Can harvesting techniques modify postoperative results of the radial artery conduit?

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Background. **Inappropriate harvesting of arterial conduits can lead to severe postoperative complications. We analyzed clinical and functional results of patients undergoing radial artery (RA) harvesting by means of three techniques.**

Methods. **From January 2001 to January 2004 188 patients undergoing coronary artery bypass graft with RA were divided into three groups: harmonic scalpel was employed in 61 (RA1), electrocautery in 63 (RA2), Potts-scissors and clips in 64 (RA3) patients. Harvesting time, local complications, number of clips employed, graft flowmetry, postoperative troponin I, incidence of re-exploration for bleeding due to the graft were analyzed.**

Results. **RA1 and RA2 showed a lower harvesting time (RA1 16.2 ± 8.4 vs RA3 41.4 ± 7.7 min, p = 0.0001; RA2 21.1 ± 10.4 min, p = 0.001). Postoperative hand paresthesia was detected in RA1 (5/61; 8.2%) and RA2 (5/63; 7.9%), but not in RA3 (p = 0.048 and p = 0 .05, respectively). More clips were necessary in RA3 compared to RA2 (p = 0.04) or RA1 (p = 0.0001 vs RA3; p = 0.001 vs RA2). RA1 showed significant higher values of maximum flow (RA1 59.4 ± 37.5 vs RA2 22.1 ± 7.7 ml/min, p = 0.0001; vs RA3 31.3 ± 12.0 ml/min, p = 0.001), mean flow (RA1 23.4 ± 17.3 vs RA2 10.2 ± 5.7 ml/min, p = 0.001; vs RA3 11.6 ± 8.9 ml/min, p = 0.001), minimum flow (RA1 11.6 ± 6.5 vs RA2 4.2 ± 3.7 ml/min, p = 0.01; vs RA3 4.7 ± 3.3, p = 0.03), and pulsatility index (RA1 0.9 ± 0.8 vs RA2 2.1 ± 1.3, p = 0.03; vs RA3 1.7 ± 2.1, p = 0.04). Troponin I was significantly lower in RA1, compared to RA2 and RA3 at 12 hours (p = 0.01 and p = 0.03, respectively) and 24 hours (p = 0.05 and p = 0.045, respectively). No RA1 patient underwent re-exploration for bleeding compared to RA2 (p = 0.011) and RA3 (p = 0.02).**

Conclusions. **RA harvesting with ultrasounds is fast, determines high flowmetry values, low enzyme release and rarely causes local complications.**

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Introduction

Arterial grafts have been increasingly used in coronary artery bypass surgery over the last three decades[1]. Arterial grafts, especially the left internal mammary artery (LIMA), have been proven to have higher patency rates than vein grafts[1].

The use of the radial artery (RA) for coronary artery bypass grafting (CABG) was first described by Carpentier et al.[2] in the early 1970's. They harvested the RA graft using an open skeletonized fashion, and did not use any vasodilators. The patency of these initial RA grafts was very poor, and therefore this arterial graft for CABG was abandoned. Many years later, a number of original RA grafts that had been thought to have been occluded were found to be patent. This finding along with the use of vasodilators[3] and a different harvesting technique (pedicle)[4] resulted in the re-use of the RA for CABG. Since that time many studies have been published on the use of RA as a graft for myocardial revascularization[5-12].

Early graft failures were attributed to graft vasospasm and premature occlusions to intimal hyperplasia. In the second era of RA utilization, to prevent graft vasospasm and achieve a better long-term patency, harvesting techniques were clearly refined. The storage media was scrutinized, and the systemic and topical vasodilator drugs were introduced in routine practice[13,14]. Disruption and disintegration of the endothelium of this muscular artery during harvesting could prevent endothelium-dependent relaxation and probably cause early graft failure[13]. Therefore trauma during the harvesting time is the major cause of endothelial damage and subsequently graft failure[13,14].

Conventional techniques have been utilized for harvesting including sharp and blunt dissection, electrocautery, and control of branches of the RA with small clips. Despite significant experience and what is generally considered as meticulous, non-traumatic methods, Ronan et al.[15] found a significant spasm occurring in many RAs, with loss of pulsation during harvesting with traditional techniques and no distal flow after completion of the proximal anastomosis, before the distal anastomosis. Experience with ultrasonic dissection of RA pedicles and avoidance of hemostatic clips suggested some authors that there was reduced spasm in the conduit with this approach[15,16].

Therefore, the aim of our study was to evaluate differences in clinical outcome and functional results of patients undergoing CABG with RAs harvested with three different techniques during the last 3 years.

