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Changes in Blood Velocity Following Microvascular Free Tissue Transfer

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Abstract

Understanding how pedicle blood velocities change after free tissue transfer may enable microvascular surgeons to predict when thrombosis is most likely to occur. A 20-MHz Doppler probe was used to measure arterial and venous blood velocities prior to pedicle division and 20 minutes after anastomosis in 32 microvascular free flaps. An implantable Doppler probe was then used to measure arterial and venous blood velocities daily for 5 days. Peak arterial blood velocity averaged 30.6 cm/s prior to pedicle division and increased to 36.5 cm/s 20 minutes after anastomosis ($p < 0.05$). Peak venous blood velocity averaged 7.6 cm/s prior to pedicle division and increased to 12.4 cm/s 20 minutes after anastomosis ($p < 0.05$). Peak arterial blood velocities averaged 34.0, 37.7, 43.8, 37.9, 37.6 cm/s on postoperative days (PODs) 1 through 5, respectively. Peak venous blood velocities averaged 11.9, 14.5, 18.2, 16.8, 17.7 cm/s on PODs 1 through 5, respectively. The peak arterial blood velocity on POD 3, and peak venous blood velocities on PODs 2, 3, and 5 were significantly higher than 20 minutes after anastomosis ($p < 0.05$). Arterial and venous blood velocities increase for the first 3 postoperative days, potentially contributing to the declining risk for pedicle thrombosis during this time period.

Keywords

Blood velocity; microvascular free flap; Doppler ultrasound; implantable Doppler

Microvascular free tissue transfer is now a commonly performed procedure but is still associated with flap loss rates of 1 to 5% even among experienced surgeons.^{1–5} The overall thrombosis rate for free flaps is even higher, ranging from 10 to 12%, though 50 to 85% of flaps with thrombosis are ultimately salvaged after reexploration and revision surgery.^{1–5} Quantifying blood velocity during the postoperative period would help inform the surgeon as to when vascular thrombosis, which is associated with low velocity states, as well as turbulent flow and intimal injury, is most likely to occur.⁶ Our goals in the present study were to quantify arterial and venous blood velocities in microvascular free flaps prior to pedicle division and

after anastomosis to understand how free tissue transfer affects blood flow through the flap and to understand how arterial and venous blood velocities change during the early postoperative period when the risk of thrombosis has been observed to be the greatest.

METHODS

Thirty-two free flaps were performed for immediate reconstruction of head and neck defects after cancer resection by the primary author (M.M.H.) from January 2007 to May 2007. Patients included 24 men and 8 women with a mean age of 60.2 years (standard deviation, 15.9 years; range, 14 to 84 years). Free flaps included: 14 anterolateral thigh free flaps, 8 fibula osteocutaneous free flaps, and 10 radial forearm fasciocutaneous free flaps. Arterial anastomoses were performed end-to-end to the facial artery ($n = 21$), superior thyroid artery ($n = 4$), distal external carotid artery ($n = 4$), or lingual artery ($n = 3$). Venous anastomoses were performed end-to-side to the internal jugular vein ($n = 17$) or end-to-end to the facial vein ($n = 15$). Topical vasodilators, such as lidocaine or papaverine, were not used in this series. Antithrombotics, such as dextran, heparin, or aspirin, were not used before or after surgery. There were no reexplorations for flap compromise and no flap losses in this series. Institutional Review Board approval was obtained prior to undertaking this study.

During surgery, a 20-MHz needle-type Doppler ultrasound probe, built by C.J.H. in our laboratories and previously validated, was held at a 45-degree angle to the flap artery or vein to measure blood velocity prior to flap pedicle division and 20 minutes after microvascular anastomosis (Fig. 1).⁷ After the anastomosis was completed, a Cook-Schwartz (Cook Vascular Inc., Vandergrift, PA) implantable Doppler probe was placed around the artery in all 32 patients and around the vein in 12 patients, at least 10 mm distal to the microvascular anastomosis (Fig. 2). In some cases, the implantable probe was not placed around the vein either due to concern by the surgeon that the silastic cuff attached to the probe could lead to unfavorable positioning of the vein (i.e., kinking or twisting of the vein) or because the diameter of the vein was too great to accommodate the silastic cuff (i.e., the size of the cuff limits use of the implantable Doppler probe to vessels 5 mm or less in diameter).

