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Intraoperative Renal Duplex Sonography: a Valuable Method for Evaluating Renal Artery Reconstructions

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Objectives: *to determine the ability of duplex sonography to intraoperatively detect technical problems with renal artery reconstructions.*
Design: *retrospective evaluation of a standard protocol.*
Patients and methods: *the outcome of intraoperative duplex was compared with postoperative angiography, surface duplex, MRA, echo or direct inspection in case of re-exploration in 77 renal artery reconstructions in 62 patients. These included six extracorporeal reconstructions, eight and 17 reconstructions with an artery and autogenous vein respectively, 10 renal artery re-implantations in the aorta (prosthesis), 32 endarterectomies and four reconstructions of kidney transplant vessels.*
Results: *intraoperative duplex was normal in 67/73 reconstructions with sufficient data. In six cases technical problems were revealed by intraoperative duplex and the reconstruction was re-explored. After re-exploration intraoperative duplex was normal in all cases. Confirmatory studies demonstrated normal results in 61/64 reconstructions with normal intraoperative duplex and abnormal results in 6/6 reconstructions with technical problems revealed by intraoperative duplex. Three reconstructions with normal intraoperative duplex occluded as demonstrated by angiography less than 2 weeks after surgery.*
Conclusions: *renal duplex sonography is a valuable method available for intraoperative detection of technical problems. Haemodynamic duplex data were less important than B-mode imaging in discriminating between normal and abnormal reconstruction.*

Key Words: Ultrasonography; Doppler; Duplex; Renal artery; Renal artery/us (ultrasonography).

Introduction

As with all vascular repairs, renal artery reconstruction may fail because of technical problems. These problems can occur especially at anastomoses, suture lines, end-points of endarterectomies, and include stenosis, local thrombosis, intimal flaps or an incomplete endarterectomy. The optimal way to identify and correct these technical errors is during the operation. Such a test should be both sensitive and specific. After completion of most peripheral artery reconstructions intraoperative angiography has been advocated. However, angiography of renal artery reconstructions is difficult to use for several reasons. First, it provides evaluation in only one projection and stenosis can easily be missed. Second, many of the patients submitted to renal artery reconstruction have renal insufficiency so that the risk of contrast nephropathy is increased.[1,2] Duplex sonography is not associated with these disadvantages and is emerging as a useful procedure for evaluating renal artery reconstructions.[1–4]

In this retrospective cohort study we report our experience with an intraoperative duplex protocol to determine its ability to detect technical problems after completion of renal artery reconstructions.

Material and Methods

Patient material

A cohort of consecutive patients that had been referred for renal artery reconstruction between January 1991 and June 1998 was identified retrospectively. During this period 204 renal artery reconstructions were performed and in 77 cases intraoperative duplex was used. These were performed on 62 patients (40 men and 22 women) of mean age 57.8 years (range 16 to 80 years). The use of duplex was dictated by its

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availability, and that of a technician, rather than by the operating surgeon or the type of reconstruction. In the patients without intraoperative duplex, the reconstruction was only evaluated clinically at the time of surgery. However, postoperatively all patients underwent angiography or MRA.

Operative management

Forty-nine patients underwent unilateral renal artery reconstruction (one patient underwent two different types of reconstructions), and 13 patients underwent bilateral renal artery reconstruction (one patient underwent three different types of reconstructions). Extracorporeal reconstruction was used in six cases, reconstruction with an artery in eight cases, reconstruction with an autogenous vein in 17 cases, renal artery reimplantation in the aorta (or aortic prosthesis) in 10 cases and endarterectomy in 32 cases. Finally, four were reconstructions of kidney transplant vessels.

Technique of intra-operative renal duplex sonography

Intraoperative duplex is performed by placing a mechanical probe in a sterile sheath filled with acoustic gel. Saline solution, either in the wound or in a rubber glove, was used to facilitate scanning. The renal arteries are scanned through the surgical incision from a number of different angles. The peak systolic velocity (PSV) and end-diastolic velocity (EDV) were measured and the renal aortic ratio or RAR (=renal artery PSV/aorta PSV) and the resistive index or RI (=(PSV–EDV)/PSV) calculated.

