Eur J Vasc Endovasc Surg **28**, 310–316 (2004)
doi: 10.1016/j.ejvs.2004.06.005, available online at http://www.sciencedirect.com on SCIENCE DIRECT®

Evaluation of Flow Hemodynamics by Color-Doppler Following Two Different Brachial Arterial Repair Techniques

S. Kılıç,[1*] A. K. Bacakoğlu,[1] A. Y. Göktay,[2] M. H. Özkan,[1] G. Ergör,[3] K. Bayatlı,[4] A. Gürbüz[4] and A. Ekin[1]

[1]*Division of Hand Surgery, Department of Orthopaedics and Traumatology,* [2]*Department of Radiology,* [3]*Department of Public Health, Dokuz Eylül University School of Medicine, and* [4]*Department of Cardiovascular Surgery, Atatürk Education and Research Hospital, İzmir, Turkey*

Objectives. *We compared the clinical and hemodynamic results following surgical repair of traumatic brachial artery injury using two different techniques micro- and macrovascular repair*
Materials and Methods. *This was a retrospective study of 27 patients who had sustained penetrating, clean cut injuries of the brachial artery. Macrovascular techniques and a saphenous vein graft was used in 13 patients, while 14 patients were treated by primary microsurgical technique. Postoperatively, patients were followed for a mean of 26 months. All patients had color Doppler examination of the brachial artery, digital artery pressures and transcutaneous oxygen saturation determined.*
Results. *Clinical results based on distal pulses, Allens test and digital pressures were similar in the two groups. Color Doppler showed 8/13 anastomotic stenoses in macrovascular vein grafted repairs and 2/14 in microvascular repairs ($p < 0.05$). The ratio of flow velocity proximal compared distal to the injury was significantly decreased in patients who had macrovascular repairs.*
Conclusion. *Using ratio between proximal and distal site of anastomosis maximal peak systolic velocity as a objective color Doppler parameter, we were able to demonstrate differences in the hemodynamic status following macrovascular repair with vein grafts and microvascular primary repair. The results emphasize the importance of using a standard repair technique for similar injuries rather than the preference of the surgeon.*

Key Words: Brachial artery; Clean-cut injury; Color-Doppler Sonography; Macrovascular; Microvascular surgery; Flow hemiodynamic; Vein graft; Upper extremity.

Introduction

The brachial artery is the most frequently injured artery following traumatic upper extremity lacerations (50%).[1–8] The success of arterial repair not only depends on the etiology of the injury but also on the repair technique. An unsuccessful repair contributes to a number of complications including symptoms associated with an ischemic hand or, in severe cases, distal amputations.[1,4,7,9]

Following brachial artery repair, reconstruction is primarily evaluated by palpation of the distal pulses (radial and ulnar artery). However, although this enables determination of patent anastomoses it does not reveal whether the perfusion and hemodynamics of the distal extremity is completely normal. The aim of this study was to use color Doppler to compare the hemodynamics of the upper extremity following repair of brachial artery lacerations with the same etiology and at the same location using two different surgical techniques.

Materials and Methods

The study group consisted of 27 patients (23 male, four female) who had sustained penetrating clean-cut glass or knife injuries of the upper extremity. The mean age was 30 (range 10–73) years. All lacerations were located between the antecubital fossa above the bifurcation of the brachial artery and lower half of the volar arm. In 15 patients, the injury was on the dominant side. All patients had concomitant vein, muscle and tendon injuries and 18 patients had associated nerve injuries. None of them had bony or

*Corresponding author. Dr S. Kılıç, MD, Dokuz Eylül, Division of Hand Surgery, Department of Orthopaedics and Traumatology, University School of Medicine, 35340 Inciralti, İzmir, Turkey.

1078–5884/030310 + 07 $35.00/0 © 2004 Elsevier Ltd. All rights reserved.

articular injuries. All patients had a minimum follow-up of 6 months (mean 26, range 6–57).

