

## NONINVASIVE EVALUATION OF HAND CIRCULATION BEFORE RADIAL ARTERY HARVEST FOR CORONARY ARTERY BYPASS GRAFTING

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**Objective:** Radial artery harvesting for coronary artery bypass may lead to digit ischemia if collateral hand circulation is inadequate. The modified Allen's test is the most common preoperative screening test used. Unfortunately, this test has high false-positive and false-negative rates. The purpose of this study was to compare the results of a modified Allen's test with digit pressure change during radial artery compression for assessing collateral circulation before radial artery harvest. **Methods:** One hundred twenty-nine consecutive patients were studied before coronary artery bypass operations. A modified Allen's test was performed with Doppler ultrasound to assess blood flow in the superficial palmar arch before and during radial artery compression. A decreased audible Doppler signal after radial artery compression was considered a positive modified Allen's test. First and second digit pressures were measured before and during radial artery compression. A decrease in digit pressure of 40 mm Hg or more (digit  $\Delta P$ ) with radial artery compression was considered positive. **Results:** Seven of 14 dominant extremities (50%) and 8 of the 16 nondominant extremities (50%) with a positive modified Allen's test had a digit  $\Delta P$  of less than 40 mm Hg (false positive). Sixteen of 115 dominant extremities (14%) and 5 of 112 nondominant extremities (4%) with a negative Allen's test had a digit  $\Delta P$  of 40 mm Hg or more with radial artery compression (false negative). **Conclusion:** Use of the modified Allen's test for screening before radial artery harvest may unnecessarily exclude some patients from use of this conduit and may also place a number of patients at risk for digit ischemia from such harvest. Direct digit pressure measurement is a simple, objective method that may more precisely select patients for radial artery harvest. Additional studies are needed to define objective digital pressure criteria that will accurately predict patients at risk for hand ischemia after radial harvest. (*J Thorac Cardiovasc Surg* 1999;117:261-6)

The radial artery (RA) conduit for coronary artery bypass grafting (CABG) was introduced by Carpentier and colleagues in 1973.<sup>1</sup> Currently, the long-term patency rates for the RA grafts approach those of the internal thoracic artery graft, and these conduits are being used increasingly in preference to autogenous saphenous vein.<sup>2,3</sup> The Allen's test is the most commonly used screening method for evaluation of the adequacy of col-

lateral hand circulation before RA harvest for CABG.<sup>3,4</sup> Shortcomings of the Allen's test have been recognized.<sup>5</sup> The assessment of digit pressures with RA compression may represent a more objective test for determining collateral hand circulation. The purpose of this study was to compare the modified Allen's test with digit pressure measurements before and during RA compression in patients undergoing preoperative evaluation for RA harvesting.

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## Methods

One hundred twenty-nine consecutive patients referred to the noninvasive vascular laboratory at St Joseph Mercy Hospital for preoperative evaluation of hand circulation before CABG were included in this study (October 1996 through October 1997). Institutional Review Board approval was granted. Informed consent was obtained from each patient. All testing was done by 2 registered vascular technologists. Complete noninvasive upper extremity arterial evaluation consisting of segmental pressure measurements and arterial Doppler waveform analysis was performed first to rule out significant subclavian, axillary, or brachial artery stenosis.

A modified Allen's test was then performed with an 8-MHz continuous wave Doppler probe (model 3000-LA; Parks Mini Lab IV, Aloha, Ore) to locate and evaluate blood flow in the superficial palmar arch (SPA). The tip of the probe was placed on the palmar surface of the hand opposite the third metacarpal head and moved proximally until a biphasic arterial Doppler signal was heard. A second 8-MHz Doppler probe was placed over the RA to confirm complete occlusion. The audible SPA signal was assessed before and during RA compression. A decrease in the audible Doppler signal with RA compression was considered a positive modified Allen's test. No change or an increase in the signal was considered a negative result.

