (group B)*

	Group A (*n* = *174*)	*Group B* (*n* = *11*)	*p*
Brachial			
PSV	55.80 ± 11.70	54.70 ± 3.23	NS
EDV	1.30 ± 3.10	1.35 ± 2.46	NS
RI	0.98 ± 0.05	0.98 ± 0.40	NS
Radial			
PSV	37.82 ± 11.93	34.50 ± 4.50	NS
EDV	1.90 ± 4.26	1.60 ± 1.46	NS
RI	0.96 ± 0.09	0.95 ± 0.04	NS
Ulnar			
PSV	32.60 ± 11.71	31.10 ± 6.87	NS
EDV	2.15 ± 4.42	0.58 ± 1.41	NS
RI	0.95 ± 0.11	0.99 ± 0.04	NS
SPA			
PSV	23.39 ± 6.22	24.12 ± 5.49	NS
EDV	1.30 ± 2.81	1.57 ± 2.18	NS
RI	0.96 ± 0.10	0.95 ± 0.15	NS
I ray			
PSV	16.60 ± 8.10	17.10 ± 3.74	NS
EDV	1.39 ± 3.21	1.65 ± 1.45	NS
RI	0.94 ± 0.10	0.90 ± 0.14	NS
II ray			
PSV	16.70 ± 6.80	17.12 ± 7.30	NS
EDV	1.40 ± 2.60	1.27 ± 1.61	NS
RI	0.93 ± 0.10	0.91 ± 0.10	NS
III ray			
PSV	17.10 ± 6.70	18.42 ± 9.04	NS
EDV	1.20 ± 2.60	1.74 ± 0.77	NS
RI	0.94 ± 0.10	0.89 ± 0.15	NS

Values are mean ± standard deviation.

Discussion

In patients undergoing CABG, accurate vascular evaluation before RA removal is useful to confirm the patency of the artery to be used as a bypass graft and to avoid ischemic complications to the hand. Contraindications to the use of the RA were as follows: atherosclerosis of the upper limb arteries, anatomic variations of the arterial circulation of the hand and forearm potentially limiting adequate ulnar supply, and Raynaud's disease. Only the non-dominant arm was examined because the cardiac surgeons chose to wait for longer follow-up before considering the use of both arms.[5] We performed a continuous wave Doppler static evaluation of the arteries of the upper limb and a DDT of the ulnar artery, SPA, and common palmar digital arteries during RAC. Because of the increasing use of RA grafts, we consider our proposed Doppler evaluation to be more worthwhile and safer, yet negligibly more costly in terms of time to perform and expense incurred, than the Allen test alone. The Allen test does not allow reliable evaluation of the single arteries of the hand, and it has long been criticized for its considerable rate of false-positive and false-negative results.[13-16] A more detailed analysis of each artery can undoubtedly be obtained with Doppler evaluation.[14] Examination under basal conditions allows the identification of atherosclerotic lesions, which in our opinion should constitute an a priori criterion for exclusion of patients from this procedure. Patients with such lesions would be more susceptible to embolic episodes, which could be catastrophic in the presence of a single blood supply

Table II. *PSV, EDV, and RI changes in examined arteries during RAC in patients considered suitable for RA harvesting (group A) and in those rejected as candidates (group B)*

