Palmar Microcirculation After Harvesting of the Radial Artery in Coronary Revascularization

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Purpose. **To evaluate real-time parameters of palmar microcirculation before and after harvesting of the radial artery in coronary revascularization using a laser Doppler flowmetry and remission spectroscopy system (O_2C).**

Description. **Fifteen patients (11 males, 54 ± 4 years, mean New York Heart Association [NYHA] class of 2.3 ± 0.3) were prospectively scheduled with control measurements of the fingertips of D1, D3, and D5 at base line, after suprasystolic, and after selective radial or ulnar compression for tissue oxygen saturation (SO_2), postcapillary venous recombinant hemoglobin (rHb) concentration, superficial (2 mm) blood flow, and deep (8 mm) blood flow.**

Evaluation. **Preoperatively during suprasystolic compression SO_2 decreased significantly for the fingertips of D1, D3, and D5 by −58%, −74%, and −63%, respectively ($p < 0.05$). Radial compression reduced $SO_2$for all fingertips (−12%, −14%, and −16%), as did ulnar compression (−24%, −18%, and −10%). rHb did not change significantly for either compression type. Superficial and deep blood flow decreased significantly after suprasystolic and only slightly after radial and ulnar compression at either side. No side differences were noted. After radial artery harvesting, microcirculatory parameters did not change considerably versus preoperatively.**

Conclusions. **Radial artery harvesting does not remarkably change microcirculatory parameters of the hand. The O_2C system is a safe and quantitative method to assess both preoperatively and postoperatively the palmar microcirculation and therefore adds further functional clinical information.**

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Radial artery grafts provide exceptional long-term patency, and because of that the number of patients undergoing coronary revascularization using the radial artery is increasing. Concerns regarding the reduced palmar blood flow after radial artery harvesting have been recognized. Various blood flow techniques, such as forearm plethysmography [1] or technetium 99m albumin-scans [2], have been applied to assess forearm and palmar blood flow in addition to the clinically used Allen test and have indicated contradicting results. We focused this study on the palmar microcirculation preoperatively and 2 days after radial artery grafting in coronary revascularization. To detect parameters of microcirculation we used a combined laser-Doppler flowmetry system (O_2C system), which we have described elsewhere with regard to the sternal microcirculation after harvesting of the pedicled left internal thoracic artery [3] and clinical myocardial preconditioning in off-pump coronary artery bypass surgery (OPCAB) surgery [4].

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Technology

Fifteen patients (11 males, 54 ± 4 years, mean New York Heart Association [NYHA] class of 2.3 ± 0.3), who were scheduled for coronary artery bypass graft surgery using the radial artery, were enrolled in this study once informed consent was obtained. We used the O_2C system, a laser Doppler flowmetry and remission spectroscopy system (LEA Medizintechnik, Giessen, Germany) for the measurement of palmar microcirculation. Exclusion criteria in our investigation included NYHA class III and IV as well as redo and emergency procedures. Measurements were performed for the fingertips of digits 1, 3, and 5 (D1, D3, and D5) for both the donor and nondonor hand before and on the second day after radial artery harvesting. At each site on both hands, base line measurements were performed followed by suprasystolic brachial compression and selective ulnar or radial compression (Figs 1 and 2).

Technique

The optical method for measuring blood flow using the laser Doppler technique and hemoglobin oxygenation/

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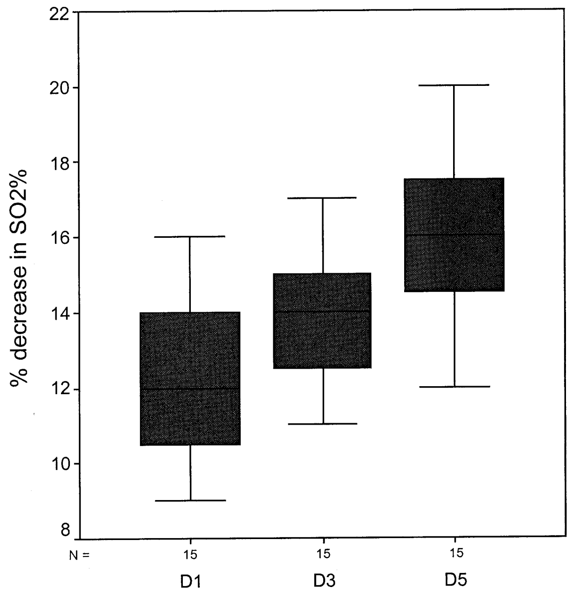