Methods

Patients. From January 2001 to January 2004, 188 patients undergoing myocardial revascularization with both LIMA and RA were enrolled in the study. Preoperative demographic data are shown in table I.

Patients were divided into three groups, according to the RA harvesting technique: harmonic scalpel (Ethicon Endo-Surgery, Cincinnati, OH, USA) was employed in 61 patients (RA1), electrocautery in 63 (RA2), Potts-scissors and clips in 64 (RA3). The choice of the harvesting technique was left to the surgeon; however, the majority of patients undergoing CABG in the first 2 years of the study underwent RA harvesting with the traditional electrocautery or Potts-scissors/clips techniques, whereas almost all patients during the last year were treated with ultrasonic scalpel.

Exclusion criteria were associated cardiac disease (valvular, aortic disease, congenital pathology) or severe associated comorbidities (renal and hepatic failure, cancer, autoimmune disease).

Anesthetic technique. Anesthesia was performed by the same group of anesthesists (n = 3) and consisted of propofol infusion 3 mg/kg/hour and fentanyl administration 0.10 mg every 20 min. Neuromuscular blockade was achieved with pancuronium bromide.

Surgical technique. The RA was evaluated in all cases by means of the Allen test, and results were considered negative when hand vascularization became normal in < 6 s. The graft was harvested only from the non-dominant forearm in all cases. Low current electrocautery was used for the subcutaneous tissue and the deep fascia in the proximal half of the incision, with the distal deep fascia incised with scissors. The subsequent dissection differed in the three groups. The 61 patients with ultrasonic harvest (RA1) had dissection of the RA pedicle with the hook blade using the variable mode at moderate intensity. RA branches that bled during or after transection were controlled with small clips. The 63 patients in the electrocautery harvest group (RA2) underwent mobilization of the RA pedicle using electrocautery at low energy, with the control of bleeding branches with hemoclip devices; in the 64 patients who underwent traditional harvesting (RA3), a combination of blunt and sharp dissection, with control of vessel branches using two clips and division of the branches with scissors, was used. Topical vasodilators were not used during RA harvest at any time. After harvesting, RAs were placed in 100 ml NaCl 0.9% with 50 mg diltiazem and 5000 IU heparin until their use as grafts.

Table I. Preoperative variables.

	Group RA1 (n = 61)	Group RA2 (n = 63)	Group RA3 (n = 64)	p
Age (years)	67.2 ± 29.4	62.9 ± 26.3	65.0 ± 25.8	NS
Sex (M/F)	50/11	52/11	52/12	NS
Body surface area (m^2)	1.73 ± 0.4	1.80 ± 0.5	1.77 ± 0.4	NS
Hyperlipidemia	39 (63.9%)	40 (63.5%)	40 (62.5%)	NS
Hypertension	57 (93.4%)	55 (87.3%)	56 (87.5%)	NS
Diabetes mellitus	18 (29.5%)	15 (23.8%)	17 (26.5%)	NS
Smokers	42 (68.8%)	39 (61.9%)	41 (64.1%)	NS
Recent AMI	17 (27.8%)	19 (30.1%)	20 (31.2%)	NS
EuroSCORE	4.3 ± 0.9	4.1 ± 0.5	4.1 ± 0.4	NS
CCS I	2 (3.3%)	3 (4.7%)	3 (4.7%)	NS
CCS II	11 (18.0%)	10 (15.9%)	11 (17.2%)	NS
CCS III	46 (75.4%)	47 (74.7%)	46 (71.9%)	NS
CCS IV	2 (3.3%)	3 (4.7%)	4 (6.2%)	NS
LVEF (%)	42.6 ± 7.7	41.9 ± 9.3	44.1 ± 8.2	NS
WMSI	1.50 ± 0.38	1.67 ± 0.23	1.58 ± 0.34	NS

AMI = acute myocardial infarction; CCS = Canadian class score; LVEF = left ventricular ejection fraction; RA = radial artery; WMSI = wall motion score index.

The LIMA was anastomosed always to the anterior descending artery. The RA was anastomosed both to the right coronary artery and obtuse marginal branches, as shown in table II. However, the RA was used in the presence of a stenosis of 70% or greater, with expected high run-off (no previous myocardial infarction and target coronary vessel of reasonable size).

The RA was proximally anastomosed to the LIMA in 12 patients, to the ascending aorta in all the other cases. When the aorta was the RA blood source, the proximal anastomosis was performed with aortic side clamping, before distal anastomoses in off-pump CABG, following cross-clamp removal in conventional CABG on cardiopulmonary bypass.

