Redistribution of digital perfusion after radial artery harvesting in coronary artery bypass grafting

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Directed by Professor Sang Ho Cho

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This certifies that the Master's Thesis

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ABSTRACT

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Introduction Removal of the radial artery would necessitate adequate ulnar artery blood flow to the hand to prevent hand and digital ischemia. There is little information of the effect of radial artery harvesting in patients of coronary artery bypass grafting on the postoperative blood flow to the digits.

Materials and Methods This prospective study examined digital perfusion postoperatively in 24 patients who underwent coronary artery bypass grafting with radial artery free grafts in the Severance Hospital, Yonsei University College of Medicine. Digital perfusion was measured with pulse volume recording plethysmography. At the initiation of this study, to confirm the non-operated arms as controls, dominant and non-dominant arms in ten volunteers were compared in flow differences.

Results The pulse amplitude and morphology showed no significant differences between the dominant and non-dominant arms in ten volunteers.

The pulse morphology of all digits in non-operated arms, and first and second fingers in operated arms, was composed mainly of normal or reflected wave absent pattern. But the majority of the morphology in fourth and fifth fingers in operated arms revealed a marked blunted pattern (65%). The pulse amplitudes of the first, second, fourth and fifth fingers on the operated arms were decreased compared to those on non-operated arms (all $p<0.05$). On the operated arm, pulse amplitudes of the first and second fingers were much more increased than those of the fifth fingers, in spite of radial artery removal ($p < 0.05$). Digital perfusion after radial artery harvesting maintained the same patterns as that in non-operated arms where first and second fingers had a more abundant digital perfusion than the fifth fingers. Postoperatively, no hand ischemia was noted.

Conclusions This study identified a more significant reduction of digital perfusion on the fourth and fifth fingers rather than the first and second fingers on the operated arms after radial artery harvesting. These results suggest that digits and hands have an auto-regulation of blood flow between the radial and ulnar systems after radial artery harvesting.

Key words : radial artery, coronary artery bypass grafting, plethysmography

Redistribution of digital perfusion after radial artery harvesting in coronary artery bypass grafting

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I. Introduction

The incidental detection of patency of radial artery (RA) grafts has led to its revival as an important conduit in coronary artery bypass grafting (CABG).[1] Recently the RA graft is being used increasingly as an alternative to the saphenous vein for CABG because of the high patency rates and superior flow characteristics.[2]

Removal of the RA would necessitate adequate ulnar artery blood flow to the hand to prevent symptoms of hand and digital ischemia. There is little information of the effect on the postoperative blood flow to the digits after RA harvesting in patients who underwent CABG.[3-5] Anxiety over the appearance of inadequate collateral circulation may limit harvesting of the RA. Inadequate collateral circulation can result in complications and ultimately amputation as a result of arterial insufficiency.[6-8]

The perfusion of digits after RA harvesting in CABG has not yet evaluated. Some reported a preoperative assessment of hand circulation by RA compression at wrist with Doppler ultrasonography or pulse volume recording plethysmography.[3, 4, 9-11] However, the study through RA compression showed immediate and transient changes of hand circulation, and Doppler studies are limited because they can only effectively evaluate the superficial palmar arch. Preoperative and postoperative comparisons of digital perfusion would have no significance, given that Dumanian et al[4] reported that the postoperative digital-brachial index for the index finger and the fifth finger was statistically lower in comparison with preoperative values for both the operated and the non-operated arms, and that Starnes and associates showed that mean preoperative and postoperative digit pressure changes in non-operated arms were significantly different.[9]

Pulse volume recordings (PVR) have become an important part of noninvasive studies of vascular disorders. Digital plethysmography was used to determine preoperatively which hand was critically supplied for blood flow by the radial artery. The PVR studies are painless, quick, produce a print-out of results, and require only one person to administer. Zweifler et al[12] have clearly shown that PVR is a reliable indicator of digital blood flow. Archie and Larson compared plethysmography and PVR with arteriography and found a 100% correlation.[13] Berger and Kleinert found a 97% correlation between arteriography and various noninvasive modalities that included PVR.[14]

Therefore, we planned a postoperative comparison between operated and non-operated arms after proving no differences of digital perfusion between dominant and non-dominant arms, to determine the changes of digital perfusion in response to the loss of the RA with pulse volume recording plethysmography.