Patients were treated in two different surgical centers. In one center, brachial artery repair was performed by a vascular surgeon using an autogenous reversed interpositional saphenous vein graft with a running suture technique (6-0 prolen, Ethicon). Two patients, who had secondary revision surgery due to aneurysm and occlusion, one patient who had limited elbow motion and one patient with early post-operative deep infection were excluded from the study in this group. The time period of these evaluated 13 patients were June 2000–December 2002, and the mean age of this group was 30 years. The mean length of vein graft was 4.5 cm (range 3–6 cm). Following completion of brachial artery repair, nerve and soft tissue injuries were repaired by neurosurgeons and orthopedic surgeons respectively, at the same session. Three patients also underwent secondary nerve surgery. The mean follow-up time for this group was 21 (range 6–36) months.

In the second center patients were treated in a specialized hand-surgery clinic. Two patients due to diabetes and systemic or peripheral vascular disease, and one patient with contralateral neurovascular injury on the wrist level were also excluded from the study in this group. The brachial artery was repaired end to end under surgical-loupe magnification (× 4.5, distance 32 cm) using a vascular approximator with an interrupted suture technique (8-0 prolene, Ethicon). The associated soft tissue and nerve lacerations were repaired simultaneously by the same surgeon using microsurgical techniques. In this group, no secondary operations were performed. The mean age of these patients was 34 years and their time period was September 1998–January 2001. The mean follow-up time of the microvascular repair group is 30 (range 17–57) months. Concominant vein repair or postoperative fasciotomy was performed routinely in any of the patients. The mean immobilization time with long arm cast-brace for all patients was 4.5 weeks (range 4–6). All patients underwent a non-standardised rehabilitation program.

All patients were evaluated clinically by the Allen test and palpation of the radial and ulnar artery pulses. We used cold sensitivity scala of Mc Cabe for symptomatologic evaluation of patients since cold intolerance is one of the most important persistent symptom following these type of injuries.[10] Digital arterial pressures of the 1st, 3rd and 5th digits of both hands were obtained using an autoinflate digital electronic BP manometer and brachial pressures using a Microlife BP TO11 semiautomatic manometer. The digital brachial indices (DBI) for three digits were then calculated. The transcutaneous oxygen saturation of the 1st and 5th digits of both hands was also measured (Sp02%, Nellcor Puriton Bennet, NPB).

Color Doppler (HDI 5000 ATL, Bothell, USA with linear transducer 5–12 MHz) was used to determine the distal physiologic flow characteristics, patency and structure of anastomoses following vascular repair. All color Doppler examinations were performed at the same anatomic location, without arterial compression, after 20 min resting at room temperature with the patient lying in the supine position and the elbow flexed at 20°. Color Doppler examinations were performed by the same radiologist. The parameters were evaluated proximal and distal to the brachial artery repair, at the site of anastomoses, at the distal radial and ulnar arteries of both extremities (5 cm above volar flexor crease of the wrist) and also the midpoint of the graft for patients in macrovascular vein grafted repair group. The presence of stenoses, diameter changes, flow pattern, turbulence and the presence of valve and intimal hyperplasia were recorded in macrovascular vein grafted patients. Maximal peak systolic velocity (V_{max}) values were calculated for each repaired artery and distal forearm arteries.

We defined anastomotic stenosis as decreased diameter and/or V_{max} ratio >2.0 at this level comparing the V_{max} at the repair site with the proximal part of the native brachial artery. We defined the increase in the diameter of the graft as an increase of the luminal diameter at the level of the graft compared to the proximal brachial artery with considerable changes of the spectral wave-form; such as monophasic signals throughout the graft. The results of color Doppler examinations of the injured artery were compared to the contralateral side and the results from patients with macrovascular vein grafted repair were compared to those of microvascular repaired patients. In addition, in order compare results of two techniques for V_{max} value the ratio was calculated. The Ratio; defined as the ratio of V_{max} value proximal to the repair to V_{max} values in the distal radial and ulnar arteries.

Statistical analyses were performed using SPSS for Windows version 11-0. The Mann–Whitney U-test was used for analyses between groups, the Wilcoxon Rank Test for analyses within groups and Spearman test for correlation.

Results

In two patients, the radial arterial pulse was absent and the Allen test was positive for the radial artery,

probably due to anatomical variation rather than associated with arterial injury and repair. Except for these two patients all distal arterial pulses were present and the Allen test was negative. There was no significant difference in DBI measurements between the injured and uninjured 1st, 3rd or 5th digits. There was a significantly lower oxygen saturation of the 5th digit in the injured side compared to the uninjured side in the patients from microvascular repaired group ($p = 0.02$).