Ten min following protamine administration flow measurements in all the RAs were performed by the senior author (A.R.) using transit time flow probes (Transonic HT107, 3 mm probe, Linton Instrumentation, Norfolk, UK) in ml/min: maximum flow, mean flow, minimum flow and pulsatility index were recorded.

Statistical analysis. The continuous variables were expressed as mean values ± SD, and categorical data as proportions. Comparisons of continuous variables were made with two-tailed Student's t-test (paired or unpaired when appropriate). Categorical variables were compared with the χ^2 test or the Fisher exact test. One-way analysis of variance (ANOVA) was used to evaluate the significance of the differences among the three groups. If the F value was significant and variance was homogeneous, Tukey's multiple comparison test was used to assess the differences between the individual groups; otherwise, Tamhane's T2 test was used. The Kruskal-Wallis test was used to compare the three groups in terms of dichotomous variables. A p value of < 0.05 was considered as significant. Data were statistically analyzed using SPSS 10.0 (SPSS, Chicago, IL, USA).

Results

Preoperative patients' profiles were similar among the three groups, as shown in table I. Operative data are reported in table II.

Global postoperative mortality was 2.1% (4/188 patients); no differences were found among the three groups (RA1 1/61 [1.6%] vs RA2 1/63 [1.5%], p = 0.811; vs RA3 2/64 [3.1%], p = 0.664; RA2 vs RA3 p = 0.714).

Similarly 7 patients (3.7%) developed postoperative myocardial infarction. Again, no differences have been shown among the three groups (RA1 2/61 [3.2%] vs RA2 2/63 [3.1%], p = 0.864; vs RA3 3/64 [4.6%], p = 0.712; RA2 vs RA3 p = 0.598).

Patients undergoing ultrasonic harvesting showed a lower harvesting time (p = 0.001 vs RA2; p = 0.0001 vs RA3) as shown in figure 1; no differences in harvesting time was shown between harmonic scalpel and electrocautery (p = 0.814) (Fig. 1).

A higher number of hemostatic clips were necessary in the Potts-scissors group (RA3 52.8 ± 24.2),

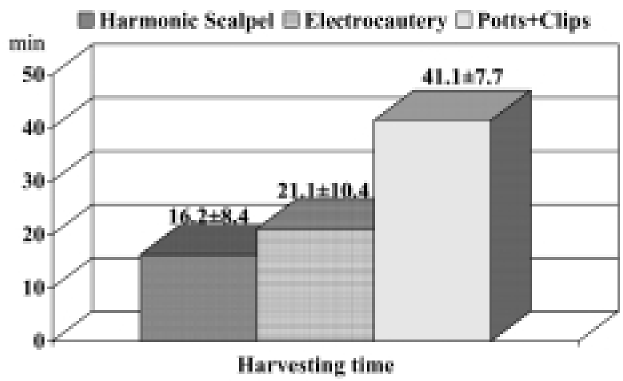

Figure 1. *Harvesting time with the three different techniques.*

Table II. Operative variables.

	Group RA1 (n = 61)	Group RA2 (n = 63)	Group RA3 (n = 64)	p
No. grafts/patient	4.1 ± 0.38	4.0 ± 0.66	4.1 ± 0.7	NS
RA-Cx grafting	48 (78.6%)	50 (79.3%)	48 (75.0%)	NS
TIMI 0	31 (64.6%)	34 (68.0%)	32 (66.7%)	NS
TIMI 1	13 (27.1%)	11 (22.0%)	12 (25.0%)	NS
TIMI 2	4 (8.3%)	5 (10.0%)	4 (8.3%)	NS
RA-Rx grafting	13 (21.4%)	13 (20.7%)	16 (25.0%)	NS
TIMI 0	8 (61.6%)	7 (53.8%)	9 (56.3%)	NS
TIMI 1	2 (15.3%)	3 (23.1%)	3 (18.7%)	NS
TIMI 2	3 (23.1%)	3 (23.1%)	4 (25.0%)	NS
LIMA-RA "Y"	4 (6.6%)	4 (6.3%)	4 (6.2%)	NS
OPCAB	10 (16.4%)	9 (14.3%)	12 (18.7%)	NS
ACC time (min)	42.4 ± 21.6	44.6 ± 25.1	46.1 ± 20.9	NS
CPB time (min)	72.6 ± 27.2	75.8 ± 20.8	69.8 ± 23.0	NS

ACC = aortic cross-clamp; CPB = cardiopulmonary bypass; Cx = circumflex artery; LIMA-RA "Y" = Y configuration between the left internal mammary artery and the radial artery; OPCAB = off-pump coronary artery bypass surgery; RA-Cx grafting = radial artery grafting on the circumflex territory; RA-Rx grafting = radial artery grafting on the right coronary territory.

compared to electrocautery (RA2 28.6 ± 34.5, $p = 0.04$) or harmonic scalpel group (RA1 10.1 ± 4.0, $p = 0.0001$ vs RA3, and $p = 0.001$ vs RA2, respectively).