Reduction in digital artery systolic pressure with RA compression (digit  $\Delta P$ ) was assessed by measuring the first and second digit pressures before and during RA compression with a 2.5-cm digit pressure cuff placed on the proximal phalanx. A light emitting diode photoplethysmography probe (model 1050-A; Parks Medical Electronic Inc, Aloha, Ore) was placed on the distal phalanx to detect blood flow. For the purpose of this study, a digit  $\Delta P$  that was equal to or greater than 40 mm Hg in either digit with RA compression was empirically chosen as a positive result. A temperature-sensitive Sharn Crystalline Temperature Trend Indicator Strip (model 5101b; Symedco, Tampa, Fla) was placed on the index finger to ensure that the subject's skin digit temperature was kept between 36°C and 37.5°C during the testing. If the skin temperature was less than 36°C, a heating pad was placed on the hand and monitored until the skin temperature was in the designated testing range.

Fifty-two of the 129 patients underwent RA harvesting for CABG and were re-evaluated 6 weeks after the operation. The modified Allen's test and digit  $\Delta P$  with RA compression were again obtained in the nondonor extremity. In addition, the SPA signal and absolute digit pressures were measured in the donor extremity. Patients were asked to fill out a questionnaire regarding symptoms of hand ischemia.

Descriptive statistics (mean  $\pm$  SD for age; frequencies for gender) were compiled on demographic variables. All statistical analyses were conducted with SPSS 6.1 for Windows (SPSS Inc, Chicago, Ill) and SAS system version 6.12 (SAS Institute Inc, Cary, NC).

To determine the point that optimized the dichotomy of digit  $\Delta P$  with respect to its being predicted by the results of the modified Allen's test, comparisons of receiver operator

characteristic (ROC) curves were performed. This was done statistically by comparing areas under the ROC curves (plot of sensitivity [the true-positive rate] versus 1-specificity [the false-positive rate]) to obtain a value of digit  $\Delta P$  that produced the highest combination of specificity and sensitivity when the modified Allen's test is used as a predictor. The area under the ROC curve is a measure of the capacity of the modified Allen's test to correctly identify those patients having a positive or negative classification of digit  $\Delta P$  for a given dichotomy.

The modified Allen's test in this study was used as a predictor of the dichotomized digit  $\Delta P$ .  $\chi^2$  Analysis was used to test for a statistically significant association between the dichotomized digit  $\Delta P$  and the modified Allen's test. A false-negative result was an extremity with a negative modified Allen's test but a digit  $\Delta P$  greater than a specified value. A false-positive result was an extremity with a positive modified Allen's test having a digit  $\Delta P$  less than or equal to a specified value.

To assess the reproducibility of digit  $\Delta P$  measurements over time, digit  $\Delta P$  was measured in 10 normal volunteers at 2 time points (baseline and 1 hour later). The reliability of digit  $\Delta P$  was examined by Pearson's correlation coefficient, paired *t* tests, and concordance correlation coefficient for baseline versus 1-hour measurements.<sup>6</sup> Pearson's correlation coefficient measured the overall level of association between baseline and 1-hour digit  $\Delta P$  tests. Paired *t*-tests assessed whether a significant mean difference between the baseline and 1-hour pressure change existed. The concordance coefficient was used as an omnibus measure of the association between the 2 measurements, accounting for variation and bias. Alpha of .05 was considered to be the level of statistical significance.

## Results

Results of the modified Allen's test and digit pressure measurements are shown in Tables I and II. Both extremities were studied in all 129 patients. The nondominant extremity of one patient was excluded because of the presence of a hemodynamically significant subclavian artery stenosis. Therefore 257 extremities were included for analysis. The study group included 107 men and 22 women. Mean  $\pm$  SD age was 60.5  $\pm$  10.3 years (range, 36–84 years).