II. Materials and Methods

1. Patients

At the initiation of this study, to confirm the non-operated arms as controls, dominant and non-dominant arms in ten volunteers were compared in the digit and forearm flow differences by pulse volume recording (PVR) plethysmography (MVL Modulab, Life Sciences, Inc., HealthWatch Company, USA) (Figure 1.).

Figure 1. Pulse volume recording plethysmography.

Two hundreds and forty digits from twenty four patients who underwent CABG with RA free grafts at the Severance Hospital, Yonsei University College of Medicine were included in this study. Preoperative exclusion criteria for RA harvesting were the positive modified Allen's test and serum creatinine greater than 2.0 mg/dL.[15] Informed consent for RA harvesting was obtained preoperatively from all patients.

Radial arteries were harvested from the non-dominant arms (all left arms). Operated arms were defined as those upper extremities from which the RAs were harvested; non-operated arms were defined as those upper extremities from which the RAs were not harvested.

2. Assessment of hand circulation before RA harvesting

Preoperative assessment of hand circulation was performed using photo-plethysmography with oxymeter (Nellcor, N-200, USA) in the operation theater.[16,17] The oximeter's digital probe was applied to the thumb, ensuring that the photoelectric sensor was correctly positioned over the nail bed. The RA was compressed manually at the wrist, and compression of the RA was maintained for a period of approximately 30 seconds. A flat line of the SpO_2 to the thumbnail bed was obtained. The compression of ulnar artery was released and SpO_2 was checked within 5 seconds. When the SpO_2 was checked over 5 seconds, Allen's test was regarded as positive and the RA was not harvested.

Intraoperative assessment of ulnar artery blood supply to the hand was performed before removing the RA from the forearm. During RA harvesting, the proximal end part of the RA was ligated and divided first. The pulsatile flow was examined with the release of the proximal site of the harvested RA. The presence of a pulsatile flow was arbitrarily used as evidence of adequate collateral flow. Finally the distal part of the RA was ligated and divided. The harvested RA was prepared with heparinized autologous blood mixed with 1 % papaverine 4 cc.

3. Surgical techniques

RAs were exposed using a modified protocol with a harmonic scalpel (Ultracision Inc, Smithfield, RI, USA).[18,19] The RA was used as an aortocoronary bypass or as a composite Y-graft with left internal mammary artery. CABG was performed under mild hypothermia (33°C) with cardiopulmonary bypass (CPB). Postoperatively diltiazem hydrochloride (Herben SR®) and nicorandil (Sigmart®) were administered to all patients. In this study, to keep the same surrounding circumstances among patients, all subjects underwent CABG under CPB, and took a calcium channel blocker.

4. Pulse volume recording

The patients were completely relaxed during the study. The room temperature in the laboratory was maintained at between 23℃ and 25℃ because a cold room will cause excessive vasoconstriction. Likewise, muscle tension will cause artifacts in pulse morphology. Therefore, the plethysmography was performed in the comfortable supine position. Pulse volume recordings were obtained from the upper arms (12 cm x 23 cm cuffs), proximal forearms (12 cm x 23 cm cuffs), and the wrist (6 cm x 12 cm cuffs). A pressure of 65 mm Hg was reached with 100 ± 15 ml of air. Digital pressure cuffs were then attached to all fingers and the thumb (7 cm x 2 cm cuffs for most fingers and 9 cm x 3 cm for larger fingers). Air, 5 ml ± 3ml, was injected into the cuffs to reach 40 mm Hg pressure. The recordings process was then obtained.

5. Data collection

Pulse volume recording plethysmography was performed seven days after the operation. The pulse morphology and amplitude of digits on both arms were evaluated and compared. Digital pulse morphology is classified in three categories of normal, reflected wave absent, and marked blunted (Figure 2.). The postoperative clinical evaluation included examination for compromise in hand function, including strength, grip, ability to perform fine motor functions, and hand ischemia.

6. Statistical analysis

Analysis of the data was performed with SPSS for Windows, version 11.0 (SPSS, Inc, Chicago, Ill). Results are presented as mean and standard deviation. The Wilcox signed ranks test (paired test) was used to compare differences in digit pulse amplitudes between operated and non-operated arms. Pearson's χ^2 test or Fisher's exact test was applied to compare differences in pulse morphology.

Normal | Absence of Reflected Wave | Marked Blunted

Figure 2. Pulse volume recording plethysmographic pulse morphology. A normal pulse morphology is characterized by rapid systolic up-slope, a sharp systolic peak, and a diastolic down-slope with a dicrotic wave. An absense of reflected wave pulse morphology has a rapid ascending limb, an anacrotic notch, and a dicrotic notch high on the down-slope. A marked blunted pulse morphology has a delayed up-slope, a rounded peak, and a convex down-slope that bows away from the baseline.

