Long-term digital blood flow after radial artery harvesting for coronary artery bypass grafting\textsuperscript{*}

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Abstract

Objective: The radial artery is widely used as a bypass conduit in coronary artery bypass surgery, but the long-term flow readjustment in the hands and fingers induced by the removal of the radial artery is poorly understood. Methods: Using pulse-volume-recording plethysmography, digital blood flow was measured semiquantitatively in 24 patients immediately after harvesting of the radial artery for coronary artery bypass grafting (short-term group) and reassessed in 15 of these patients 3 years later (long-term group). Measurements taken from the fingers of the operated arms were evaluated and compared to those taken from the opposite or control arms. The short- and long-term changes in digital blood flow were also compared. Results: Postoperatively, there was an overall decrease in blood flow to all the fingers of the operated arms. There was also evidence of redistribution of digital blood flow favoring the thumb and index finger over the fourth and fifth fingers, with the same distribution pattern seen in the fingers of control arms. Over time, the digital blood flow in operated arms recovered to levels similar to those in control arms. Conclusion: The study showed that there was an overall decrease in digital blood flow following radial artery harvesting. The resulting blood supply in the remaining ulnar artery still provided more flow to the thumb and index fingers than to the fourth and fifth fingers, indicating the existence of an autoregulatory mechanism operating to satisfy the physiologic needs of the fingers. The long-term results showed that the overall decrease in distal blood flow immediately after radial artery harvesting was significantly recovered by physiologic adaptation.

Keywords: Radial artery; Coronary artery bypass conduits

1. Introduction

The radial artery is used widely in coronary artery bypass grafting due to its excellent patency rates when used as a bypass conduit [1]. The removal of the radial artery in properly selected patients is considered safe [2–4], but there is limited information on the status of digital flow after radial artery harvesting. There is continuing concern over the occurrence of postoperative circulatory insufficiency of hands and fingers in these patients [5–7].

To address this concern, attempts have been made to assess the adequacy of collateral flow by radial artery compression at the wrist using Doppler ultrasonography [8] or pulse-volume-recording (PVR) plethysmography [2,3,8–10]. These widely used methods, however, are inadequate for assessing the status of postoperative digital blood flow because they measure only the immediate and transient changes in blood flow. Starnes et al. also reported a substantial proportion of false positives and false negatives with these tests [9].

PVR plethysmography has become an important instrument in noninvasive studies of vascular disorders because of its accuracy in measuring the blood flow. Zweifler et al. clearly showed that PVR is a reliable indicator of digital blood flow [11]. Archie and Larson found a 100% correlation between PVR and arteriography [12], and Berger and Kleiner found a 97% correlation between arteriography and various noninvasive methods, including PVR [13].

Lee et al. showed that there is substantial reduction of blood flow to the fingers of the operated arm 7 days after radial artery harvesting, and that the flow to the fingers is redistributed whereby more blood flows to the thumb and index finger than to the fourth and fifth fingers even in the absence of the radial artery [14].

In order to evaluate the circulatory changes over time after removal of the radial artery, we studied digital blood flow by PVR plethysmography in 15 patients for 3 years after they had undergone coronary artery bypass grafting using the radial artery.
2. Materials and methods

Twenty-four patients (18 males, 6 females; age 59.8 ± 7.6 years, mean ± SD), who underwent coronary artery bypass grafting using the radial artery as free grafts at the Severance Hospital, Yonsei University College of Medicine, were included in this study. The digital flow in 15 patients of these patients (11 males, 4 females; age 59.1 ± 7.0 years) was reassessed 39.0 ± 2.5 months after the surgery.

2.1. Radial artery harvesting

The adequacy of the ulnar artery and collateral flow were evaluated preoperatively in three stages. Patients with a positive modified Allen’s test and serum creatinine greater than 2.0 mg/dl were excluded from the study [15]. Hand circulation was then checked again using photoplethysmography with an oxymeter (N-200, Nellcor, NELLCO Inc, Hayward, CA, USA) in the operating room [16,17]. The digital probe of the oxymeter was applied to the thumb, ensuring that the photoelectric sensor was correctly positioned over the nail bed. The radial and ulnar arteries were compressed manually at the wrist for a period of approximately 30 s, which resulted in a flat SpO$_2$ line over the thumb. The compression of the ulnar artery was released and SpO$_2$ was checked again. If the reappearance of the SpO$_2$ curve was delayed by more than 5 s, Allen’s test was considered positive. Radial arteries were harvested from the nondominant left arm in all patients.