The accuracy of the arterial and, when available, venous blood velocity measurements using Cook-Schwartz implantable Doppler probe was verified by comparing it to the measurements obtained using the needle-type handheld Doppler probe, which has been previously validated.⁷ The measurements obtained from the two Doppler probes were compared using the method described by Bland and Altman (Figs. 3 and 4).⁸ The Bland-Altman technique is used to compare measuring devices by plotting the difference between the two measurements as a function of the average of the two measurements of each sample, which is the best estimate of the true value. The bias (difference between the means) was 0.015 cm/s and the 95% confidence interval was -0.69 to 0.71 cm/s. Given the high degree of correlation between the measurements obtained from the implantable Doppler probe and the needle-type Doppler probe and the small bias (0.1% of the mean blood velocity measured 20 minutes after microvascular anastomosis), the measurements obtained from the implantable Doppler probe were presumed reliable.

Beginning on the first postoperative day, the Cook-Schwartz implantable Doppler was used to measure arterial and venous blood velocity daily for 5 days. Measurements were performed with the patient supine, to duplicate the positioning in the operating room. All patients received antihypertensive medication or fluid resuscitation, as appropriate, to keep their blood pressure in the normotensive range (90/60 to 140/90 mm Hg), and heart rate between 60 and 100 beats per minute. No patients in this study received vasopressors. The needle-type probes and the Cook-Schwartz probes were connected to a 20-MHz pulsed Doppler velocimeter, also constructed by C.J.H. in our laboratories. The audio output of the pulsed Doppler was

connected to the audio line input of a laptop computer, which was used to capture and store 10-second audio files (.WAV files) for later analysis. In each case, the sound produced by the 20-MHz needle Doppler or the Cook-Schwartz implantable Doppler ultrasound was recorded and analyzed using Spectrogram Version 11 (Visualization Software L.L.C., www.visualizationsoftware.com), a commercially available audio spectrogram software program. The resulting display is similar to the spectral Doppler display on clinical ultrasound and color Doppler systems and can be analyzed using established methods as described below.^{9,10}

The arterial and venous peak blood velocities were obtained by averaging three representative spectral peak frequencies from each audio file (Figs. 5 and 6). Blood velocities were then calculated using the Doppler equation:

$$v = f \times c / (2 \times F \times \cos(q))$$

In this equation, v is the blood velocity, f is the measured Doppler frequency, c is the acoustic velocity in blood (1.54×10^5 cm/s), q is the angle between the Doppler probe, and the blood vessel axis (45 degrees), and F is the transmitted frequency (20 MHz).

All values are shown as mean $\pm$ standard deviation. Differences between blood velocities measured 20 minutes after anastomosis and on postoperative days 1 through 5 were evaluated using the two-tailed unpaired t test. Differences in blood velocities measured between different flap types (anterolateral thigh, fibula osteocutaneous, and radial forearm) were evaluated using an analysis of variance. A p value less than 0.05 was considered significant.

RESULTS

Peak arterial and venous blood velocities observed before and after free tissue transfer are shown in Tables 1 and 2, respectively. There were no statistically significant differences in average peak arterial and venous blood velocities prior to pedicle division or at 20 minutes after anastomosis when the three free flaps types (anterolateral thigh free flap, fibula osteocutaneous free flap, and radial forearm fasciocutaneous free flap) were compared with each other. The average peak arterial blood velocity for all flaps was 30.6 ± 15.9 cm/s prior to pedicle division and increased to 36.5 ± 14.7 cm/s 20 minutes after anastomosis ($p = 0.04$). The average peak venous blood velocity for all flaps was 7.6 ± 5.7 cm/s prior to pedicle division and increased to 12.4 ± 3.3 cm/s 20 minutes after anastomosis ($p = 0.04$).

There were no statistically significant differences in mean peak arterial or venous blood velocities on postoperative days 1 through 5 when the three free flaps types were compared with each other. The average peak arterial blood velocity on postoperative day 3 was significantly higher than 20 minutes after the anastomosis ($p = 0.04$). The average peak venous blood velocities on postoperative days 2, 3, and 5 were significantly higher than 20 minutes after anastomosis ($p = 0.04$, $p = 0.002$, $p = 0.03$, respectively). In addition, the increase in observed peak venous blood velocity approached statistical significance by two-tailed t test on postoperative day 4 ($p = 0.05$).