Interpretation was as follows: (1) normal renal artery reconstruction indicated by a normal B-mode image and PSV<1.8 m/s; (2) technical problems indicated by an abnormal B-mode image (e.g. intimal flap, thrombus, dissection) and PSV<1.8 m/s; (3) normal renal artery reconstruction indicated by a normal B-mode image and PSV>1.8 m/s (diffuse); (4) technical problems indicated by an abnormal B-mode image (stenosis) and PSV>1.8 m/s (focal). If multiple measurements were obtained, the measurement with the highest PSV was used, unless another measurement was more relevant due to stenosis or occlusion revealed by postoperative study at the location of that measurement.

Study methods and data collection

Patient records were reviewed to determine gender, age, intraoperative duplex data and confirmatory postoperative angiography data. In four reconstructions there were no intraoperative duplex data recorded, leaving 73 reconstructions for further study. In nine cases no postoperative confirmatory study was available. In these cases the following additional information was reviewed; postoperative morbidity and mortality and renal perfusion scan results. In the remaining cases the confirmatory study consisted of postoperative angiography in 54 cases, postoperative surface duplex in six cases, postoperative MRA in three cases and postoperative echo in one case. In cases of a re-exploration, the confirmatory study consisted of direct visual inspection of the opened renal artery. In addition, the results of renal artery reconstruction without intra-operative duplex ($n=127$) were evaluated by routine postoperative imaging. Considering the postoperative confirmatory studies, the study closest in time to the reconstruction (usually at discharge) was used for comparison, unless information in this study could not be interpreted. Additional information was reviewed where intraoperative duplex was not in agreement with the postoperative confirmatory study result.

Results

Duplex data were of sufficient quality for intraoperative evaluation in 73 cases. Of these, duplex was normal in 67 cases (91.8%). In six cases (8.2%) intraoperative duplex revealed technical problems requiring immediate re-exploration. These comprised one extracorporeal reconstruction, two reconstructions with an autogenous vein, one renal artery reimplantation in the aorta and two endarterectomies. Considering the two endarterectomies, re-exploration resulted in coaptation of two renal artery branches in one case and saphenous vein patch angioplasty in the other case. Considering the other four reconstructions, re-exploration revealed no technical problems after opening the vessel. After each of these re-explorations a further intraoperative duplex was performed and in all cases was considered normal (Table 1). Where the intraoperative duplex was normal, the B-mode image was normal in 47 cases, there was insufficient visualization in three cases and there was no B-mode information available in 23 cases. Six reconstructions had technical problems revealed by intraoperative duplex (Table 2). Where there was no postoperative

Table 1. Mean duplex data for normal and abnormal intraoperative duplex after re-exploration.

	Normal duplex			Abnormal duplex			Duplex after re-exploration		
	Mean ± SD	Range	*n*	Mean ± SD	Range	*n*	Mean ± SD	Range	*n*
PSV	1.16 ± 0.69	0.29 to 3.17	48	2.96 ± 1.50	1.24 to 4.00	3	1.43 ± 0.81	0.47 to 2.52	5
EDV	0.37 ± 0.30	0.06 to 1.16	44	0.46 ± 0.64	0 to 0.91	2	0.47 ± 0.40	0.13 to 1.11	5
RI	0.70 ± 0.13	0.4 to 0.9	44	0.85 ± 0.21	0.7 to 1.0	2	0.70 ± 0.12	0.6 to 0.9	5
RAR	2.51 ± 1.41	0.7 to 5.9	33	7.80 ± 7.35	2.6 to 13.0	2	2.65 ± 1.48	1.6 to 3.7	2

PSV, peak systolic velocity in m/s; EDV, end diastolic velocity in m/s; RI, resistive index; RAR, renal aortic ratio.

Table 2. Intraoperative duplex data indicating technical problems with the reconstruction in six cases.