Intraoperative flowmetry with Transonic showed in RA1 significant higher values in terms of maximum flow (59.4 ± 37.5 vs RA2 22.1 ± 7.7 ml/min, $p = 0.0001$; vs RA3 31.3 ± 12.0 ml/min, $p = 0.001$), mean flow (23.4 ± 17.3 vs RA2 10.2 ± 5.7 ml/min, $p = 0.001$; vs RA3 11.6 ± 8.9 ml/min, $p = 0.001$), minimum flow (11.6 ± 6.5 vs RA2 4.2 ± 3.7 ml/min, $p = 0.01$; vs RA3 4.7 ± 3.3 ml/min, $p = 0.03$), and pulsatility index (0.9 ± 0.8 vs RA2 2.1 ± 1.3, $p = 0.03$; vs RA3 1.7 ± 2.1, $p = 0.04$).

Postoperative troponin I was significantly lower in RA1 at 12 hours ($p = 0.01$ vs RA2 and $p = 0.03$ vs RA3, respectively) and 24 hours ($p = 0.05$ vs RA2 and $p = 0.045$ vs RA3, respectively) (Fig. 2).

Postoperative hand paresthesia was experienced by RA1 (5/61; 8.2%) and RA2 patients (5/63; 7.9%), not by RA3 patients (0/64; $p = 0.048$ vs RA1 and $p = 0.05$ vs RA2, respectively).

Early postoperative intravenous calcium channel blocking agent administration for the management of RA spasm was necessary only in patients who had undergone electrocautery (RA2 12/63; 19.4%) and Potts-scissors sharp dissection (RA3 14/64; 21.8%), never in ultrasonic harvesting technique (RA1 0/61; $p = 0.0002$ vs RA2 and $p = 0.0001$ vs RA3, respectively).

Finally no RA1 patient underwent re-exploration for bleeding compared to RA2 (11.1%; $p = 0.011$) and RA3 (7.8%; $p = 0.02$).

Discussion

Carpentier's first use of RA for CABG was thought to be a failure due to poor early graft patency[2]. However, the interest in this technique was renewed after long-term follow-up showed promising patency of the RA grafts. Since that time many studies have described the successful use and patency of RA conduits for CABG[5-12]. Most of these studies have described the use of an open technique for the RA harvesting. The open technique used in this study was similar to the one described by Reyes et al.[4].

The RA, by definition, is a type III artery[17] which is expected to be more vasospastic compared to other coronary bypass arterial grafts, due to its characteristics of being a type III artery having α-adrenergic receptors, predominantly. The combined thickness of media and intima of the RA is the greatest among the arterial grafts[17]. These properties of the RA are probably the reason for its major disadvantage, which is the propensity to vasospasm. Enhanced reactivity of the RA has been well documented both in clinical and *in vitro* studies. Despite this major drawback, the RA is still an attractive arterial conduit for CABG for several reasons: 1) it is easy to harvest in parallel with the LIMA; 2) it is long enough to be used as a graft for any coronary artery; 3) it is large enough in caliber to match most of the coronary arteries; and 4) it is easy to handle due to its thick muscular wall[17].

Systemic and topical vasodilator drugs are used in routine practice to prevent early graft spasm[3,18]. Our study demonstrated that ultrasonic harvesting of the graft correlated with higher flowmetry values and better pulsatility index compared to the two other traditional techniques, suggesting a better maintenance of vasodilating properties by the RAs of the RA1 group. Accordingly, a recent study by Maruo et al.[19] demonstrated *in vitro* arterial dilation in response to ultrasonic stimulation, to a greater extent due to an endothelium-dependent nitric oxide and prostacyclin release and, and to a lesser extent to an endothelium-independent component, secondary to the interaction of ultrasonic energy with vascular endothelium and smooth muscle cells. The nature of interaction between ultrasonic energy and endothelial cells promoting release of vasoactive substances remains to be defined yet. However, Investigators have observed that cellular changes occurring after