Anastomotic stenosis was found on color Doppler examination in 8/13 patients from macrovascular vein grafted repair group, although six of these were relative constrictions due to graft dilatation. This compares to only 2/14 stenoses in microvascular repaired group, while the remaining 12 patients from this group had anatomical congruence at the anastomotic level (Chi-squared: $p < 0.05$) (Fig. 1). Eight patients had an increase in graft diameter. Tortuosity was observed in four graft, and three long grafts were detected by color Doppler. In one patient, valves in the vein graft were observed and intimal hyperplasia in the graft wall seen in another two patients (Fig. 2). In three patients with long grafts, where the site of repair was located close to the bifurcation reduction of flow velocity in the distal region when the elbow was flexed to 90° was observed (Fig. 3). Spectral analysis, just distal to the repair site revealed a three phasic flow pattern in seven patients from macrovascular vein grafted and two from microvascular repaired patients. In five patients from group 1, a turbulent flow pattern with associated decreased velocity in the graft and increased velocity at the stenotic anastomoses were seen. (Figs. 1–3).

The mean ($\pm$SD) V_{max}, for the uninjured distal radial artery from both groups was 60.5 $\pm$ 19.2 cm s^{-1} and for the ulnar artey was 69.2 $\pm$ 17.5 cm s^{-1}. Comparing the values for the injured to the uninjured side, a significant decrease in V_{max} was found for values obtained from the ulnar artery of patients with macrovascular vein grafted repairs ($p = 0.013$). Ratio of V_{max} proximal to the repair to V_{max} in the distal radial artery was significantly increased for macrovascular