DISCUSSION

Despite the fact that microvascular surgery is widely practiced, few studies have examined the hemodynamics of free tissue transfer to correlate quantitative results with clinical observations. To our knowledge, this is the first study to quantify changes in venous blood velocity after free tissue transfer and complements prior studies examining changes in arterial blood velocity after free tissue transfer. We also examined the changes in arterial and venous blood velocity on a

daily basis during the early postoperative period (postoperative days 1 through 5), when thrombosis is most likely to occur.⁵ Our findings indicate that arterial and venous blood velocities increase significantly after free flaps are transferred to head and neck recipient vessels. They also show that flow velocity increases over the first 3 days and then may decrease slightly after that.

We used an external laptop computer and software to analyze, display, and store the audio signals from the pulsed Doppler instrument. Most clinical Doppler units, including handheld units, have audio (headphone) outputs, and all computers have audio inputs such that most clinics can use this technology at minimal cost. Although the quadrature stereo output from the pulsed Doppler instrument used in this study contains information regarding the direction of flow, the spectral software does not display the direction, and thus any flow reversals will not be displayed properly. Transient flow reversals are possible on the arterial side of high-resistance vascular beds, but we did not attempt to detect or analyze pulsatility index or flow reversals in this study.¹¹

Findings in this study appear to be corroborated by other data available in the literature. Lorenzetti et al¹² measured arterial blood velocity in 10 free latissimus dorsi muscle flaps used for lower-extremity reconstruction after anastomosis and on postoperative days 2, 5, and 10 using color Doppler ultrasound. They noted a significant increase in peak arterial blood velocity after flap transfer on postoperative day 5. Similarly, the pulsatility index, which is defined as (maximum blood velocity – minimum blood velocity)/mean blood velocity, was shown by Numata et al¹¹ to increase after anastomosis and on the first postoperative day, then decrease from postoperative days 3 to 7 in radial forearm free flaps and rectus abdominis musculocutaneous free flaps that were examined by color Doppler ultrasound before and after anastomosis and on postoperative days 1, 3, 5, and 7. Increased blood flow volume (measured in mL/s) was reported by Ichinose et al¹³ in recipient facial arteries after radial forearm fasciocutaneous free flap transfer compared with the contralateral unoperated facial artery as measured by color Doppler ultrasonography. The authors also observed a significant ($p < 0.05$) increase in arterial and venous blood flow volume within the flap between the first and third days after surgery in their study.¹³ Both Ichinose et al¹³ and Heitland et al¹⁴ found that the relative increase in free flap pedicle arterial blood velocity appears to be maintained long-term, based on measurements at 6 months and 18 months, respectively.

Increased blood velocity after free tissue transfer is probably due to several factors. Restoration of vascular integrity after ischemia and reperfusion injury in the hours to days after microvascular anastomosis probably plays a major role in decreasing vascular resistance within the flap microcirculation and increasing blood flow.^{15,16} Ichinose et al¹³ outlined several other possible etiologies for the increased flap pedicle blood flow they observed during the first several days after free tissue transfer. Within the first minutes to hours after flap transfer, vasospasm of the pedicle decreases, resulting in decreased resistance and increased blood velocity and flow. Sympathetic denervation of the flap results in vasodilation and decreased vascular resistance throughout the flap. Choke vessels between angiosomes incorporated within the flap dilate, resulting in decreased resistance to blood flow within the flap. Finally, resistance due to high interstitial pressures caused by edema within the flap also decreases during the first days to weeks after flap transfer.

The observation that blood velocities increase immediately after free tissue transfer suggests that flow through the flap while it remains attached to the donor site may not necessarily be predictive of perfusion after anastomosis. In addition to some of the causative factors for increased blood velocity after transfer listed above, blood velocities may be generally greater in the head and neck recipient vessels than the donor vessels. Unfortunately, it was usually not possible to obtain values for recipient blood vessels prior to division, because nearly all patients

in this series underwent a neck dissection and we preferentially used blood vessels that had been ligated and divided by the oncological surgeon as recipient vessels.