Measurement of digit  $\Delta P$  was found to be reproducible. Scatter plots of digit  $\Delta P$  at baseline versus digit  $\Delta P$  at 1 hour for the dominant hand (first and second digits) and the nondominant hand (first and second digits), respectively, are presented in Fig 1. Validation testing performed in 10 healthy volunteers suggested that the first and second digit  $\Delta P$  were reproducible from the baseline to the 1-hour tests. The Pearson's correlation coefficients were all highly statistically significant (dominant hand, first and second digits:  $r = 0.675$ ,  $P = .0321$ , and  $r = 0.806$ ,  $P = .005$ , respectively; nondomi-

**Table I.** Results of Allen's test and digit  $\Delta P$  for dominant extremity

Allen's test	Digit $\Delta P \geq 40$	Digit $\Delta P < 40$	Total
Positive	7	7	14
Negative	16	99	115
TOTAL	23	106	129

\* $\Delta P$  is the change in digit pressure with RA compression.

nant hand, first and second digits:  $r = 0.895$ ,  $P = .0005$ , and  $r = 0.841$ ,  $P = .002$ , respectively). No paired  $t$  test was statistically significant, indicating that the mean difference between the baseline and 1-hour digit  $\Delta P$  was not significantly different from 0 mm Hg (dominant hand, first and second digits:  $P = .500$  and  $P = .45$ , respectively; and nondominant hand, first and second digits:  $P = .271$ , and  $P = .140$ , respectively). The concordance coefficients indicated moderate agreement (dominant hand, first and second digits:  $r_p = 0.598$  and  $r_p = 0.701$ , respectively; and nondominant hand, first and second digits:  $r_p = 0.781$  and  $r_p = 0.725$ , respectively).

On the basis of the ROC curve analysis, it was determined that the modified Allen's test was most accurate at predicting the outcome of digit  $\Delta P$  when digit  $\Delta P$  was dichotomized at 40 mm Hg for the nondominant hand and at 36 to 37 mm Hg for the dominant hand. With the value of 40 mm Hg for the dichotomy, a sensitivity of 50.0%, a specificity of 96.4%, an accuracy of 90.6%, and an area under the curve (ROC) of 0.732 were obtained for the nondominant side. The results for the dominant hand were similar with the best dichotomy of digit  $\Delta P$  of 36 to 37 mm Hg, resulting in a sensitivity of 57.1%, a specificity of 85.2%, an accuracy of 82.2%, and area under this curve of 0.680.

The  $\chi^2$  tests resulted in statistically significant associations between digit  $\Delta P$  dichotomized at 40 mm Hg and the modified Allen's test in the dominant hand ( $P = .001$ ) and the nondominant hand ( $P = .0001$ ).

A positive modified Allen's test was noted in 14 dominant extremities (10.9%) and 16 nondominant extremities (12.5%). Of these extremities with a positive modified Allen's test, 7 of 14 dominant extremities (50.0%) and 8 of 16 nondominant extremities (50.0%) had digit  $\Delta P$  of less than 40 mm Hg with RA compression (false positive). A negative modified Allen's test was obtained in the remainder of the extremities. Of these, 16 of the 115 dominant extremities (13.9%) and 5 of the 112 nondominant extremities (4.5%) had a digit  $\Delta P$  of 40 mm Hg or more with RA compression (false negative). Digit  $\Delta P$  with RA compression ranged from 0 to 104 mm Hg (mean  $\pm$  SD;  $21.6 \pm 17.9$  mm Hg;

**Table II.** Results of Allen's test and digit  $\Delta P$  for nondominant extremity

Allen's test	Digit $\Delta P \geq 40$	Digit $\Delta P < 40$	Total
Positive	8	8	16
Negative	5	107	112
TOTAL	13	115	128

\* $\Delta P$  is the change in digit pressure with RA compression.

Table III). Digit  $\Delta P$  in extremities with a negative Allen's test ranged from 0 to 60 mm Hg (mean  $\pm$  SD;  $14.1 \pm 13.01$  mm Hg).

Fifty-two of the 129 patients underwent RA harvesting. Of these 52 patients, one patient died after the operation and one patient was lost to follow-up; therefore postoperative data were available for 50 patients. The most common reasons for not harvesting the RA were the preferential use of other conduits and a preoperative digit  $\Delta P$  of 40 mm Hg or more. Of the 50 patients who had an RA harvested, 43 were men and 7 were women. Ages ranged from 36 to 80 years (mean  $\pm$  SD;  $58.3 \pm 9.5$  years). Forty-seven patients had RA harvesting from the nondominant extremity; two, from the dominant extremity; and one, from both extremities. Digit  $\Delta P$  with RA compression in the donor extremity ranged from 0 to 34 mm Hg, although the modified Allen's test was positive in 4 of these extremities before the operation. Ischemic hand complications did not occur in any patient. Symptoms of hand ischemia were not reported by any patient on postoperative questionnaires.