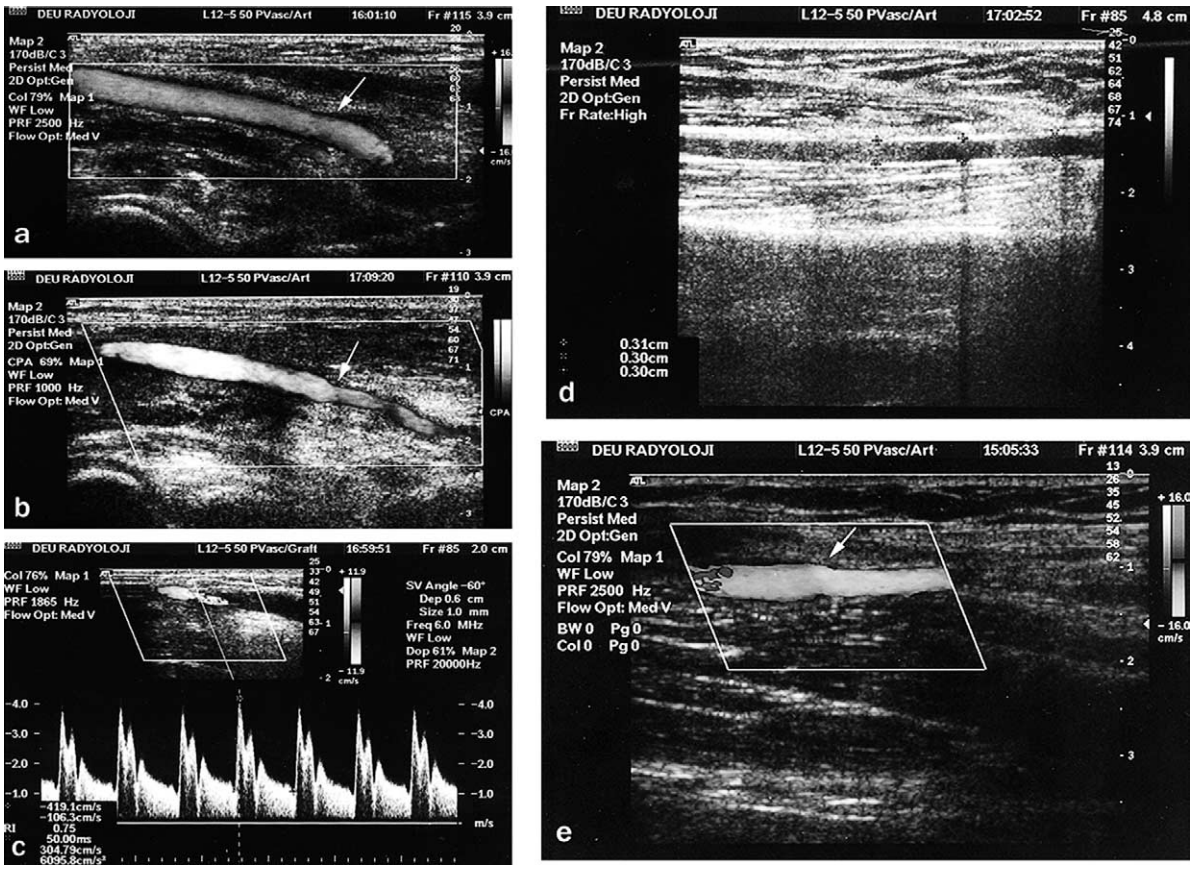


Fig. 1. (a) Normal distal anastamosis of a vein graft (group1). (b) Relative stenosis at the distal anastamosis due to graft dilatation (group 1). (c) Stenosis at the proximal anastamosis of a vein graft (upper panel). Spectral analysis showing an increased V_{max} at the stenotic area (lower panel) (group1). (d) Anastamosis following primary repair (group 2). (e) Stenosis following primary anastomosis (group 2).