II. Results

In ten normal volunteers for determination of non-operated arms as the control, the pulse amplitude and morphology showed no significant differences in the brachial, forearm, wrist, hand, first, second, third, fourth and fifth fingers between the dominant and non-dominant arms. For this reason, non-operated arms served as the control group in this study.

The mean ages of the 24 patients were 59.8 ± 7.6 years. There were 18 males and 6 females patients. Mean left ventricular ejection fraction was 50.9 % ± 17.9%. The mean number of grafts for CABG was 3.25 ± 0.53. Table 1 showed the frequency of pulse morphology patterns. In the control group, the morphology between first and fifth fingers, second and fifth fingers, and third and fifth fingers showed significant differences.

In the operated arms, the morphology between first and fourth fingers, first and fifth fingers, and second and fifth fingers showed significant differences. In comparison of the morphology between the control and operated arms, pulse morphology of all digits was significantly different.

Table 1. Frequency of pulse morphology in digits of the operated and non-operated arms[1]

Pulse morphology[2]	First finger		Second finger		Third finger		Fourth finger		Fifth finger	
	C	Op	C	Op	C	Op	C	Op	C	Op
Normal	11	6	8	5	7	5	6	2	5	2
RWA	13	13	16	13	17	10	15	8	11	5
Marked blunted	0	5	0	6	0	9	3	14	8	17

[1] Operated arms were defined as those upper extremities from which the radial arteries were harvested and non-operated arms (control) were defined as those upper extremities from which the radial arteries were not harvested.

[2] Digital pulse morphology is classified in three categories of normal, reflected wave absent, and marked blunted.

C : control arms, Op : operated arms, RWA : absence of reflected wave.

In the control group, the amplitude of the first fingers was higher than those of the third, fourth, and fifth fingers. Also, the amplitude of the second fingers was higher than that of the fifth fingers. In the operated arms, the amplitudes of first and second fingers were higher than that of the fifth fingers. Mean amplitudes were significantly lower in the first, second, fourth and fifth fingers in operated arms than in control arms. Serious decline of the amplitude in the fifth fingers of operated arms was remarkable (Table 2). In the third fingers of operated arms, there was no significant decrease of amplitude, but the mean amplitude between control and operated arms as 2.29 ± 2.63 mm and 1.33 ± 2.21 mm showed itself to be quite different ($p = 0.081$) (Table 2). Figure 3 shows the mean amplitudes of all fingers in control and operated arms. In the control arms, distribution of amplitudes had a significant negative correlation with digits ($r = -0.279$, $p = 0.002$). Also, there was the same distribution in the operated arms ($r = -0.165$, $p = 0.038$).

Digital plethysmography of the forearm and digital perfusion revealed no evidence of significant ischemia. After RA harvesting, there was no loss of fine or gross motor function, nor did patients have functional limitations. One patient reported transient dysesthesia in operated extremity along the distribution of the superficial branch of the radial nerve, which was not vascular in cause.

Table 2. Comparison of pulse amplitudes between the operated and non-operated arms[1]

Variables	Non-operated arm Amplitude	Operated arm Amplitude	Decline ratio[2]	*P**
First finger	3.83 ± 3.16	2.08 ± 3.31	0.42 ± 0.87	0.010
Second finger	3.25 ± 2.88	1.58 ± 2.32	0.35 ± 1.17	0.019
Third finger	2.29 ± 2.63	1.33 ± 2.22	0.51 ± 0.72	0.081
Fourth finger	2.25 ± 2.00	1.17 ± 2.50	0.61 ± 0.52	0.011
Fifth finger	1.71 ± 2.16	0.67 ± 1.37	0.78 ± 0.40	0.027

[1] Values are mean ± SD in millimeters. Operated arms were defined as those upper extremities from which the radial arteries were harvested and non-operated arms (control) were defined as those upper extremities from which the radial arteries were not harvested.

[2]

$$\text{Decline ratio} = \frac{\text{the amplitude (non-operated arm – operated arm)}}{\text{the amplitude of non-operated arm.}}$$

[*] Analysis was performed by Wilcox signed ranks test. A value of p <0.05 was taken as significant.