Fig 1. Box plot of the decrease (%) of tissue oxygen saturation (SO_2 *%) after radial compression before radial artery harvesting. (*D1, D3, *and* D5 = *the fingertips of digits 1, 3, and 5, respectively).*

hemoglobin concentration in tissue by spectrometric techniques has been described in detail elsewhere [5]. The determination of hemoglobin and the principle of blood flow measurements are combined in the O_2C system. The local oxygen supply parameters, blood flow, oxygen saturation of hemoglobin SO_2 (%), and amount of local recombinant hemoglobin (rHb) are recorded by an optical fiber probe (O_2C; LEA Medizintechnik, Giessen, Germany) (Fig 3).

The tissue is illuminated with a coherent laser light of

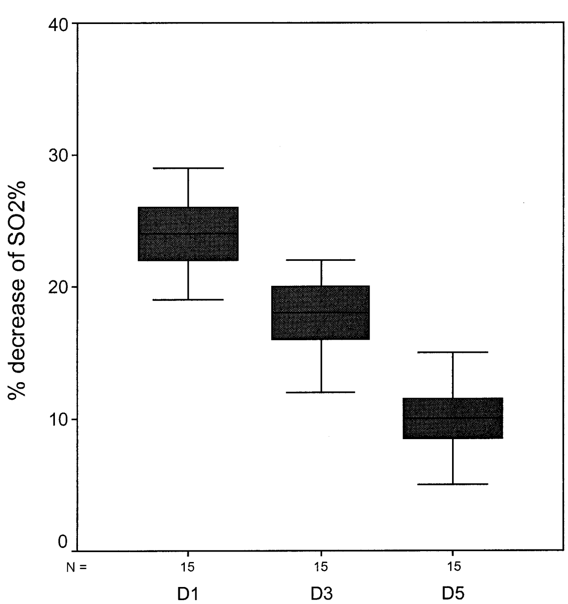

Fig 2. Box plot of the decrease (%) of tissue oxygen saturation (SO_2 *%) after ulnar compression before radial artery harvesting. (*D1, D3, *and* D5 = *the fingertips of digits 1, 3, and 5, respectively).*

Fig 3. O_2C *system of LEA Medizintechnik, Giessen, Germany.*

830 nm and 30 mW from a laser diode through a fiber-optic light guide. Backscattered light is collected by the same probe and frequency-shifted light is extracted using a heterodyne light-beating technique. The power spectral density of shifted light is a linear function of the average velocity of moving cells within the tissue. As laser Doppler flowmetry detects moving particles at a certain velocity, it measures blood flow.

Laser Doppler perfusion measurements can increase sampling depth by using near-infrared laser light and changing detector geometry. Although it is commonly accepted that separation and the use of light in the near infrared light range increases sampling depth, actual measurements and calculations in the range of the used probe (separation 2–4 mm) are rare. In the near infrared range a mathematical model for measurements of skin blood oxygenation estimated a fiber separation of 400–800 μm for the blood sample. A measurement depth of 3.4 mm was illustrated with a fiber separation of 6 mm and a fiber diameter of 3 mm.

Light of the visible range is irradiated into tissue. Backscattered light spectrum is measured over the whole range from 500–630 nm through the same glass fiber probe. Light penetrates into the tissue and is partly absorbed, reflected, and scattered. The main absorber, hemoglobin, changes its absorption characteristics with oxygen saturation. Fully oxygenated hemoglobin indicates two absorption peaks at 542 and 577 nm and one deoxygenated blood peak at 556 nm. Oxygen saturation of the blood within microvessels is calculated with appropriate algorithms and additional absorption by other tissue chromophores such as melanin and cytochrome by fitting measured spectra with spectra of known oxygen saturation. Measured spectra is further influenced by the path length of photon through tissue. In the past different tissue models have been used to simulate the path of a photon through tissue to determine multiple scattering influences on absorbance spectra. Here a modified diffusion approximation to the transport equation is used that includes changes in the whole spectra to estimate scattering influence and calculate absolute oxygen saturation values. Information is mainly gathered from small arteries, capillaries, and venules as light entering vessels larger than 100 μm is completely absorbed [6]. As 85% of the hemoglobin is in the capillary-venous compartment of the microcirculation, measurements with the spectrophotometer reflect mainly capillary-venous oxygen saturation.