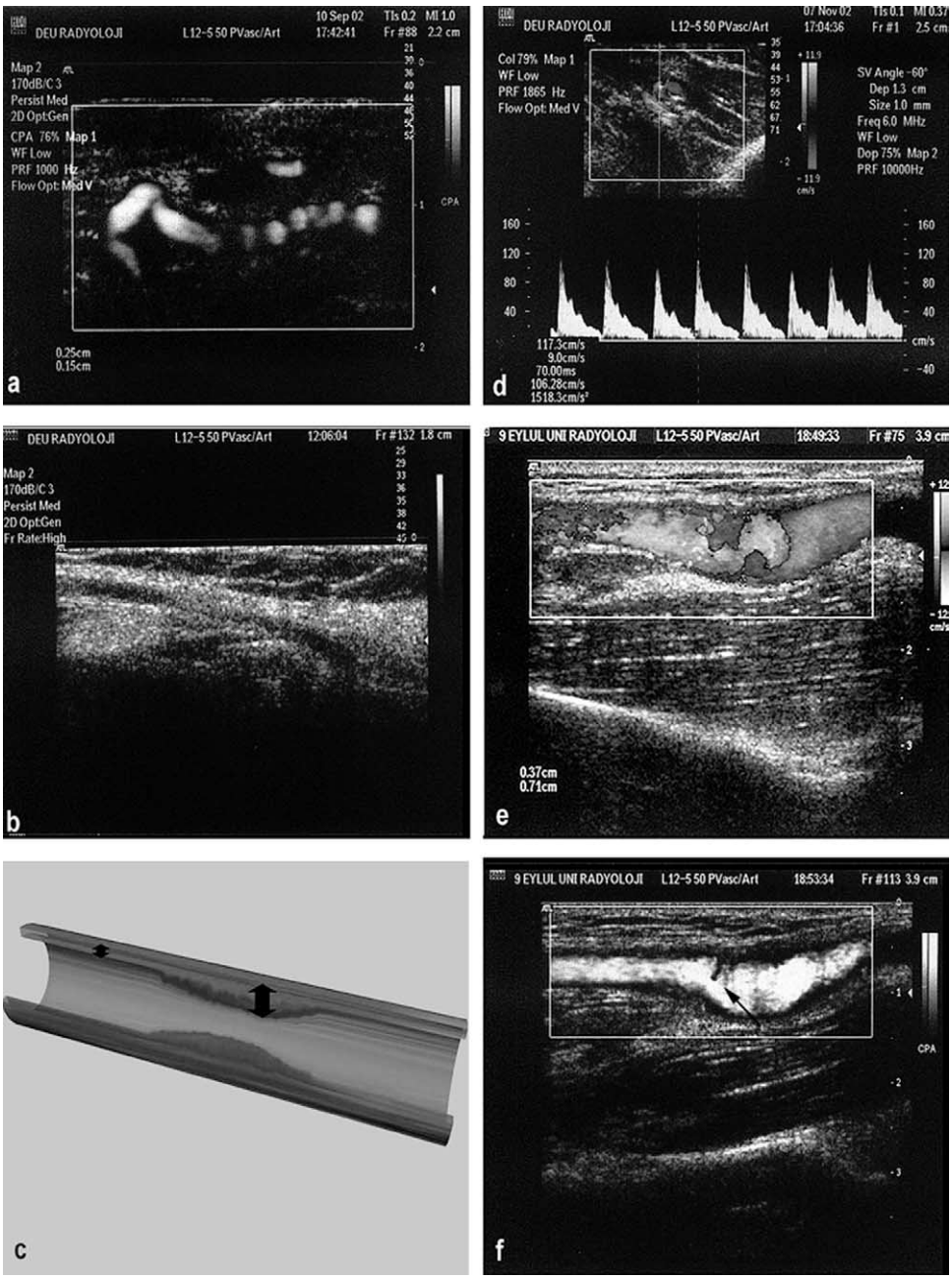


Fig. 2. (a) Long graft showing tortuosity. (b) Narrowing of the lumen due to intimal hyperplasia in the graft. (c) Schematic illustration of intimal hyperplasia as seen in Fig. 2(b). (d) Turbulence within the vein graft. (e) Dilatation of a graft. (f) Demonstration of a valve in a saphenous vein graft.

vein grafted patients compared to microsurgical repair ($p = 0.01$).

Mean Mc Cabe cold intolerance scores were 135.3 (0–314) in macrovascular vein grafted patients and 66.4 (0–270) in microvascular repair ($p = 0.048$). For macrovascular vein grafted patients decrease of V_{max} in radial artery compared to uninjured site also correlated with Mc Cabe Scores ($p = 0.036$, $r = 0.6$).

Discussion

In our study, we sort to compare the hemodynamics following repair of the brachial artery using two different surgical approaches. Although this was not a randomised trial, we only choose patients fulfilling specific criteria in order to make the two techniques as comparable as possible. The major differences were