	Group A (n = 174)			Group B (n = 11)		
	Basal	RAC	p	Basal	RAC	p
Ulnar						
PSV	32.60 ± 11.71	47.20 ± 14.50	<0.0001	31.10 ± 6.87	32.10 ± 8.22	NS
EDV	2.15 ± 4.42	4.80 ± 6.70	<0.0001	0.58 ± 1.41	0.25 ± 0.71	NS
RI	0.95 ± 0.11	0.91 ± 0.13	<0.05	0.99 ± 0.04	0.99 ± 0.02	NS
SPA						
PSV	23.39 ± 6.22	−5.50 ± 11.60	<0.0001	24.12 ± 5.49	0.00 ± 0.00	<0.0001
EDV	1.30 ± 2.81	0.00 ± 0.00	<0.0001	1.57 ± 2.18	0.00 ± 0.00	<0.0001
RI	0.96 ± 0.10	1.00 ± 0.00	<0.0001	0.95 ± 0.15	0.00 ± 0.00	<0.0001
I ray						
PSV	16.60 ± 8.10	9.00 ± 5.90	<0.001	17.10 ± 3.74	1.25 ± 2.10	<0.0001
EDV	1.39 ± 3.21	0.40 ± 1.70	<0.05	1.65 ± 1.45	0.13 ± 0.30	<0.05
RI	0.94 ± 0.10	0.98 ± 0.10	<0.05	0.90 ± 0.14	0.83 ± 0.30	NS
II ray						
PSV	16.70 ± 6.80	12.20 ± 6.80	<0.001	17.12 ± 7.30	1.00 ± 1.50	<0.0001
EDV	1.40 ± 2.60	0.90 ± 2.50	NS	1.27 ± 1.61	0.00 ± 0.00	<0.05
RI	0.93 ± 0.10	0.95 ± 0.10	NS	0.91 ± 0.10	1.00 ± 0.00	<0.05
III ray						
PSV	17.10 ± 6.70	16.00 ± 6.80	NS	18.42 ± 9.04	7.25 ± 7.70	<0.05
EDV	1.20 ± 2.60	1.20 ± 2.60	NS	1.74 ± 0.77	0.00 ± 0.00	<0.001
RI	0.94 ± 0.10	0.94 ± 0.10	NS	0.89 ± 0.15	1.00 ± 0.00	<0.05

Values are mean ± standard deviation.

Table III. *Comparison between basal and postoperative values of PSV, EDV, and RI in examined arteries*

	Basal (n = 174)	10 days (n = 100)	p	1 yr (n = 63)	p
Ulnar					
PSV	32.60 ± 11.71	52.60 ± 14.60	<0.0001	44.60 ± 12.40	<0.0001
EDV	2.15 ± 4.42	7.80 ± 8.60	<0.0001	5.20 ± 6.40	<0.05
RI	0.95 ± 0.11	0.87 ± 0.10	<0.0001	0.89 ± 0.10	<0.001
SPA					
PSV	23.39 ± 6.22	−10.40 ± 15.33	<0.0001	−6.81 ± 13.59	<0.0001
EDV	1.30 ± 2.81	0.00 ± 0.00	<0.0001	0.00 ± 0.00	<0.0001
RI	0.96 ± 0.10	1.00 ± 0.00	<0.0001	1.00 ± 0.00	<0.0001
I ray					
PSV	16.60 ± 8.10	12.70 ± 8.70	<0.05	11.90 ± 5.70	<0.05
EDV	1.39 ± 3.21	1.80 ± 3.90	NS	1.40 ± 2.60	NS
RI	0.94 ± 0.10	0.93 ± 0.10	NS	0.91 ± 0.10	NS
II ray					
PSV	16.70 ± 6.80	18.80 ± 8.40	<0.05	16.30 ± 6.60	NS
EDV	1.40 ± 2.60	2.90 ± 4.70	<0.05	2.20 ± 3.20	<0.05
RI	0.93 ± 0.10	0.89 ± 0.20	<0.05	0.87 ± 0.10	<0.0001
III ray					
PSV	17.10 ± 6.70	19.60 ± 8.08	<0.05	19.30 ± 7.40	<0.05
EDV	1.20 ± 2.60	2.50 ± 4.60	<0.05	3.10 ± 4.10	<0.05
RI	0.94 ± 0.10	0.91 ± 0.20	NS	0.86 ± 0.20	<0.0001

Values are mean ± standard deviation.

to the forearm. For this reason, three patients (1.6%) with significant stenosis of the subclavian artery were withdrawn from the study after the basal Doppler evaluation.

To further screen patients placed at risk by RA removal because of inadequate collateralization, the DDT was employed. This test can thoroughly explore efficiency of terminal anastomosis between the radial and ulnar territories. In our opinion, RA removal was contraindicated when the following conditions were concomitantly present under conditions of RAC: (1) absence of the expected PSV and EDV increases in the ulnar artery and (2) disappearance of the flow in the SPA. The association of these two criteria, as observed in 5.95% of patients, suggests inadequacy of the superficial palmar arch and the absence of other anastomotic sites between the ulnar and RA.