The proportional relationship between blood velocity and volume flow is only valid when the vessel diameter at the measurement site is constant and the vessel is not compressed or kinked. In this study, care was taken to select measurement sites where the vessel was relatively straight and the diameter was not constricted. If vessel reactivity, clots, or hyperplasia causes changes in diameter, the relationship between velocity and flow will not be proportional, and thus care must be taken in interpreting results based on measurements of blood velocity alone. In all cases, the implantable Doppler cuff was placed at least 10 mm from the anastomosis, the area of the blood vessel theoretically most likely to thrombose or develop subintimal hyperplasia.

The size of the flap and type of tissue transferred (skin, muscle, bone, etc.) probably affect the change in vascular resistance observed. Nevertheless, we observed that the anterolateral thigh flap, which was a relatively large fasciocutaneous flap, the radial forearm flap, which was a relatively small fasciocutaneous flap, and the fibula osteocutaneous flap, which has bone and fasciocutaneous components, all demonstrated a significant increase in blood velocity 20 minutes after transfer and over the first several days. Numata et al¹¹ also showed similar patterns of change in the pulsatility index of radial forearm fasciocutaneous free flaps and rectus abdominis muscle free flaps occurring during the postoperative period using color Doppler ultrasonography. In contrast, Lorenzetti et al¹⁷ used transit-time ultrasonic flowmetry to measure arterial blood velocities before and after free tissue transfer and found decreased arterial blood flow (mL/min) in radial forearm free flaps and increased arterial blood flow in transverse rectus abdominis myocutaneous free flaps and various muscle free flaps immediately after anastomosis.

Our findings correlate with the clinical observation that pedicle thrombosis associated with low blood velocity conditions is most common during the first 2 to 3 days after surgery and relatively uncommon thereafter.¹⁸ Our findings also correlate with clinical signs of improved flap perfusion, including increased flap temperature, improved flap color and capillary refill, and the appearance of previously undetectable arterial and venous signals when the flap is examined by handheld Doppler ultrasound during the first few days after surgery. The findings of this study emphasize the need for close observation and frequent flap assessment during the first 3 days after flap transfer, as this is the time period when blood velocity is seen to increase from the immediate postoperative state. In cases where low blood velocity is a causative—or at least a contributory—factor in thrombosis, the risk for vascular occlusion within the flap should decrease with time. Mechanical causes of thrombosis, such as pedicle twisting, kinking, or compression, probably account for the majority of late free flap thrombosis, occurring on postoperative day 4 and after, when the patient becomes more mobile.¹⁸

Knowledge of when the risk of thrombosis is greatest is valuable because flaps can be monitored more closely during these time periods, hopefully resulting in earlier detection of flap compromise. Early detection and rapid reexploration of flaps with signs of vascular compromise are associated with better outcomes.^{4,19} For example, Bui et al⁴ found that salvaged free flaps were reexplored significantly more quickly than failed flaps (average of 4 hours after detection of compromise compared with 9 hours, respectively; $p = 0.01$) in a series of 38 patients with signs of free flap vascular compromise. In addition, the technique we describe for measuring arterial and venous blood velocities in microvascular free flaps is relatively simple, uses widely available technology (implantable Doppler probe) and audio spectrogram software, and could be adapted to wide-spread clinical use for quantitative monitoring after free tissue transfer, if an audio output were to be included with the Doppler ultrasound unit. Continuous data regarding the maturing flap circulation could prove useful in

focusing flap salvage efforts, as well as in further dissecting the process each flap undergoes in its new location.

CONCLUSIONS

Arterial and venous blood velocities increase significantly after flap transfer, probably due to multiple factors affecting the vascular resistance within the arterial and venous pedicles and distal flap microcirculation. Both arterial and venous blood velocities were observed to increase daily and peak on the third postoperative day. This observation suggests that increasing blood velocity makes vascular thrombosis less likely as time goes on during the first several days after surgery and correlates with the clinical observation that thrombosis declines significantly during the first 2 to 3 postoperative days.

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Figure 1.
A 20-MHz needle-type Doppler ultrasound probe held at a 45-degree angle used to measure blood velocity in an anterolateral thigh free flap pedicle vein.

Figure 2.
A Cook-Schwartz implantable Doppler probe (arrowhead) placed around an anterolateral thigh free flap pedicle artery just distal to the microvascular anastomosis (long arrow).