Postoperative vascular studies of the nondonor upper extremity digit  $\Delta P$  of 49 patients differed from preoperative studies. The preoperative mean  $\pm$  SEM  $\Delta P$  for the nondonor first and second digits were  $14.5 \pm 1.81$  mm Hg and  $13.3 \pm 1.99$  mm Hg and the postoperative mean  $\pm$  SEM  $\Delta P$  values were  $15.5 \pm 1.93$  mm Hg ( $P = .036$ ) and  $10.0 \pm 1.47$  mm Hg ( $P = .012$ ), respectively.

## Discussion

This study was conducted to compare the modified Allen's test with digit pressure measurements before and during RA compression in patients undergoing preoperative evaluation for RA harvesting. There is a potential risk of hand ischemia with the increasing use of the RA conduits for CABG. A dual blood supply to the hand is present in most patients with the superficial and deep palmar arches forming collaterals between the ulnar and radial arteries. The SPA, mainly derived from the ulnar artery, is the major arterial supply to the digits. In most cases the RA can be harvested safely because the ulnar artery will provide adequate blood

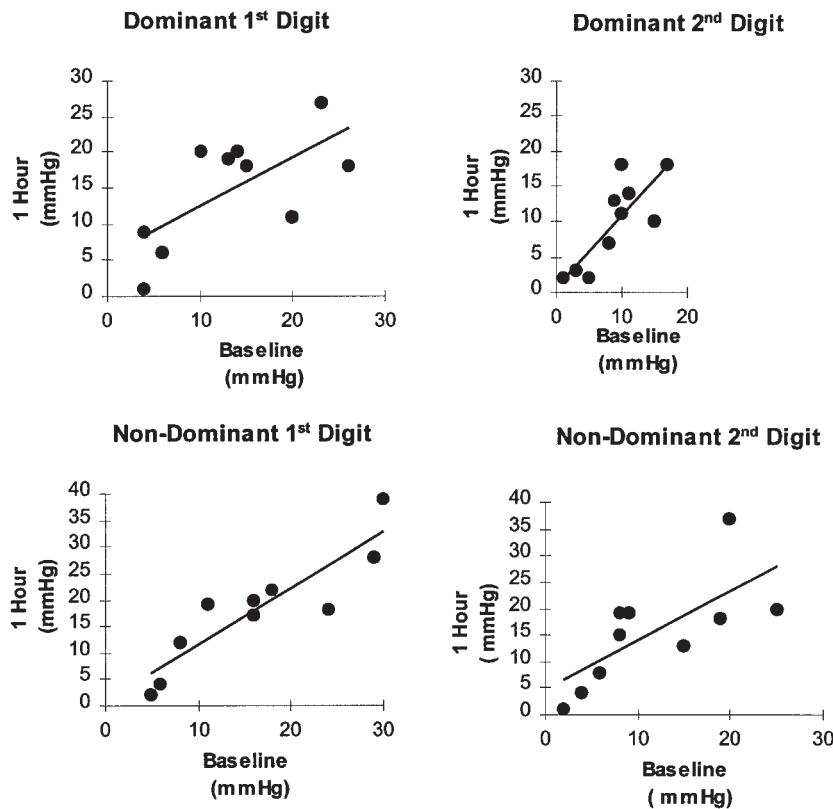


Fig 1. Baseline vs 1-hour digit ΔP (mm Hg).

Table III. Range of digit pressure change with RA compression

Extremity	Δ Pressure (mm Hg)					
	0-19	20-39	40-59	60-79	80-99	>100
Dominant: Allen's positive	4	3	4	1	1	1
Nondominant: Allen's positive	3	5	3	2	2	1
Dominant: Allen's negative	69	30	14	2	0	0
Nondominant: Allen's negative	66	41	5	0	0	0

supply to the digits. However, there are certain anatomic variations (eg, RA dominance of the SPA, absence or malformations of the ulnar artery, and an incomplete SPA) that may lead to digital ischemia after RA harvest. An incomplete SPA is the most common of these variations. In 1961, Coleman and Anson<sup>7</sup> reported an incomplete SPA in 21.5% of 650 autopsy specimens.