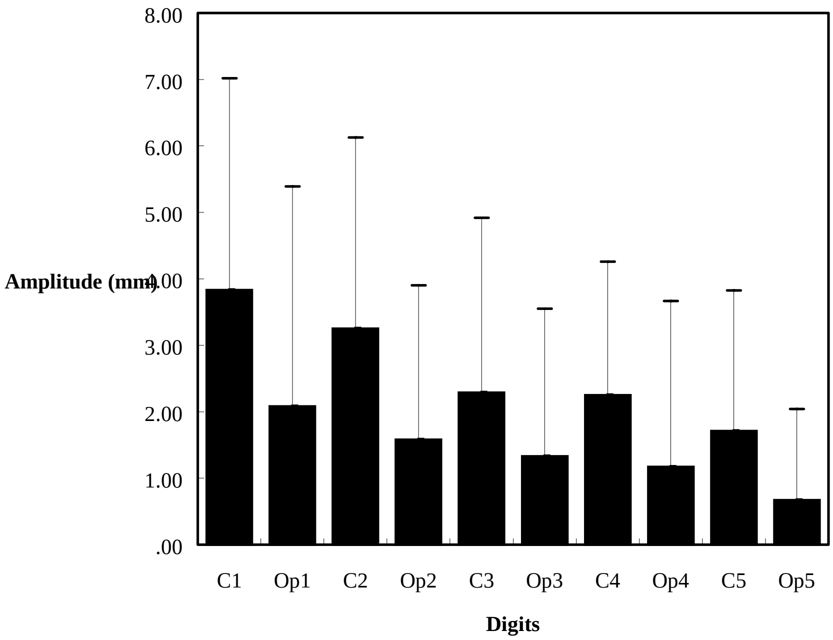

Figure 3. Comparison of digital pulse amplitudes between operated and non-operated arms. In the operated arms, the amplitudes of first and second fingers were higher than that of the fifth fingers. Mean amplitudes were significantly lower in the first, second, fourth and fifth fingers in operated arms than in control arms. Digital perfusion after RA harvesting had the same patterns as those in the hand without RA harvesting where the first and second fingers had more abundant perfusion than the fifth fingers.

C: control arms, Op: operated arms, 1: first finger, 2: second finger, 3: third finger, 4: fourth finger, 5: fifth finger.

IV. Discussion

Evaluation of the actual anatomy of the hand is difficult because of the complexity of the anatomy and various anastomosing branches. Coleman and Anson[20] stated that a complete arch is present in about 80% percent of cases, and so in 20% of hands the collateral flow between the ulnar and radial systems would possibly be inadequate. The thumb, index finger and the radial side of the middle finger derive their supply from the deep arch, or radial artery. The ulnar side of the middle finger, the ring finger, and the little finger collectively are supplied almost exclusively from the superficial arch, which means by the ulnar artery (UA). In this 20% of hands in particular, the thumb blood flow is primarily from the radial artery and the fifth finger blood flow primarily from the ulnar artery. Coleman and Anson predicted that the thumb and fifth finger should act differently to radial and ulnar artery compression at the wrist.[20]

Ruengsakulrach et al[21] reported that the most common variant of the ulnar artery is the complete superficial palmar arch in 66% defined when it supplied all the fingers and the ulnar side of the thumb, and the complete deep palmar arch in 90%. Even though the superficial palmar branch of the ulnar artery did not supply the thumb in about 34% of hands, a complete deep palmar arch was present in all of these hands (Figure 4.).

There were four types of this communication between the superficial palmar branch of the ulnar artery and the radial artery at the level of the arches (Figure 5.). Similarly, even though an incomplete deep palmar arch was found in 10%

of hands, all of these cases had a complete superficial palmar arch. They suggested that the size of the superficial palmar arch was inversely proportional to that of the deep palmar arch.[21] This implies that the thumb receives its blood supply from the UA at the ulnar side after RA harvesting. These anatomical structures would be possible for the hand to regulate circulation automatically such as single vasculature.