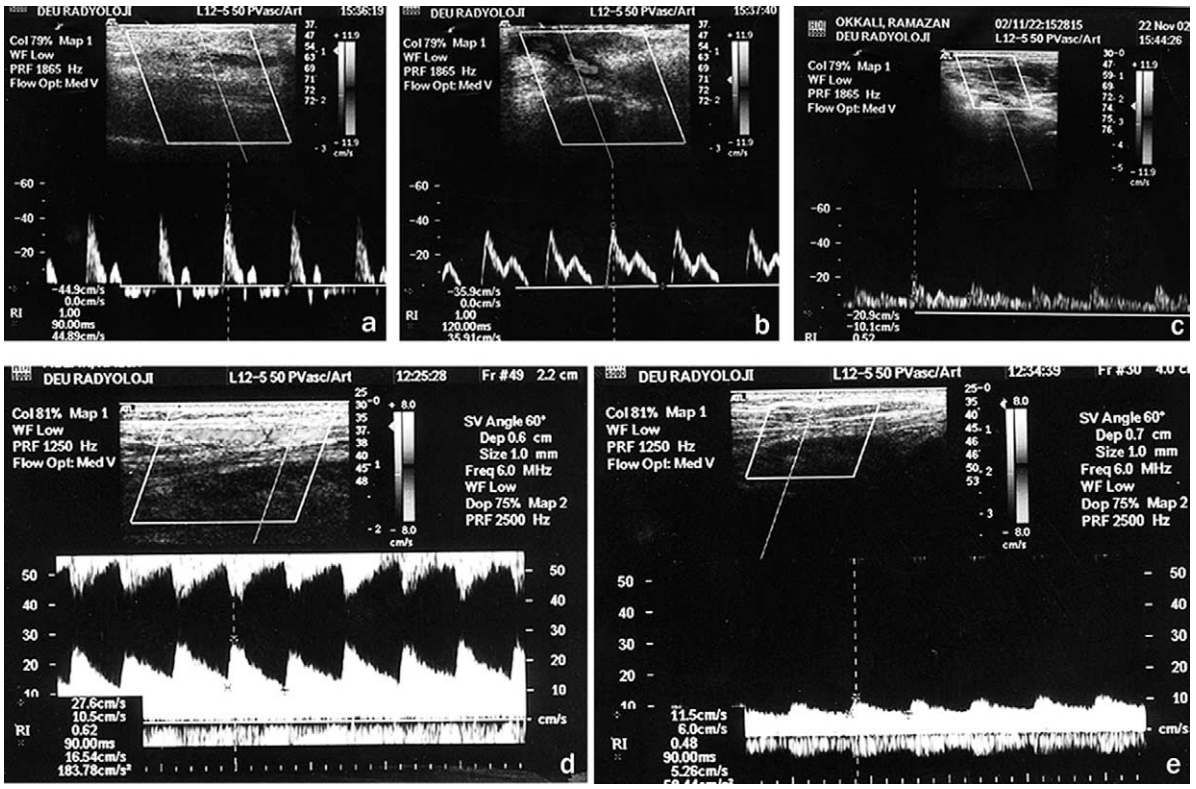


Fig. 3. (a) Normal triphasic flow pattern. (b) Impaired triphasic flow pattern within a graft. (c) Impaired flow pattern distal to a graft. (d) Flow characteristics of the distal radial region from a patient with a long graft with the patients elbow extended. (e) The same patient as in Fig. 3(d) with the elbow flexed showing a reduction in V_{max}.

the repair techniques using a graft with macrovascular anastomosis and microsurgical primary anastomosis. We used clinical and radiodiagnostically derived parameters to compare the two techniques. Following brachial artery repair patency is usually evaluated by examination of the distal pulses and assessment of anastomoses radiodiagnostically.[1,2,4,7,9] However, the patency of a repair does not always correlate with clinical symptoms or necessarily mean that the distal hemodynamics are normal. As we found in our study, clinical examination of the distal radial and ulnar arterial pulses combined with the Allen test are not sufficient alone to assess the hemodynamic status following repair.[11,12] DBI and transcutaneous oxygen saturation are often used in the evaluation of peripheral vascular and ischemic disorders, however, in this study we did not find them useful for detailed assessment of distal hemodynamics.[13,14]

Angiography is recognized as the gold standard for demonstrating the anatomy of anastomoses and the distal vessels, however, this is an invasive technique that does not provide information on the dynamics of flow.[15] In this context, color Doppler has several advantages in that. It is noninvasive and provides direct and indirect information on the hemodynamics of flow. Disadvantages include the need for operator experience, the effect of body hemodynamics on measurements and the sensitivity of the device. In addition, measurements should be performed under standard conditions with good patient cooperation.[16–18,19] A number of parameters derived from color Doppler measurements have been used to describe the newly formed hemodynamic status and correlated with clinical symptoms.[11,15,19–23] In our study, we used V_{max} spectral measurement as well as color Doppler evaluation of the arteries. V_{max}, the peak systolic velocity, is a reliable direct measurement used to evaluate the extremity arteries which normally have a triphasic flow spectrum with a dominant systolic blood supply while resting. V_{max} is the most appropriate spectral parameter to demonstrate the degree of stenosis at the anastomosis.[12,15,19–24] We found a significantly decrease in the V_{max} in ulnar artery of the injured compared to the uninjured side and significantly increase of the ratio of V_{max} proximal to the repair to V_{max} in the distal radial artery in macrovascular grafted patients. These findings suggest that the hemodynamics following microsurgical primary repair of the brachial artery are closer to

those in the uninjured side compared to those found following macrovascular repair with a vein graft.