Doppler-shifted signals	B-mode			
	Normal	Abnormal	No visualisation	Row total
PSV>1.8 m/s	0	2	2	4 (66.7%)
PSV<1.8 m/s with monophasic EDV	0	1	0	1 (16.7%)
Spectral broadening with poor arterial pulsations	0	0	1	1 (16.7%)
Column total	0	3 (50%)	3 (50%)	6 (100%)

PSV, peak systolic velocity in m/s; EDV, end diastolic velocity in m/s.

confirmatory study, the reconstruction was considered normal by intraoperative duplex in all nine cases. Three patients died early after surgery of various complications that did not appear to be related to technical problems of the reconstruction. One of these patients had a single kidney and suffered from a lack of diuresis after hepatorenal bypass grafting. The day after the operation, re-exploration revealed that the bypass graft was open, but pulsations were weak. Intraoperative duplex study was of insufficient quality, but there seemed no signs of stenosis. It was decided to perform iliacorenal bypass grafting. After surgery diuresis improved. Furthermore, one patient was operated for a second time because of complications. A small anastomotic leak was found and successfully repaired. No confirmatory study was performed after this repair. In two patients no confirmatory angiography was performed early after surgery because of preterminal renal insufficiency, probably caused by acute tubulus necrosis resulting from hypotension. In three patients no relevant additional information was found.

In the 61 (95%) of 64 reconstructions with normal intraoperative duplex the postoperative confirmatory study was also normal. Of these 61 reconstructions, confirmatory study revealed one stenosis of approximately 60% remaining in one patient after endarterectomy. This was in agreement with the intraoperative duplex data: stenosis was considered insignificant by B-mode imaging. One year and three months after surgery the stenosis was still around 60% without complications. In three reconstructions with a normal intraoperative duplex postoperative occlusion occurred. This was confirmed by angiography less than 2 weeks after surgery in all three cases. If these three cases with postoperative occlusion among the 64 normal intraoperative results are considered to be false negative and if all six cases with technical problems are considered to be true positive, intraoperative duplex was 66.7% sensitive and 100.0% specific for technical problems contributing to postoperative failure (Table 3). In this case the positive predictive value of intraoperative duplex was 100.0% and the negative predictive value was 95.3%. Considering the 127 of the 204 reconstructions without intraoperative duplex, the reconstruction was intraoperatively tested by clinical evaluation. This test showed a sensitivity of only 25.0% and specificity of 100.0%.

Table 3. Comparison of intraoperative renal duplex sonography with confirmatory study.

Duplex	Confirmatory study		
	Normal	Abnormal	Row total
Normal	61	3	64 (91.4%)
Abnormal	0	6	6 (8.6%)
Column total	61 (87.1%)	9 (12.9%)	70 (100%)

Sufficient data was available to compare intraoperative duplex data with the confirmatory study result in only 47 cases for PSV, 42 cases for EDV, 31 cases for RAR and 42 cases for RI. A boxplot of PSV versus the confirmatory study result is shown in Figure 1. Considering the reconstructions with postoperative occlusion, in one patient measurements of the aortorenal bypass were as follows: PSV = 0.51 m/s; EDV =

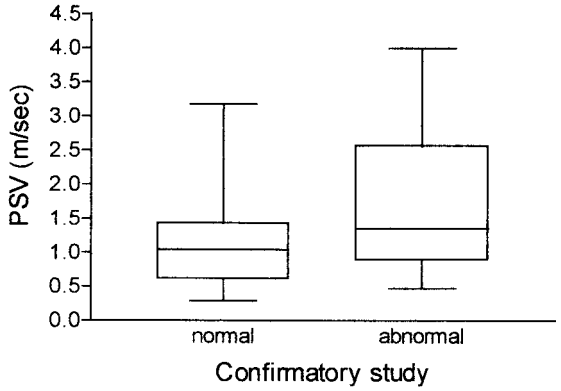

Fig. 1. Boxplot of peak systolic velocity (PSV in m/s) versus confirmatory study result ($n=41$ and $n=6$ for normal and abnormal confirmatory study result respectively).