Patients without these associated findings (94.05%) were judged suitable candidates for RA harvesting. Among these patients, the best standards of flow modifications were as follows: a systolic-diastolic increase in flow rate in the ulnar artery of 20% or more, a reversed flow at the level of the SPA, a stable flow in the III ray artery, and reductions of as much as 70% of the original value in the II ray and as much as 30% in the I ray. The increase in systolic-diastolic velocities in the ulnar artery after RAC at the wrist suggests a good compliance of the artery, one able to receive the entire flow from the brachial artery, adapting the flow velocity to the increased volume. The presence of reversed flow at the superficial palmar branch of the RA indicates the anatomic continuity of the superficial palmar arch. A complete superficial palmar arch was found in 93% of the patients in group A. The remaining 7% showed a decreased flow during RAC, which was still considered suitable because the ulnar flow increase offered a good anastomotic supply.

Further information is provided by the analysis of the flow patterns seen in the common digital palmar arteries during RAC. An unchanged flow velocity at the III ray artery, with a slight reduction at the II ray and I ray, suggests a good palmar circulation even after RA removal. Finally, the main contraindication to RA removal is an inadequate ulnar flow increase; other criteria are of secondary importance and must coexist rather than being considered separately to reach significance. Follow-up analysis confirms the utility of the tests we carried out. The check-up conducted 10 days after the operation showed a marked increase of PSV and EDV, with significant reduction of the RI at the ulnar artery, probably as a result of reactive vasodilatation and local inflammation after the operation. The variations observed at level of the SPA and the common digital palmar arteries reflect the new arrangement of regional hemodynamics: reverted (in 90% of patients) or decreased flow in the SPA (in 10% of patients), increased flow velocities at the II ray and III ray arteries, and decreased flow velocities at the I ray artery. One year after operation, the ulnar artery had persistent increases in blood flow velocities. The EDV decreased compared with the velocity observed during the immediate postoperative period because of disappearance of inflammation. The behavior of the overall flow of the SPA and the common digital palmar arteries is similar to that observed at the first examination, during RAC. The definitive interdigital flow rate redistribution can be predicted with great accuracy by means of preoperative DDT, although the absolute values registered at 1 year are superior because the collateral circulation adapts its capacity with time. The clinical relevance of this flow redistribution to the hand must be analyzed over a longer interval. The instrumental tests results are confirmed by current clinical observations: no patient reported any circulatory disturbance.

In conclusion, safe RA removal for CABG is better ensured in the absence of atherosclerotic lesions of the upper limb's arteries and of anatomic variations of the palmar circulation. In our opinion, a Doppler static evaluation and the DDT that we propose are the best tools to verify these conditions.

Table IV. *Comparison between RAC and postoperative (1 year) values of PSV, EDV, and RI*

	RAC (*n* = 174)	*1 yr* (*n* = 63)	*p*
Ulnar			
PSV	47.20 ± 14.50	44.60 ± 12.40	NS
EDV	4.80 ± 6.70	5.20 ± 6.40	NS
RI	0.91 ± 0.13	0.89 ± 0.10	NS
SPA			
PSV	−5.50 ± 11.60	−6.81 ± 13.59	NS
EDV	0.00 ± 0.00	0.00 ± 0.00	NS
RI	1.00 ± 0.00	1.00 ± 0.00	NS
I ray			
PSV	9.00 ± 5.90	11.90 ± 5.70	<0.0001
EDV	0.40 ± 1.70	1.40 ± 2.60	<0.0001
RI	0.98 ± 0.10	0.91 ± 0.10	<0.0001
II ray			
PSV	12.20 ± 6.80	16.30 ± 6.60	<0.0001
EDV	0.90 ± 2.50	2.20 ± 3.20	<0.001
RI	0.95 ± 0.10	0.87 ± 0.10	<0.0001
III ray			
PSV	16.00 ± 6.80	19.30 ± 7.40	<0.0001
EDV	1.20 ± 2.60	3.10 ± 4.10	<0.0001
RI	0.94 ± 0.10	0.86 ± 0.20	<0.0001

Values are mean ± standard deviation.

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