As there is little data comparing the hemodynamic status of the peripheral arteries following different repair techniques, we decided to use ratio in order to further compare the two different repair techniques.[24,25] Ratio of V_{max} showed changes of perfusion from proximal to distal. It was able to show the hemodynamics differences between these two techniques by using this ratio method. We also compared distal perfusion in the injure limb with the normal side. There is no difference in the values of flow parameters between the dominant and non-dominant sides, and therefore it is important to compare the arterial perfusion following repair, as the patient acts as their own control.[11,26]

Due to the wide diameter of the brachial artery, microsurgical repair is not absolutely necessary, however, as it is an atraumatic technique we would expect to see better patency compared to macrovascular techniques especially in the early period following repair.[6–9] In the late follow-up period, as in our study, the effect of anastomosis technique is questionable because in a high proportion of cases there is relative stenosis due to widening of the graft. We observed this phenomenon in 6/8 patients with anastomotic stenosis from the macrovascular group. This suggests that the major factor influencing hemodynamic impairment is not the macrovascular technique but the use of a graft, which might not always be necessary especially in clean cut injuries. In addition, there is a chance of graft occlusion due to factors such as turbulence in graft blood flow, increase in compliance, presence of valves and intimal hyperplasia.[27,28]

There are a number of reasons why the vascular surgeons chose to use grafts, these include the expertise of the surgeon in preparation of the stumps without using a tourniquet, so that the anastomosis can be performed with the elbow extended, to allow wide debridement of the vascular stumps and reduced use of a vascular approximator. Although short vein grafts were used in these patients the long and tortuous appearance on the Doppler scan can be related to the above factors. Previous reports indicate that vascular surgeons will use grafts in as many as 25–35% of brachial artery reconstructions irrespective of the etiology of the injury.

Cold intolerance is the persistent symptom of the clinical results of hemodynamic changes in our patients. The cold sensitivity scale of Mc Cabe is an important diagnostic criteria to show upper extremity ischemia.[10] Mc Cabe scores show significant difference between the patients in favor of microvascular repaired patients. There is correlation between the decreased distal radial artery V_{max} and Mc Cabe score. This correlation is important to show the relation between the impaired perfusion and ischemic symptomatology. Although the correlation studies showed that the decreased V_{max} ratios in the radial artery is important for cold intolerance in all patients, it should be kept in mind, that the concomitant nerve injury and recovery effects these results significantly.[29,30]

In conclusion, we found a qualitative and quantitative differences in the flow hemodynamics as assessed by color Doppler examination following brachial artery reconstruction of clean cut injuries using either macrovascular repair with grafts or microvascular primary repair. This suggests that the newly described ratio method derived from color Doppler parameters might be the appropriate instrument to compare the hemodynamics following different repair techniques. However, it will need to be tested in a larger homogeneous group of patients preferably in a prospective setting and it will need to correlate the hemodynamic parameters to patients' sympotomatology. Furthermore our study emphasizes the importance of using a standard repair technique for similar injuries rather than the decision being made in accordance to the surgeons preference.

References

1 Hardin WD, O'Connell RC, Adinolfi MF, Kerstein MD. Traumatic arterial injuries of the upper extremity: determinants of disability. *Am J Surg* 1985; **150**:266–270.
2 Degiannis E, Levy RD, Sliwa K, Potokar T, Saadia R. Penetrating injuries of the brachial artery. *Injury* 1995; **26**: 249–252.
3 Borman KR, Snyder WH, Weigelt JA. Civilian arterial trauma of the upper extremity. An 11 year experience of 267 patients. *Am J Surg* 1984; **148**:796–799.
4 Hermreck AS, Slifers TM, Reckling FW, Asher MA, Hardin CA. Traumatic vascular injuries. Methods and results of repair. *Am J Surg* 1974; **128**:813–817.
5 Hunt CA, Kingsley JR. Vascular injuries of the upper extremity. *South Med J* 2000; **93**(466):68.
6 McCready RA. Upper-extremity vascular injuries. *Surg Clin North Am* 1988; **68**:725–740.
7 McCroskey BL, Moore EE, Pearce WH, Moore FA, Cota R, Sawyer JD. Traumatic injuries of the brachial artery. *Am J Surg* 1988; **156**:553–555.
8 Fields CE, Latifi R, Ivatury RR. Brachial and forearm vessel injuries. Vascular trauma: complex and challenging injuries, Part 2. *Surg Clin North Am* 2002; **82**:105–114.
9 Ashbell TS, Kleinert HE, Kutz JE. Vascular injuries about the elbow. *Clin Orthop* 1967; **50**:107–127.
10 McCabe SJ, Mizgala C, Glickman L. The measurement of cold sensitivity of the hand. *J Hand Surg [Am]* 1991; **16**(6):1037–1040.
11 Doscher W, Viswanathan B, Stein T, Margolis IB. Hemodynamic assessment of the circulation in 200 normal hands. *Ann Surg* 1983; **198**:776–779.
12 Bacakoglu AK, Ozkan MH, Coskunol E, Ozdemir O, Ekin A.