Oxygen saturation of hemoglobin is calculated in percent SO_2 (%), which is an absolute measure. The local amount of hemoglobin is calculated in relative absorbance units (RAU) of rHb processed from the spectral absorption of the hemoglobin. The hemoglobin amount (rHb) is measured by the sum of absorption at all wavelengths ("area under the curve") and is corrected by the characteristic differences in absorption; fully oxygenated blood absorbs approximately 15% more than deoxygenated blood. As with hemoglobin amount measurement volume is changed. The hemoglobin values are relative values and reflect the filling of vessels or vessel density per catchment volume.

The heart consists of myoglobin—as each muscle does—which exhibits a similar structure to that of hemoglobin and works as an oxygen storage location within the cell. Myoglobin exhibits similar absorption properties to hemoglobin and therefore oxygen saturation measurements in the heart reflect oxygen saturation of both hemoglobin and myoglobin.

The data are presented as median and range values for continuous variables or the numbers and percentages for dichotomous variables. Univariate analysis of categorical data were carried out using the χ^2 or Fisher exact test. A p value less than 0.05 was considered to indicate statistical significance. The SPSS statistical software package 11.5 for Windows (SPSS, Inc., Chicago, IL) was used to calculate statistical analysis.

Clinical Experience

Base line tissue oxygen saturation for the fingertips was (D1, D3, and D5) 75%, 78%, and 79%, respectively, for the dominant hand and 79%, 76%, and 82%, respectively, for the nondominant hand (not significant [NS]). Suprasystolic brachial compression decreased the tissue oxygen saturation of the fingertips of the scheduled donor hand significantly for all fingertips examined (D1, D3, and D5 to 58%, −74%, and −63%, respectively; $p < 0.05$). There was no significant difference between the donor and nondonor tissue oxygen saturation. Radial compression decreased the tissue oxygen saturation significantly, but to a lesser degree versus suprasystolic compression (D1, D3, and D5 to 12%, −14%, and −16%, respectively; $p < 0.05$). Ulnar compression versus base line decreased tissue oxygen saturation significantly (D1, D3, and D5 to 24%, −18%, and −10%, respectively; $p < 0.05$).

Base line palmar postcapillary venous filling pressure was (D1, D3, and D5) 58, 61, and 60 U for the donor arm, respectively, versus 61, 59, and 58 U for the nondonor arm, respectively (NS). Suprasystolic, radial, and ulnar compression did not considerably change postcapillary venous filling pressures for either hand.

Base line superficial blood flow determined in 2 mm tissue depth (D1, D3, and D5 to be 135, 189, and 179, respectively) versus the corresponding deep blood flow in 8 mm tissue depth (D1, D3, and D5 to be 256, 304, and 318, respectively) indicated a significant difference. There was no significant difference, however, between the donor and the nondonor arm. Suprasystolic compression significantly decreased both superficial and deep blood flow for all fingertips (−83%, −97%, and −82%, respectively, versus −79%, −93%, and −89%, respectively; $p < 0.05$).

Radial compression decreased both superficial (−38%, −28%, and −41%) and deep blood flow (−41%, −38%, and −28%; $p < 0.05$) for both arms without any side difference. Tissue oxygen saturation measured on postoperative day 2 was (D1, D3, and D5) 73%, 71%, and 81%, respectively, for the donor arm and 81%, 74%, and 79%, respectively, for the nondominant hand, which did not significantly differ from the measurements indicated preoperatively. Postoperative versus preoperative postcapillary venous filling pressure was not changed (D1, D3, and D5 = 61, 58, and 67 U for the donor arm versus D1, D3, and D5 = 58, 63, and 68 U for the nondonor arm [NS]).

After radial artery harvesting, superficial blood flow, determined in 2 mm tissue depth, (D1, D3, and D5 = 113, 158, and 139, respectively) and deep blood flow, determined in 8 mm tissue depth (D1, D3, and D5 = 227, 288, and 269, respectively), was not significantly reduced when compared preoperatively.