The Allen's test and its multiple modifications have been the standard screening test used before RA cannulation or harvesting. However, this test is subjective. Kamienski and Barnes<sup>8</sup> reported a 73% false-positive rate for a modified Allen's test as assessed by incomplete capillary refilling of the tested hand. These

authors reported a positive predictive value of 0.47 and a negative predictive value of 0.992 for the modified Allen's test. There have been multiple reports of digit ischemia, even requiring amputation, after placement of arterial lines in the RA after a negative Allen's test.<sup>9-12</sup> Previous work from our laboratory has demonstrated poor correlation of the modified Allen's test to predict a decrease in digit pressure with RA compression in healthy volunteers.<sup>5</sup>

Fifty percent of extremities with an abnormal modified Allen's test had a digit ΔP of less than 40 mm Hg with RA compression in this study. Therefore these patients would have been unnecessarily excluded from

RA harvest for CABG based on the modified Allen's test. Nine percent of extremities with a negative modified Allen's test were found to have a digit  $\Delta P$  of 40 mm Hg or more with RA compression. These patients are potentially at risk for digit ischemia with RA harvest, although the exact pressure change above which RA harvest is unsafe has not been established. Some authors<sup>13</sup> have suggested that an absolute thumb systolic blood pressure of 40 mm Hg or less predicts inadequate collateral blood supply before RA cannulation. Additional studies are clearly needed to establish safe clinical end points for digit blood pressure before RA harvest. Of the 50 patients who underwent RA harvest in this study, all had pressure changes ( $\Delta P$ ) of less than 40 mm Hg. There were no ischemic complications even among patients with a positive modified Allen's test.

Mean preoperative and postoperative digit  $\Delta P$  in non-donor extremities were statistically different. Although this finding was unexpected, the differences were small and of no appreciable clinical significance.

A likely explanation for the high false-positive and false-negative rates for the modified Allen's test compared with digit pressure measurements may relate in part to the difficulty of accurately insonating the SPA with a continuous wave Doppler probe.<sup>5</sup> Similar audible Doppler signals may be obtained from the superficial palmar arch, deep palmar arch, common digital arteries, and the deep interosseus branch of the ulnar artery. Interpretation of changes in Doppler signals in these vessels during RA compression is potentially misleading.

## Conclusion

Direct digit pressure measurement before and during RA compression is a simple and objective method that may more accurately select patients for RA harvest. The use of the modified Allen's test for assessing collateral hand circulation before RA harvest for CABG may place some patients at risk for digit ischemia and may unnecessarily exclude others from the use of this desirable conduit. Additional studies are needed to establish objective digit pressure criteria that can accurately predict patients in whom RA harvest may result in ischemic complications.

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## Discussion

**Dr Elliot T. Gelfand** (*Edmonton, Alberta, Canada*). The problem we are talking about is a relatively straightforward one, in light of the increasing trend in coronary operations to the use of arterial conduits, in particular, the RA. How can we best assure ourselves that by removing the RA, the hand involved will suffer no ischemic consequences? The standard means of assessment has been the Allen's test. The Allen's test was described in 1929 by Dr E. V. Allen in the *American Journal of Medical Science*, and the classic Allen's test is a subjective test as mentioned. Many modifications have been suggested, and in this paper a continuous wave Doppler was placed on the superficial palmar arch to see whether with RA compression the audible palmar arch signal decreased. By any criteria, the Allen's test, modified or not, would have to be considered a very subjective test.

In this study, the modified Allen's test is compared with a plethysmographic study of first and second digit pressure with and without RA compression, where a pressure drop of 40 mm Hg was considered relevant. My simplistic take on the data is that a positive Allen's test means nothing, because in this study and in other studies a positive Allen's test is as likely to have a 40 mm Hg pressure drop as not. So it means in my mind, nothing. A negative Allen's test in the dominant



extremity has a 14% likelihood and in the nondominant extremity a 4% likelihood of having a significant pressure drop with RA compression.

