Directional Doppler and angiography in the assessment of the postoperative function of the microvascular anastomoses: a comparative study

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Abstract

Purpose The aim was to evaluate the achieved patency rates and to compare directional Doppler with angiography in the assessment of the vascular patency.

Methods Two different methods were used in evaluation of the vascular function of reconstructed fingers and hands. Directional Doppler mapping of anastomosed arteries was compared with conventional angiographical study in the same individuals in the examination of 110 arteries.

Results The results showed equal findings in majority of examined vessels (93%) using both methods. There was erroneous interpretation in Doppler study of 4 arteries and in 3 angiographies the interpretation differed from Doppler study mainly due to projection difficulty. There were also 4 digital arteries which were considered open in Doppler study but angiography showed arterial recanalization or neovascularization phenomenon.

Conclusion The patency rates at digital artery level (70%) were lower than at metacarpal and forearm level (81%). The results were in concordance with previous studies.

Keywords Doppler ultrasound · Hand angiography · Microanastomosis · Patency rates · Replantation.

Introduction

The successful replantation of amputated extremities or parts of an extremity demands meticulous microvascular surgery. Without successful microvascular anastomosis the replanted tissue does not remain viable. In ideal experimental circumstances the patency rates over 90% after microvascular anastomosis are commonly reported [1, 2]. In less favorable clinical situations the success rates remain lower.

The immediate postoperative follow-up of microvascular anastomosis is mainly done using temperature measurements, photoelectric oscillometry, Doppler ultrasonography or laser Doppler. Angiography has been used by vascular surgeons for assessing long-term patency of peripheral vascular anastomoses especially after lower limb arterial reconstructions and after post-traumatic forearm arterial repairs. At finger level the information received from angiography has varied according to technical set-up, degree of sympaticolysis or blockage and proper timing of exposures after contrast medium injection. Noninvasive methods of studying peripheral arterial function were popularized by Strandness and Sumner 1972 [3].

Doppler ultrasound diagnosis as an alternative to arteriography was introduced by Fitzgerald and Carr in 1975 [4] and thereafter mainly noninvasive methods have been used to check the patency of repaired vessels. In 1981 Rossi et al. [5] compared directional Doppler and electromagnetic flow probe for experimental patency studies. They found the directional Doppler to be superior as the condition of the anastomosis could always be accurately assessed by the directional Doppler but not always by the electromagnetic flow probe. Color-Doppler ultrasonography and angiography has been compared by Bacakoglu et

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al. [6] in assessing forearm arterial repairs and they demonstrated a difference of 14.2%, which was considered as a failure of color Doppler ultrasonography.

The patency control after microvascular surgery with angiography has not routinely been used for its invasiveness and in the fear of possible harmful side effects. Previously continuous wave Doppler ultrasound study has been used to assess the achieved patency of the microvascular anastomosis after the replantation [7]. The degree of stenosis at the anastomotic site using the waveform characteristics has also been tried [8]. The correlation of Dopplex ultrasonography and selective angiography has been studied previously by Lee et al. in 2005 [9] during the first 60 days after replantation in 18 patients. They found a good correlation in their series.

The purpose of our study was to visualize the patterns of arterial circulation after established viability in the replanted parts and in order to evaluate the reliability of directional Doppler ultrasonography in the late postoperative assessment of the microvascular anastomosis. The main interest was focused to the arterial microanastomoses and to their patency status within first postoperative year in order to get more knowledge about circulatory function in the replanted extremity part. The main indication in favor of performing angiography in these patients was to double-check the patency rates in order to get comparative information for Doppler evaluation and the assessment of factors influencing to the result after the clinical microvascular anastomosis. Other indications for arteriography were the prognostic evaluation of vascularity at muscle and bone junction areas in macroreplantation cases as well as preoperative assessment before further reconstructive procedures for these patients.