After radial artery harvesting but during coronary revascularization, neither superficial nor deep harvest site infections occurred in the 15 patients studied. Comparatively leukocyte levels and C-reactive protein could be monitored during the hospital stay. One patient did complain of numbness within the thumb that resolved 4 weeks after the procedure. All of the other patients did not exhibit neurological deficits or persistent pain.

Comment

The crucial findings of this study establish that radial artery harvesting for coronary revascularization does not change the parameters of palmar microcirculation. However though tissue oxygen saturation and tissue capillary blood flow both decrease after radial compression, determination on postoperative day 2 failed to demonstrate any considerable reduction for the parameters of microcirculation. O_2C is an objective method that can be used to detect parameters of microcirculation within the hand. It is also a safe and quantitative clinical assessment technique for bypass surgery which can be used to determine ulnar artery capability with regard to collateral compensation in the hand after radial artery harvesting.

The use of the radial artery for coronary revascularization is an innocuous procedure that demonstrates exceptional results with a 10-year-patency of 92% versus 98% with regard to the left internal thoracic artery [7]. In coronary revascularization—with the exception of the left internal thoracic artery—the radial artery is revealed to be the more improved second arterial graft as compared with the right internal thoracic artery [8]. Independent predictors of operative mortality include an ejection fraction below 30%, reexploration, and stroke, whereas the use of saphenous vein grafts and renal impairment are considerable independent predictors of late mortality after radial artery harvesting [9]. Typically the nondominant forearm is considered for radial artery grafting and performing an Allen's test proved to be negative.

Besides the conventional complete forearm incision technique, minimally invasive techniques regarding radial artery harvesting have been described. Similar to the preparation of the internal thoracic artery, skeletonization of the radial artery [10] with an ultrasonic scalpel has been determined to be a feasible and safe technique with convincing patency rates at a follow-up period of 1.4 years. In a series of 197 patients [11], 16.5% who underwent traditional harvesting of the radial artery complained of temporary dysesthesia versus 2% who underwent the less invasive harvesting technique of the radial artery. On average, neurological symptoms ceased average after 3.8 months (1–12 months). Nonetheless neither technique has been evaluated for parameters of microcirculation of the hand in patients who were operated on using either of these techniques.

Wound complications such as infection, hematoma, or seroma may complicate the postoperative course and deteriorate forearm function after radial artery harvesting. In a cohort of 217 patients [12] with 338 donor arms examined, 0.6% of the hematomas requiring operative drainage were evident. Minor wound complications including skin dehiscence, superficial infections, small hematomas, and seromas were experienced by 4.1% of the patients. The risk of any arm complication was not elevated in patients older than 65 years. In a case-controlled study [13] both preoperative hyperglycemia ($>$ 200 mg/dl) and surgery duration greater than 5 hours were independent risk factors for radial harvest site infections. In our limited study no wound complications occurred.

In the aforementioned study by Greene and Malias, 10.7% of cutaneous paresthesias in the radial distribution of the lateral antebrachial cutaneous nerve or superficial branch of the radial nerve were documented. Short-term motor hand function, assessed as gripping power and fine motor skills 5 days after radial artery harvesting, was determined not to be significantly reduced at radial artery harvesting [14]. Chong and associates ascertained that in patients with a negative preoperative score for the Allen test, radial artery harvesting did not adversely affect subsequent forearm function 3 months postoperatively [1].

Forearm function determined by neural sensation, which was not affected, forearm circumference and grip power, which were both notably reduced 3 months after radial artery grafting, and cyclical exercise fatigue, which was improved 3 months after radial artery harvesting, have been evaluated in this study. In 13% of the patients reduction of the pinprick sensation was evident in the distribution of the lateral antebrachial cutaneous nerve. In a larger cohort [15] of 271 patients undergoing radial artery grafting, 0.7% of the patients reported donor arm weakness 8 weeks postoperatively. Cutaneous paresthesia was noted at the 6-month follow-up in 3.7% of all patients. Univariate analysis revealed smoking and diabetes as risk factors for persistent cutaneous paresthesia.

The largest published series [16] evaluating self-reported neurological complications by telephone interview after radial grafting (n = 560) was performed by Denton and associates. Their study indicated neurological complications of 30.1% with a 5.5% decrease in thumb strength and sensation abnormalities of 18.1% at a mean follow-up of 15 months. They reported a high rate of symptom improvement over an average of 9 months. One patient in our cohort (6.7%) complained of thumb numbness that resolved within 4 weeks postoperatively. Further clinical studies evaluating the neurological status as well as the vascular status of patients with an extended follow-up period are necessary to assess the benefits and possible long-term complications after radial artery harvesting.