As a final check during surgery, the adequacy of ulnar blood flow was determined by ligating and dividing the radial artery proximally and then, after releasing the proximal end, observing the blood flow from the divided end. The presence of a pulsatile flow was arbitrarily used as evidence of an adequate collateral flow. Finally the distal part of the radial artery was tied and divided. The harvested vessel was preserved in heparinized autologous blood mixed with 5.0 ml of 1.0% papaverine.

The radial artery was exposed with a harmonic scalpel (Ultrascision, Smithfield, RI, USA) using a modified version of a previously described protocol [18]. The harvested radial artery was used either as a free graft or as part of a composite Y-graft with the left internal mammary artery. Coronary artery bypass grafting was performed under mild hypothermic (33 °C) cardiopulmonary bypass conditions, and all patients received diltiazem hydrochloride (Herben SR$^{a}$) and nicorandil (Sigmart$^{a}$) postoperatively.

2.2. Pulse-volume recording

PVR plethysmography (MVL Modulab, Life Sciences, HealthWatch Company, Vista, CA, USA) of the arm and the fingers was performed both 7 days and 3 years after the removal of the radial artery. The patients were completely relaxed and the ambient temperature in the laboratory was maintained between 23 and 25 °C to prevent the induction of excessive vasoconstriction by cold air. With the patients in a supine position without sedation, the PVRs were obtained from the upper arms (12 x 23 cm cuffs), proximal forearms (12 x 23 cm cuffs), and wrist (6 x 12 cm cuffs). A pressure of 65 mmHg was applied with 100 ± 15 ml of air. Digital pressure cuffs were then attached to all fingers and the thumb (7 x 2 cm cuffs for most fingers and 9 x 3 cm for larger fingers). Air (5 ± 3 ml) was injected into the cuffs to attain a pressure of 40 mmHg.

2.3. Statistical analysis

The data were analyzed statistically using SPSS for Windows, version 11.0 (SPSS, Chicago, IL, USA). Results are presented as mean and standard deviation. The Wilcoxon signed rank test (paired test) was used to compare differences in digital pulse amplitudes between operated and unoperated arms. Pearson’s $\chi^2$ test or Fisher’s exact test was applied to compare differences in pulse morphology. A probability value of $P<0.05$ was taken as indicative of statistical significance.

3. Results

The pulse morphology was divided into three general categories: normal, no reflected wave, and blunted waveform, representing normal, intermediate, and minimum blood flow, respectively (Fig. 1). The distributions of each category in the fingers of the operated and control arms are shown in Fig. 2. In the short-term, the overall digital flow was lower in the operated arms than in the control arms, as indicated by the increased number of blunted flow waveforms. It was noticeable also that, in the absence of the radial artery, there was still more blood going to the thumb and index finger than to the fourth and fifth fingers. The recovery of digital flow over time is shown in Fig. 2. In the long term, there was no significant difference between control and operated arms in terms of the pulse waveforms.

The pulse-amplitude findings are shown in Fig. 3. In the operated arms, there was again a general decline in the amplitude in all the fingers of the operated arms. Again, as in the fingers of the control arms, the wave amplitude was the greatest in the thumb, gradually tapering to a minimum in the fifth finger. Table 1 showed that the short-term group showed a statistically significant decrease in pulse amplitude in all the fingers, except for the middle finger. The long-term group exhibited an overall increase in the flow amplitude in all fingers.

![Fig. 1. Types of waveforms recorded by pulse-volume-recording plethysmography.](image)
4. Discussion

Evaluating the blood flow of the hand and fingers is difficult because of the dual arterial supply and the complex and inconsistent anastomosing branches. Coleman and Anson stated that a complete arch is present in about 80% of cases, and that in the remaining 20% the collateral flow between the ulnar and radial systems may be inadequate [19]. From a study of 50 cadaver hands, Ruengsakulrach et al. [20] reported that the superficial palmar arch of the ulnar artery supplied blood to all fingers in 66% of the hands and that the deep palmar arch of the radial artery supplied blood in 90% of the hands. They found that there was at least one major branch connecting the radial and ulnar arteries and that, in the absence of vascular disease, harvesting the radial artery should be considered safe. However, that anatomical study did not investigate the actual blood flow through the vessels. Dumanian et al. [21] suggested that