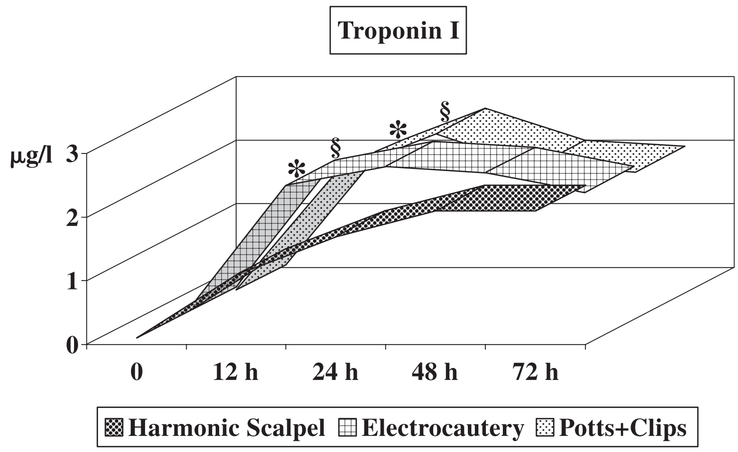

Figure 2. *Troponin I values following coronary artery bypass grafting in the three groups. * p ≤ 0.05 RA1 vs RA2; § p ≤ 0.05 RA1 vs RA3.*

a period of sonication are quite similar to those promoted by mechanical shear stress and cavitation[20]. Moreover, our study demonstrated that intravenous administration of calcium channel blockers since the early postoperative period was accomplished in a significant proportion of patients belonging to RA2 and RA3, but was unnecessary in the subset of patients in whom RA was harvested with the aid of the ultrasonic scalpel. All these findings provide insights into the augmentation of free flow in RAs and the excellent clinical short-term patency rates observed after CABG with arterial grafts harvested with ultrasonic technology. In this scenario, we can speculate that the lower postoperative troponin I leakage in the RA1 group can be attributed to a better preservation of the endothelial-derived vasodilating properties and to the maximized graft flow.

Another technical advantage of ultrasound is the reduced harvesting time compared to traditional techniques. Ultrasonic dissection is associated with transformation of mechanical into thermal energy with plasma protein denaturation, which leads to coagulation and contemporary branch cut. Therefore bleeding from branches is uncommon and usually occurs when the branch is damaged or is rarely recognized later in the operation. All these factors may explain the quickness in arterial conduit harvesting, the lower need for hemostatic clips, and the lower postoperative bleeding complications with this technique.

Finally, it has to be considered that RA harvesting is safe in patients who have a normal collateral circulation to the hand; in fact complications are reported to occur infrequently[21,22]. Studies looking specifically at motor and sensory function of the hand after RA procurement also report objective neurological deficits as being infrequent[21,22]. Our study similarly reported the complete absence of vascular complications, and a low rate of postoperative neurological symptoms, being always temporary and reversible paresthesias of the thenar eminence. However, the lowest rate of neurological complications was found in the RA3 group, maybe because the blunt and sharp dissection with scissors resulted in fewer cutaneous nerves being transected, whereas the use of ultrasonic or electric energy may sometimes result in thermal spread of energy, with lesions of the nerves of the forearm.

In conclusion, these data supported the continued use of RA as a conduit for CABG, and suggested that RA harvesting with harmonic scalpel is faster, allows higher flowmetry values, a lower enzyme release and rarely causes local forearm complications.

Study limitations. An ideal comparison between two treatments should be performed on the basis of a prospective randomized study. Although the study has been prospectively designed no real randomization has been performed. The choice of the harvesting technique was left to the surgeon, being the ultrasonic technology preferred during the last years. There is a time-depending choice of the RA harvesting technique, being the majority of the patients, during the first 2 years of the study, treated with the traditional electrocautery or Potts-scissors/clips techniques, and almost all patients, during the last year, treated with ultrasonic scalpel. However, all surgeons were skilled in the RA harvesting, therefore no learning-curve related bias can be advocated. However, except for the arterial conduit harvesting technique, the pre, intra and postoperative management was unchanged over the entire study period, therefore differences in outcome can be considered secondary to the only changing variable, i.e. the RA harvesting technique itself.

According to transit-time flowmetry, it should be kept in mind that not only the harvesting technique, but also the run-off bed of the grafted coronaries determine the results. However, the TIMI angiographic score was similar among the three groups. Moreover, despite off-pump surgery and Y-grafting may result in different flowmetry patterns, it has to be considered that such cases were uniformly distributed among the three groups, and did not prove to have statistical significance in one of the three groups, so as to be considered as a potential bias.

However prospective randomized trials are needed to definitely demonstrate the superiority of ultrasonic harvesting on the traditional techniques.

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