Materials and methods

Material consisted of 30 replantation or revascularization patients. Twenty patients had replantations, 15 were at finger or hand level and 5 were macroreplantations (1 hand replantation at proximal to wrist level, 1 at distal third and 1 at mid third and one forearm replantation at elbow level and one midshaft leg replantation). Ten patients had revascularizations of 15 micro level subtotal amputations and 1 macrorevascularization of the hand was performed just proximal to the wrist joint). An informed consent was obtained from all patients, who underwent postoperative directional Doppler-mapping study as well as an angiographic study 2–12 months postoperatively (5.2 months in mean) after a successful replantation. There were 27 male and 3 female patients with mean age of 32 years (14–64 years). Conventional microsurgical techniques were used. There were 40 reconstructed parts, replantation in 22, revascularization in 18 and a total of 66 repaired arterial microanastomoses.

Double evaluation of the circulatory status was made in 30 extremities involved. First a directional Doppler study was done with clinical examination. On the following day a conventional hand angiography was performed. The 'Doppler maps' which were drawn on the basis of Doppler flow study were compared with angiographic findings.

Routine of Doppler flow study

PARKS 806A directional ultrasonic device was used entirely throughout the series. A 9.6 MHz probe was used. The extremity to be examined was kept in warm (37°C) water bath for 10 min before examination and the smoking was not allowed on the same day. Direction of the flow in the main arteries of the wrist and hand or digits were recorded (Fig. 1). This was considered important

Fig. 1 Principle of directional Doppler. The shift ($F\Delta$) in ultrasound frequency is positive or negative according to movement or the velocity of blood flow against or away from the probe

Fig. 2 Compression test or Doppler enhanced Allen's test. In Radial artery occlusion (1a) there may be a strong reverse flow in the distal part of the artery. During compression (1b) the flow will stop or it changes direction depending on the collaterals. When radial artery is patent the normal flow speed (2a) will duplicate during compression (2b)

in double circulation areas (digits, palm, antebrachium, and lower leg). Compression tests were applied on to get information of arterial patterns and dynamic vascular function using Doppler monitored Allen test (Fig. 2). The test was also modified for single finger examination (Fig. 3). The aim was to evaluate if there were other sources of blood supply than repaired vessels to the reconstructed part. A 'Doppler map' was drawn with necessary functional remarks (direction, collateral flow sounds, stenoses) [10]. The points of occlusion were registered and measured.

Routine of angiography

Hand angiograms were performed according to general principles [11]. Axillary plexus blockade with Citanest® 1% (prilocain hydrochloride) in amount of 25–35 ml was used in all examinations. The brachial artery was punctured in the antecubital fossa retrogradely with short teflon cannula for contrast medium injection. The timing of

filming and plexus blockade was tried to adjust optimally for the visualization of the distal vascular tree in all finger replant cases (Fig. 4) and otherwise according to the level of original amputation injury. In case of the patient with successful leg replantation the angiography was done through ipsilateral antegrade transfemoral route in local anesthesia.

Results

In the comparative study the total number of examined arteries (Table 1) was 110. In 103/110 (94%) of the

Fig. 3 Principles of single finger examination with compression tests. In single artery finger the opposite side recordings show either reverse or forward flow depending on site of Doppler examination (D3, D4). During compression of the single artery (C1) whole finger flow will stop at D1–D4. In the option that the RDA is patent the flow direction changes into forward flow on radial side (D3, D4) and into reverse flow proximally on ulnar side (D1) during similar compression

Fig. 4 An angiogram 6 months after successful right thumb replantation at proximal phalanx level. Patient is a 15-year-old girl. RDA function is very normal both in angiography and Doppler examination. UDA is occluded. The venous phase also clearly demonstrates the repaired dorsal thumb vein system a = artery v = vein.