Regarding the forearm blood supply, the radial artery has been determined to be the dominant artery in most patients. In the aforementioned study by Chong and associates [1] focusing on forearm blood flow, which was assessed by forearm plethysmography, they ascertained no difference between both forearms. To assess the forearm tissue perfusion, 20 patients after radial artery harvesting underwent technetium 99m albumin-scans indicating a substantially reduced donor hand and forearm tissue perfusion without any clinical effect with regard to short-term hand function [2]. Our study evaluated the microcirculation and could detect the reduction of microvascular blood flow after the Allen test. However on the second postoperative day after radial artery harvesting, we could not detect any change in the microcirculatory parameters of the donor versus the nondonor hand.

In conclusion 2 days after radial artery harvesting detected by the O_2C system was performed, no remarkable changes regarding palmar microcirculation parameters were determined This noninvasive system distinguishes itself as a safe and quantitative method for preoperative and postoperative assessment with regard to palmar microcirculation and therefore adds further functional clinical information beyond both the clinical Allen test and ultrasound.

Disclosures and Freedom of Investigation

The O_2C system was purchased for a regular market price from LEA Medizintechnik, Giessen, Germany. No author funds have been given to the investigators. The authors had full control regarding the study design, methods, outcome parameters and analysis of data.

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NEW TECHNOLOGY

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Disclaimer

The Society of Thoracic Surgeons, the Southern Thoracic Surgical Association, and *The Annals of Thoracic Surgery* neither endorse nor discourage use of the new technology described in this article.

INVITED COMMENTARY

Coronary artery bypass grafting (CABG) with saphenous vein conduits is one of the most commonly performed surgical procedures worldwide. Unfortunately, saphenous vein graft patency is only 50% at 10 years. As a result, there has been a growing interest in the use of arterial conduits, particularly the radial artery (RA), as excellent midterm patency results of more than 90% have been reported. Nevertheless, concerns have been raised about decreased blood flow to the hand with potential morbidity after RA harvesting. This paper by Knobloch and colleagues describes a novel combined laser-Doppler flowmeter system that can be used to measure palmar microcirculation in attempts to avoid ischemic complications of the hand.

Palmar circulation was evaluated using the laser-Doppler flowmeter before and 2 days after RA harvesting. Patients were tested for either complete suprasystolic occlusion of the brachial artery or alternate occlusion of the radial and ulnar arteries. As expected, changes in both blood flow and tissue oxygenation saturation decreased with various occlusive maneuvers. After RA harvest, tissue flows and saturations were the same as for the nondonor hand. This “proof-of-concept” study is small with only 15 patients, all of whom were less than 60 years of age. One wonders how well this system would work in the elderly, smoking, or diabetic population with small vessel occlusive disease. By including more patients and then applying a subgroup analysis, the authors might have answered this question.

The Allen test is simple and safe, and is performed commonly to assess palmar circulation. Unfortunately, the authors make no mention of whether concomitant Allen testing was performed in any of these patients. Furthermore, there are no comparative results or descriptions of how the device might be more reliable than the Allen test. Correlation with the laser-Doppler flowmeter system would have been interesting and would have validated the utility.

Nevertheless, one of the more interesting points of the paper was that despite reduction in palmar blood flow and tissue oxygen saturation with RA harvesting, 2 days postoperatively both tissue oxygen saturation and blood flow were not reduced compared with the other hand and, more importantly, compared with preoperative values. Potential mechanisms might include increased compensatory blood flow from the remaining artery or the opening of small collaterals within the palmar arch hand. This finding raises a critical point in the use of this new technology. Should decreases in blood flow and tissue oxygen saturation be disregarded as they return to baseline 2 days after RA harvest, or is there some dangerous threshold before RA harvesting that can be detected by this new method?

In summary, further work will need to include a wider patient population to determine whether this technology can add more clinical information for patients whose RA is harvested. Moreover, will this device predict and detect who may have postoperative ischemic complications? This important question must be answered before surgeons can conclude that the laser-Doppler flowmeter will add functional information that goes beyond the Allen test.

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