Multifactorial effects on the patency rates of forearm arterial repairs. *Microsurgery* 2001; **21**:37–42.
13 Zimmerman NB, Zimmerman SI, McClinton MA, Wilgis EF, Koontz CL, Buehner JW. *J Hand Surg [Am]* 1994; **19**:17–21.
14 Meland NB, Core GB, Hoverman VR. The radial forearm flap donor site: should we vein graft the artery? A comparative study. *Plast Reconstr Surg* 1993; **91**:865–870.
15 Trager S, Pignataro M, Anderson J, Kleinert JM. Color flow Doppler: imaging the upper extremity. *J Hand Surg [Am]* 1993; **18**: 621–625.
16 Schwartz M, Weaver F, Yellin A, Ralls P. The utility color flow Doppler examination in penetrating extremity arterial trauma. *Am Surg* 1993; **59**:375–378.
17 Rothkopf DM, Chu B, Gonzalez F, Borah G, Ashmead D, Dunn R. Radial and ulnar artery repairs: assessing patency rates with Color Doppler ultrasonographic imaging. *J Hand Surg [Am]* 1993; **18**:626–628.
18 Bergstein JM, Blair JF, Edwards J, Towne JB, Wittmann DH, Aprahamian C, Quebbeman EJ. Pitfalls in the use of color-flow Duplex ultrasound for screening of suspected arterial injuries in penetrated extremities. *J Trauma* 1992; **33**:395–402.
19 Baxter GM, Polak JF. Lover limb colour flow imaging: A comparison with ankle: brachial measurements and angiography. *Clin Radiol* 1993; **47**:91–95.
20 Simon AC, Flaud P, Levenson J. Non-invasive evaluation of segmental pressure drop and resistance in large arteries in humans based on a Poiseuille model of intra-arterial velocity distribution. *Cardiovasc Res* 1990; **24**:623–626.
21 Herz DB, McLorie GA, Hafez AT, Rodgers-Herz C, El-Ghoneimi A, Shuckett B *et al.* High resolution ultrasound characterization of early allograft hemodynamics in pediatric living related renal transplantation. *J Urol* 2001; **166**:1853–1858.
22 Simon AC, Levenson J. Abnormal wall shear conditions in the brachial artery of hypertensive patients. *J Hypertens* 1990; **8**: 109–114.
23 Fairlie FM, Walker JJ. Does the brachial artery Doppler flow velocity waveform reflect changes in downstream impedance ? *Am J Obstet Gynecol* 1991; **165**:1741–1744.
24 Ranke C, Creutzig A, Alexander K. Duplex scanning of the peripheral arteries: correlation of the peak velocity ratio with angiographic diameter reduction. *Ultrasound Med Biol* 1992; **18**: 433–440.
25 Polak JF. Peripheral arterial disease. Evaluation with color flow and duplex sonography. *Radiol Clin North Am* 1995; **33**:71–90.
26 Kamper AM, Chang PC. Effects of arm dominance and brachial artery cannulation on forearm blood flow measured by strain-gauge plthysmography. *Clin Sci (Lond)* 1999; **97**:539–546.
27 Mitchell III FL, Thal ER. Results of venous interposition grafts in arterial injuries. *J Trauma* 1990; **30**:336–339.
28 Mills NL, Everson CT. Vein graft failure. *Curr Opin Cardiol* 1995; **10**:562–568.
29 Visse PA, Hermreck AS, Pierce GE, Thomas JH, Hardin CA. Prognosis of nerve injuries injured during acute trauma to peripheral arteries. *Am J Surg* 1980; **140**:596–599.
30 Shaw AD, Milne AA, Chiristie J, Jenkins AMcL, Murie JA, Ruckley CV. Vascular trauma of the upper limb and associated nerve injuries. *Injury* 1995; **26**:515–518.

Accepted 3 June 2004