Figure 3.

Blood velocities (cm/s) measured by the 20-MHz needle-type Doppler probe (x-axis) compared with blood velocities measured by the Cook-Schwartz implantable Doppler probe (y-axis).

Figure 4.
Bland-Altman plot comparing the 20-MHz needle-type Doppler probe and the Cook-Schwartz implantable Doppler probe to establish its validity for quantitative blood velocity measurement.

Figure 5. Arterial Doppler spectrogram of an anterolateral thigh free flap in situ prior to pedicle division (A), 20 minutes after microvascular anastomosis to the facial artery (B), and on the third postoperative day (C).

Figure 6.

Venous Doppler spectrogram of a radial forearm fasciocutaneous free flap in situ prior to pedicle division (A), 20 minutes after microvascular anastomosis to the facial artery (B), and on the third postoperative day (C).

Table 1

Peak Arterial Blood Velocities (Mean $\pm$ Standard Deviation) in Free Flaps before and after Microvascular Anastomosis

Flap Type	In situ (cm/s)	After Anastomosis (cm/s)	POD 1 (cm/s)	POD 2 (cm/s)	POD 3 (cm/s)	POD 4 (cm/s)	POD 5 (cm/s)
ALT (<i>n</i> = 14)	2.49 $\pm$ 1.07	3.42 $\pm$ 1.35	3.15 $\pm$ 1.50	3.52 $\pm$ 1.52	4.38 $\pm$ 1.27	3.79 $\pm$ 1.33	3.76 $\pm$ 1.40
Fibula (<i>n</i> = 8)	3.39 $\pm$ 1.71	3.42 $\pm$ 2.29	3.46 $\pm$ 1.40	3.82 $\pm$ 1.35	4.33 $\pm$ 1.34	4.73 $\pm$ 0.99	4.12 $\pm$ 0.88
RFF (<i>n</i> = 10)	3.48 $\pm$ 1.48	4.31 $\pm$ 1.40	3.68 $\pm$ 1.42	4.03 $\pm$ 1.59	4.68 $\pm$ 1.33	3.36 $\pm$ 1.25	4.21 $\pm$ 1.35
Total (<i>n</i> = 32)	3.06 $\pm$ 1.59	3.65 $\pm$ 1.47	3.40 $\pm$ 1.42	3.77 $\pm$ 1.47	4.38 $\pm$ 1.27	3.79 $\pm$ 1.33	3.76 $\pm$ 1.40

POD, postoperative day; ALT, anterolateral thigh; RFF, radial forearm fasciocutaneous.

Table 2

Peak Venous Blood Velocities (Mean $\pm$ Standard Deviation) in Free Flaps before and after Microvascular Anastomosis

Flap Type	In situ (cm/s)	After Anastomosis (cm/s)	POD 1 (cm/s)	POD 2 (cm/s)	POD 3 (cm/s)	POD 4 (cm/s)	POD 5 (cm/s)
ALT (<i>n</i> = 6)	0.83 $\pm$ 0.68	1.15 $\pm$ 0.38	1.20 $\pm$ 0.53	1.36 $\pm$ 0.48	1.81 $\pm$ 0.39	2.02 $\pm$ 0.73	1.54 $\pm$ 0.81
Fibula (<i>n</i> = 2)	0.99 $\pm$ 1.40	1.61 $\pm$ 0.04	1.32 $\pm$ 0.16	1.85 $\pm$ 0.16	1.77 $\pm$ 0.14	1.77 $\pm$ 0.37	2.19 $\pm$ 1.32
RFF (<i>n</i> = 4)	0.67 $\pm$ 0.14	1.20 $\pm$ 0.24	1.13 $\pm$ 0.34	1.39 $\pm$ 0.38	1.89 $\pm$ 0.52	1.12 $\pm$ 0.34	1.86 $\pm$ 0.51
Total (<i>n</i> = 12)	0.82 $\pm$ 0.67	1.24 $\pm$ 0.33	1.19 $\pm$ 0.40	1.45 $\pm$ 0.40	1.83 $\pm$ 0.39	1.68 $\pm$ 0.67	1.77 $\pm$ 0.76

POD, postoperative day; ALT, anterolateral thigh; RFF, radial forearm fasciocutaneous.