<table>
<thead>
<tr>
<th>Finger</th>
<th>Short-term</th>
<th></th>
<th>Long-term</th>
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<tbody>
<tr>
<td></td>
<td>Nonoperated arm</td>
<td>Operated arm</td>
<td>P*</td>
<td>Nonoperated arm</td>
</tr>
<tr>
<td>First</td>
<td>3.83 ± 3.16</td>
<td>2.08 ± 3.31</td>
<td>0.010</td>
<td>11.8 ± 4.46</td>
</tr>
<tr>
<td>Second</td>
<td>3.25 ± 2.88</td>
<td>1.58 ± 2.32</td>
<td>0.019</td>
<td>6.13 ± 3.04</td>
</tr>
<tr>
<td>Third</td>
<td>2.29 ± 2.63</td>
<td>1.33 ± 2.22</td>
<td>0.081</td>
<td>8.07 ± 5.74</td>
</tr>
<tr>
<td>Fourth</td>
<td>2.25 ± 2.00</td>
<td>1.17 ± 2.50</td>
<td>0.011</td>
<td>7.40 ± 2.92</td>
</tr>
<tr>
<td>Fifth</td>
<td>1.71 ± 2.16</td>
<td>0.67 ± 1.37</td>
<td>0.027</td>
<td>4.67 ± 2.26</td>
</tr>
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Values are mean ± SD (in millimeters).

* Analysis was performed by Wilcoxon signed rank test. P < 0.05 indicates statistical significance.
vascular networks of the hand and fingers act much more like a single vascular bed than a set of semi-independent vascular beds based on the ulnar and radial arteries. They showed that the thumb and fifth fingers reacted in the same way to ulnar artery compression at the wrist, and that the majority of fifth fingers lose pulsatile flow during radial artery compression.

In our study, digital blood flow was measured semiquantitatively using PVR plethysmography, which is considered to be an accurate method of measuring blood flow [11-13]. The flow amplitude was higher in the first finger than in the third, fourth, and fifth fingers in the control group. Also, the flow amplitude was higher in the second finger than in the fifth finger. These data were consistent with those of flow-index differences calculated by photoelectric plethysmography reported by Stead and Stirt [22]. The removal of the radial artery significantly decreased the blood flow to all fingers. It is important to also note that the inflow from the remaining ulnar artery still provided more flow to the thumb and the index finger than to the fourth and fifth fingers, indicating a rapid and substantial readjustment in blood flow to the fingers. This preferential flow to the thumb makes sense since it has a larger tissue mass requiring more blood flow, a pattern seen in both the operated and the control arms. These findings suggest that the vascular bed of the hand and fingers can be considered-functionally-as a single vascular network, allowing redistribution of blood flow between the fingers to satisfy their individual requirements.

Another important factor that should be considered in the evaluation of digital blood flow is the change in size of the inflow vessel, the ulnar artery, after removal of the radial artery. Brodman et al. [23] reported that radial artery removal resulted in an 11% increase in diameter of the ulnar artery and a 20% increase in blood flow velocity (as measured by color flow and pulsed Doppler scanning, respectively). Similarly, Pola et al. [2] reported increased blood-flow velocity in the ulnar artery within 10 days and again at 1 year after radial artery harvesting.

As regards serious complications following radial artery harvesting, Nunoo-Mensah reported a patient who developed acute ischemia in spite of perioperative studies showing adequate collateral vessels. Angiography revealed the absence of the ulnar artery, and vessel continuity was re-established by a vein graft [24]. Fox et al. reported a patient who developed acute upper limb ischemia despite adequate preoperative and intraoperative assessment with Allen’s test, hand-held Doppler, and radial artery back-bleeding. The condition was successfully treated with a brachial bypass using a reversed vein graft [25]. Fortunately such complications are rare in properly selected patients. Clinically, all of our patients did well, despite an overall decrease in the digital blood flow in the operated arms. Compensatory increases in the ulnar blood flow combined with redistribution of the digital blood flow adequate to meet the physiologic demands of the hands and fingers may explain the relatively benign outcomes.

In conclusion, this study shows that there is substantial reduction of blood flow to the fingers of the operated arm 7 days after radial artery harvesting, and that there is redistribution of flow to the fingers whereby more blood goes to the thumb and the index fingers than to the fourth and fifth fingers even in the absence of the radial artery. Long-term results showed that the overall decrease in the distal blood flow immediately after radial artery harvesting significantly recovers by physiologic adaptation. This implies the existence of abundant collateral channels between the two arteries and an autoregulatory mechanism whereby blood flow to the fingers is determined by the physiologic needs of individual fingers.

Acknowledgements

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References


Appendix A. Conference discussion

Dr S. Hagl (Heidelberg, Germany): Have you had any problems seen with the fourth and fifth fingers in your patients?

Dr Lee: There was no ischemia.

Dr Hagl: No ischemia?

Dr Lee: Yes.