Fig. 5 Five months after four-finger-revascularization due to severe compression injury and proximal phalanx fractures (II–V). Patient is a 21-year-old man. One artery was repaired for each finger. A recanalization phenomenon seen in RDA III on radial side of the middle finger. All repaired arteries had a good forward flow

Table 1. Examined arteries in 30 patients

Examined arteries	Total	Microsurgically repaired		Not repaired
		End-to-end	With vein graft	
DA	90	41	9	40
CDA	8	1	4	3
Radial A	5	4	1	0
Ulnar A	5	3	1	1
Tibial A	2	1	1	0
	110	50	16	44

Table 2. Mistakes and difficulties of interpretation

7/110	(6.4%)	Differences in interpretation of examined arteries	
Erroneous Doppler finding		4 mistakes in total	Reason
D ⁺ A ⁻	A good filling of non-patent RDA (not repaired artery) in a thumb via collaterals from patent UDA was misinterpreted	Compression test inadequate	
D ⁻ A ⁺	Flow not diagnosed in a thumb UDA when RDA was clearly patent	Inadequate Doppler study	
D ⁺ A ⁻	In a finger with one healthy III UDA the flow was heard in a nonrepaired III-RDA	Compression test inadequate	
D ⁻ A ⁺	Negative mistake detecting a patent ulnar artery when radial artery flow was clearly dominant	unusual location of artery at scar	
Erroneous angiographic finding		3 mistakes in total	Reason
D ⁺ A ⁻	Due to no feeling in index finger UDA	Wrong timing or poor blockage	
Two vessels	Impossible to separate between radial and ulnar (RDA/UDA) in two thumbs with 1 patent artery	Difficulty in projection	

examined arteries the findings were identical according to these two different methods. The assessment of 7 arteries was different as shown in the Table 2.

In two cases it was impossible to differentiate in angiographic study whether the examined artery was ulnar or radial digital artery of the thumb. This happened because of the projection difficulty in the angiographic examination of those hands. In the Doppler study the correct side of the vessels in the same thumbs was easy to locate. Functionally the findings were, however, identical. In one case a reconstructed digital artery of the index finger did not fill in angiography although it was clearly patent and functioning in Doppler examination (Doppler + Angio-finding). Also in three cases an erroneous Doppler finding was recorded (2 Doppler + Angio – findings and 1 Doppler-Angio + finding). Additionally a mistake of the Doppler examination in one patent ulnar artery was probably due to a special location of the artery in deep scar tissue at wrist level. This conducted in the interpretation of a nonfunctioning vessel although angiography

showed nice filling of the same artery. Same hand had much better flow in radial artery and also an exceptionally large median artery. This can partly explain that the resultant flow was diminished to undetectable level but it should have been noticed with compression tests. We found (Table 3) two arteries where Doppler assessment of the vessel was patent but the angiographic finding showed some kind of semi-occluded condition of the artery (Fig. 5). This was considered as a recanalization phenomenon. Recanalization showed good vessels with semi occlusion segments with good distal flow. Neovascularization after thrombosis at anastomosis site appeared in two avulsion thumbs with nonpatent arteries. There were thinner than normal vessels with many tiny collaterals through the scar area according to angiography. Doppler examination told about minimally functioning vessels.

In comparing the accuracy of the Doppler, we got an Doppler error in 4/110 (3.6 %) vessels and in 3/110 (2.7%) an error was considered to be due to angiographic study.

Table 3. Special findings in angiography

	Doppler and angiography functionally similar Angiography Abnormal vessel structure	Doppler finding
2 Fingers 2 DA	recanalization with acceptable filling	good forward flow
2 Thumbs (avulsion)	neovascularization and minimal filling	poor flow sounds

Table 4. Patency in 66 microsurgically repaired arteries

	OPEN in Doppler study	Percentage	OPEN in Angiographic study	Percentage
DA	35	70%	35	70%
CDA	3	Larger vessels 75%	3	Larger vessels 81%
Radial A	5		5	
Ulnar A	2		3	
Tibial A	2		2	
	47	71%	48	73%

Patency rates in reconstructed arteries (Table 4)