Do we have any notion of what the reported incidence of hand ischemia is with RA removal? Is this a problem that we need to be concerned about, or is it something that is of minimal consequence?

**Dr Starnes.** Actually, on my literature search, I have found no cases of reported hand ischemia after RA harvesting. We have found multiple instances of hand ischemia after placement of radial arterial lines with the negative Allen's test.

**Dr Gelfand.** So we do not know whether it is important to look at this or not, really. In view of the fact that in 9 of 50 patients (18%), postoperative pressure changes in the nonoperated extremity did not correlate with preoperative studies, how do you feel about the reliability and reproducibility of this test?

**Dr Starnes.** We did study the 50 patients who underwent harvesting in the nonoperative side and found that in 9 patients the preoperative results and postoperative results do not correlate in those extremities. With 4 of the extremities, the Allen's test does not correlate.

It is hard to compare the results of the preoperative and postoperative states because there are multiple variables that we do not control for. There may have been differences in rhythm, differences in medications, and arterial lines were routinely inserted in that extremity perioperatively, so it is hard to determine why that is. We did do reliability testing on 10 healthy volunteers and found that results obtained 1 hour apart did correlate with the digit pressures.

The premise on which this study was based is that a 40-mm pressure drop was significant. Why 40 mm, why not 30 mm, why not 50 mm?

Again, that was an arbitrary number that we chose. There really is no information in the literature about what is the significant pressure drop in the hand to prevent claudication. So really 40 mm was arbitrary, and I think that would need to be further studied. We tried to be more on the conservative side to prevent the devastating consequence of hand ischemia after harvesting an RA.

**Dr Gelfand.** There was a statement in the article, and I am not sure whether it was a typographic error not. It says that pressure changes with RA compression on the operative side ranged from 0 to 34 mm Hg.

**Dr Starnes.** That was preoperative studies. The highest pressure changes we had in the harvested extremity was 34 mm Hg.

**Dr Gelfand.** Finally, is it your feeling that the potential for ischemic complications of the hand is important enough to warrant doing a test or tests of more sophistication than the Allen's test? And if so, in light of the problems with your test already brought to light, is this the test of choice? If not, what others would you suggest?

**Dr Starnes.** With the experience we have had with the Allen's test over the many years of using it, we have shown that it has significant false-positive and false-negative rates. I think with the increasing use of the RA as a conduit, it is just a matter of time before we see that complication in this population as well. So it is important to have a more objective test than the Allen's test. This test is certainly a better test than the Allen's test, because it is objective. There are other options available. Angiography is the gold standard. However, it would not be prudent to submit every patient to an arteriogram because of its expense and invasiveness. We are also going to be studying the use of another noninvasive test in which we would study ulnar artery flow velocities before the operation for RA harvesting.

**Dr Rick Barnard** (*St Louis, Mo*). Our approach has been simplistic and pragmatic; I personally have done the Allen's testing on 731 patients. Of those patients, 4.4% had bilaterally positive Allen's tests so that their radial arteries could not be harvested. Seven hundred patients did have harvesting of their RA based on the Allen's test, and we did not see or experience hand ischemia. It is unclear to me how many of your patients were denied RA harvest based on your physiologic method of assessment. I am concerned that an excessive number of your patients were denied RA harvest on the basis of your screening methods.

**Dr Starnes.** We did not compare it to the gold standard arteriogram, so you cannot discuss that.

**Dr Barnard.** Yes, but the surgeon must have made a decision based on your physiologic studies to harvest or not harvest the RA. How many patients were denied RA harvesting on the basis of your observations?

**Dr Starnes.** Because this was a new pilot study, the surgeons varied in their use of this data. Some of them did perform an interoperative standard Allen's test and used that data, and some of them used our digit pressure data also, so I do not have that information.

**Dr Robert L. Mitchell** (*Mountain View, Calif*). The ischemia from the arterial lines may be secondary to emboli rather than occlusion.