However, Dumanian and associates[22] suggested that 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 the index and fifth fingers acted statistically similarly to ulnar artery compression at the wrist and the majority of fifth fingers lose pulsatile flow with radial artery compression when the thumb loses its blood flow. In this study, the amplitude of the first fingers was higher than those of the third, fourth, and fifth fingers in the control group. Also, the amplitude of the second fingers was higher than that of the fifth fingers. These data were consistent with those of flow index difference calculated by photoelectric plethysmography reported by Stead and Stirt.[23] Digital perfusion in all fingers was markedly decreased after RA harvesting with no changes of perfusion in wrist and palm. It was quite different from what Coleman and Anson predicted[20] – that perfusion on thumb and index fingers was much more increased than that of the fifth fingers in spite of RA removal. Also, this study showed that digital perfusion after RA harvesting had the same patterns as those in the hand without RA harvesting where the thumb and index fingers had more abundant perfusion than the fifth fingers. Therefore, this study supports the hypothesis that the hand acts more like a single vascular bed than it does like two vascular systems potentially connected by a complete arch. It is proposed that the hand had an auto-regulation of blood flow between the radial and ulnar systems after RA harvesting in the direction where it was more in demand. This auto-regulation could occur through the deep palmar arch, which has a high incidence of completeness, or it could be through numerous unnamed arteries to the tissues of the hand.

Brodman and colleagues[24] demonstrate the growth of the ulnar artery diameter and flow velocity to compensate for the loss of the RA's contribution to the hand's blood supply. Ulnar artery diameter, preoperatively to postoperatively, in the arms from which the RA was harvested, had an 11% increase by color flow Doppler scanning. Ulnar artery blood flow velocity, as measured with pulsed Doppler scanning, increased by about 20% postoperatively. There was a significant increase of the ulnar artery diameter preoperatively to postoperatively in the operated extremities. Corresponding to the significant increase in ulnar artery diameter, postoperative ulnar artery velocity was significantly increased in the operated arms. This auto-regulation system of the ulnar artery should aid digital perfusion. As a matter of fact, Toschka and associates observed a statistically significant impairment of finger-to-thumb pinch strength only for the little finger in the group of patients of radial forearm flap harvesting.[8]

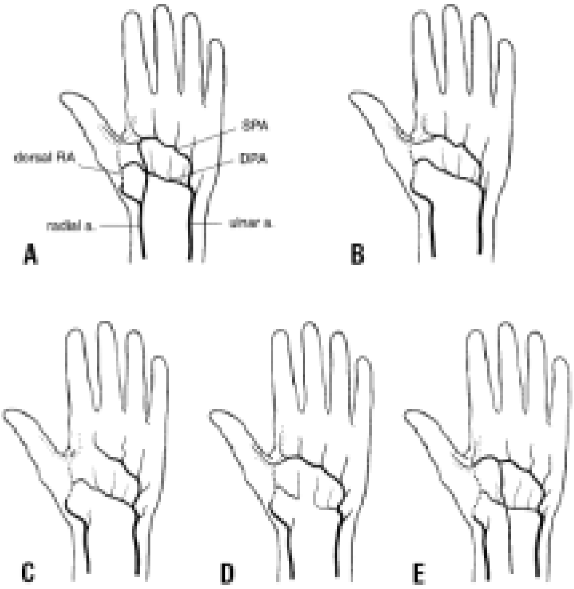

Figure 4. Variations of the hand collateral circulation, palmar aspect of left hand[22]. A, Classic (and complete) superficial palmar arch: the superficial palmar arch from the UA supplies the index finger and thumb and anastomoses with the superficial palmar branch of the RA. B, Complete superficial palmar arch: the superficial palmar arch from the UA supplies the thumb. Complete deep palmar arch: the distal end of the deep palmar arch anastomoses with the deep palmar branch of the UA. C, Incomplete superficial palmar arch: the superficial palmar arch does not provide a metacarpal branch to supply the thumb. D, Incomplete deep palmar arch: no continuity is found between the deep palmar branch of the UA and the RA. E, Median artery.

SPA: superficial palmar arch, DPA: deep palmar arch.

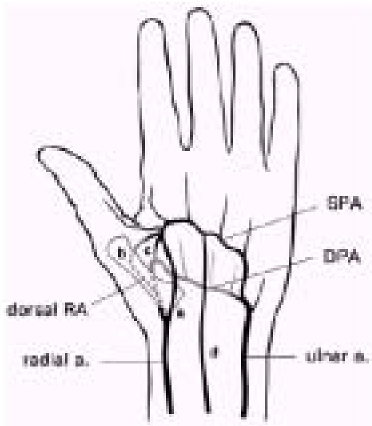

Figure 5. Four types of communication between the superficial palmar arch of the ulnar artery and the radial artery in the hand. *a*, through superficial palmar branch of RA (10%) ; *b*, through deep palmar arch (4%); *c*, through digital branch of the dorsal RA (18%); *d*, through median artery and digital branch of the dorsal RA (2%).

SPA: superficial palmar arch, DPA: deep palmar arch.