According to the Doppler flow study the patency rate of 66 microsurgically repaired arteries was 47/66 (71%). Digital arteries were open according to Doppler in 35/50 vessels (70%). Common digital arteries (metacarpal level) and forearm arteries showed a patency rate of 12/16 vessels (75%) including one negative Doppler mistake. In the angiographic study the total patency rate was 48/66 vessels (73%). The patency rate in digital arterial anastomoses was also 35/50 (70%) as in Doppler study but in larger arteries 13/16 (81%). The arterial repair with or without grafts had possibly some effect on patency rates but this reflects also the difficulty of the injury. The all over patency was 74 after direct repairs and 69% after vein graft repairs. The number of vein grafts was only 16 out of 66 vascular reconstructions. The vein grafts were utilized after two avulsion type thumb amputations and after one middle finger amputation (due to ring avulsion) and in two macro replantation cases (elbow level and mid shaft leg level). Otherwise vein grafts were used in the cases, where a primary thrombosis was achieved when trying the repair first with direct anastomosis.

Discussion

The observed patency rates are in concordance with previous studies. Bacakoglu et al. 2001 [6] reported 77.2% patency rate after 44 post-traumatic forearm arterial repairs. At digital artery level Walaszek and Zyluk in 2008 [8] found full patency in 74% and a disturbed or impaired flow in 10 (26%) studied arteries when studying the flow characteristics with a 20 MHz Doppler probe in

38 replanted digits. Lee et al. [9] in 2005 studied 18 patients, who had finger amputations and they found the results from Doppler and angiography quite equal in assessing patency rates. Their patency rates were 63% using Doppler and 57% with angiographical examination.

Their study was done at early postoperative phase or within 60 days from replantation. In the reconstruction of forearm arteries Daoutis et al. in 1992 [12] has reported 74.5% patency rate.

Doppler ultrasound flow studies are capable for highly reliable late patency rate control and for functional evaluation after microvascular surgery. The Doppler examination is noninvasive and easily repeatable what an angiography is not. The latter carries a small but real risk to the patient [13]. In the present study no harmful side-effects of angiography were recorded. Some difficulty in anatomical interpretation may be evident when thrombosis and recanalization or neovascularization phenomenon has taken place. Flow properties in the double or triple circulation areas, such as finger, hand, antebrachium, foot or leg, can lead the examiner to erroneous interpretation when the resultant flow in a particular area has no forward or reverse resultant flow phenomenon. The accuracy in Doppler examination is influenced by the examiners experience and his knowledge of vascular anatomy and also by the meticulous examination using different compression tests. Both methods need meticulous technique. It is recommended to relieve the spasm of peripheral vessels as completely as possible in both examinations in order to get reliable and fully informative results.

Doppler mapping is a practical means in the late control of anastomosed peripheral vessels. It can be also recommended as a preceding examination for such patients

where suspicion of vascular occlusion is present before any diagnostic angiography is planned for extremity. In many cases this ultrasonographic information is alone enough. Angiography should be used when vascular anatomy needs proper visualization i.e. in cases when Doppler study and clinical findings are confusing or there is a need for secondary vascular procedures and the pre-operative planning needs more details. For example: the planning of complex free tissue transfers in the reconstruction of the same extremity at a later stage. In the future, noninvasive MR angiography techniques will probably be used instead of conventional angiography as these methods are under fast development. This will require more economical resources and has still limitations in accuracy at digital arterial level [14].

Conclusion

Thirty patients after replantation or revascularization operation were examined 2–12 months postoperatively with two different methods to assess the clinical patency rate as well as accuracy of the noninvasive directional Doppler investigation. The study showed that careful Doppler mapping in clinical practice is capable for equal results with angiography. Doppler as a noninvasive, simple and inexpensive method can be used as a routine method and angiography should be reserved for unclear cases only with special postoperative needs. The same principle can be applied in many preoperative situations in the planning of microvascular reconstructive operations for example in toe-to-hand or other free tissue transplantation surgery.

Abbreviations

DA	Digital artery
CDA	Common digital artery
RDA	Radial digital artery
UDA	Ulnar digital artery

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