A physiologically complete palmar arch system and growth of the ulnar artery in velocity and diameter are essential prerequisites for RA harvesting. Clinically, blood flow remains adequate to meet the physiologic demands of the hand without causing hand ischemia or functional limitations. Thus, compensatory auto-regulation available to maintain blood flow and perfusion appear adequate after RA harvesting in properly selected patients to sustain arterial inflow to the digits and hand without clinical functional limitations.

Despite a high incidence of loss of pulsatile digital blood flow after RA harvesting there are relatively few reports of hand ischemia.[25, 26] Hand ischemia resulting in tissue loss is indeed rare, but what must be evaluated instead during follow-up after RA harvesting is the relative hand ischemia in the fourth and fifth fingers, including cold intolerance, cold-induced reduced grip strength, hand claudication and digital ulcerative lesions.

V. Conclusion

Radial artery graft has been increasingly used as a valuable conduit for CABG. This study is to evaluate the effect on the postoperative blood flow to the digits after RA harvesting in patients who underwent CABG.

The pulse morphology of all digits in non-operated arms, and first and second fingers in operated arms, was composed mainly of normal or reflected wave absent pattern. The majority of the morphology in fourth and fifth fingers in operated arms revealed a marked blunted pattern. The pulse amplitudes of the first, second, fourth and fifth fingers on the operated arms were decreased compared to those on non-operated arms. On the operated arms, pulse amplitudes of the first and second fingers were much more increased than those of the fifth fingers, in spite of radial artery removal.

This study identified a more significant reduction of digital perfusion on the fourth and fifth fingers rather than the first and second fingers in the operated arms. Digital perfusion after radial artery harvesting maintained the same patterns as that in non-operated arms where first and second fingers had a more abundant digital perfusion than the fifth fingers. However, there were no ischemic complications after RA harvesting. It is thought that digits and hands have an auto-regulation of blood flow between the radial and ulnar systems after RA harvesting. Finally, postoperative long-term follow up about the changes of digital blood flow would be necessary.

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ABSTRACT (IN KOREAN)

관상동맥 우회로술시 요골동맥 적출후 수지부 순환

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이 현 성

서론 관상동맥 우회로술에서 요골동맥 사용시 수지부의 허혈을 피하기 위해서는 척골동맥의 적절한 순환이 필수적이다. 술후 수지부 순환에 대한 요골동맥 적출의 영향은 아직까지 명백히 밝혀지지 않았다.

재료 및 방법 이 전향적 연구는 연세대학교 의과대학 세브란스 병원에서 요골동맥 이식편을 사용하여 관상동맥 우회로술을 시행 받은 24 명의 환자에서 수지부의 순환을 평가하였다. 수지혈류 측정은 비침습적인 방법인 플래시스모그래피를 이용하였다. 이 연구의 시작에 있어 비수술부위의 팔을 대조군으로 삼기 위하여 10 명의 자원자에게서 우위성팔과 비우위성팔에서 순환의 차이를 비교하였다.

결과 10 명의 자원자에서 맥박의 고도와 형태는 우위성 팔과 비우위성 팔에서 의미있는 차이를 보이지 않았다.

비수술부위 팔의 모든 수지와 수술부위 팔의 첫번째와 두번째 수지의

맥박 형태는 주로 정상이거나 반향파가 소실된 형태를 보였다. 그러나 수술부위 팔의 네번째와 다섯번째 수지부의 맥박 형태가 대부분 심하게 둔화되어 있음을 보였다. 수술부위 팔의 첫번째, 두번째, 네번째, 다섯번째 수지부의 맥박 고도는 비수술 부위와 비교하여 의의있게 감소하였다 ($p<0.05$). 수술부위 팔에서 첫번째와 두번째 수지는 다섯번째 수지의 고도에 비해 의의있게 증가된 맥박 고도를 지녔다 ($p<0.05$). 요골동맥 적출 후의 수지부 순환은 비수술부위의 수지부 순환처럼 첫번째와 두번째 수지부가 다섯번째보다 훨씬 풍부한 수지부 순환을 지녔다.

결론 이 연구는 요골동맥 적출후 수술부위 팔에서 첫번째와 두번째 수지보다 네번째와 다섯번째 수지에서 순환이 더 의미있게 감소함을 보였다. 이는 수지부와 수부에서 요골동맥 적출후 요골동맥과 척골동맥 시스템 사이의 완전 연결과 혈류의 자동조절이 기인하리라 생각된다.

핵심되는 말; 요골동맥, 관상동맥 우회로술, 플래시스모그래피