0.29 m/s; probe-angle = 15°; RI = 0.4; RAR = 2.0; no recorded B-mode data. Renal perfusion scan 1 day after surgery showed renal function to be unchanged compared to before surgery. However, there were signs of significant stenosis in the reconstructed renal artery. In another patient, measurements of the endarterectomy after re-exploration (coaptation) were as follows: PSV = 0.47 m/s; EDV = 0.13 m/s; probe-angle = 49°; RI = 0.7; RAR = 1.6; B-mode imaging showed an optimal reconstruction. In comparison to the contralateral renal artery, flow velocities were low. It was thought that the low velocities might be due to high intraparenchymal resistance. The latter patient suffered from diffuse atherosclerosis of the reconstructed renal artery. Renal perfusion scan 1 day after surgery showed almost no perfusion and a decrease of renal function compared to before surgery (before surgery: reconstructed kidney: contralateral kidney = 25%:75%; after surgery: 10%:90% respectively). Finally, in one patient measurements of the bypass were as follows: PSV = 1.47 m/s; EDV = 0.68 m/s; probe-angle = 60°; RI = 0.5; RAR = 1.3; B-mode imaging showed an open bypass. The latter patient (aged 26) underwent contralateral nephrectomy at the age of 5 and suffered from chronic renovascular hypertension and serious renal dysfunction. There was a long history of renal artery stenoses and finally occlusion of the cranial renal artery. One year before surgery the patient had already undergone successful reconstruction of the caudal renal artery combined with unsuccessful reconstruction of the cranial renal artery. The studied reconstruction consisted of a bypass, using an autogenous vein, from the aorta to the cranial renal artery. A renal perfusion scan performed 1 day after surgery showed good perfusion, but poor excretion resulting from the renal dysfunction (serum creatinine had risen to 431 μmol/l). Angiography performed 11 days after surgery revealed an occluded bypass, and the patient required haemodialysis. In all three patients kidney size did not contraindicate reconstruction (all kidneys were equal to or over 9.0 cm).

Discussion

Our experience indicates that intraoperative duplex is not very sensitive (66.7%), but is highly specific (100%) for identifying technical problems contributing to postoperative failure. A sensitivity of 66.7% is relatively low compared to other studies: 85% for Okuhn *et al.*,[1] 86% for Hansen *et al.*,[2] 100% for Dougherty *et al.*[3] and 100% for Lantz *et al.*[4] Nevertheless, a sensitivity of 25.0% for testing the reconstruction without intraoperative duplex shows, that by using intraoperative duplex the ability of detecting technical problems is considerably increased. However, it should be acknowledged that the number of patients used to calculate sensitivity and specificity is small. On the other hand, it is well known that technical errors are difficult to detect by clinical evaluation. Technical problems requiring immediate re-exploration were revealed by intraoperative duplex in 8.2% of all renal artery reconstructions. This is in general agreement with other studies: 4% for Okuhn *et al.*,[1] 11% for Hansen *et al.*,[2] 10.9% for Dougherty *et al.*[3] and 11% for Lantz *et al.*[4] Although in four reconstructions no problems were found during re-exploration, the reconstruction may have been improved imperceptibly during this re-exploration, especially when the reconstruction is considered normal by intraoperative duplex after re-exploration.

No other interpretation of the duplex data could have reduced the false negative rate (three cases). However, the false negative cases may not only be caused by missed technical problems during surgery, but also by reconstruction failure during the interval between the intra-operative duplex and the confirmatory study because of increased thrombogenicity. This occurs especially in endarterectomised or previously occluded arteries. Nevertheless, in one case renal perfusion scan 1 day after aortorenal bypass grafting already showed signs of a significant stenosis of the reconstructed renal artery without any change in renal function compared to before surgery. In this case technical problems were probably missed by intraoperative duplex. In the two other cases the kidney was seriously dysfunctional 1 day after surgery, which may have caused low perfusion resulting in the occlusion revealed later by angiography. Furthermore, considering these cases, endarterectomy was performed in one patient and a history of stenoses and

occlusion of the reconstructed renal artery was present in the other patient. These factors increase the risk of thrombogenicity as mentioned above. In conclusion, intraoperative duplex assessment of the reconstruction in the latter two cases may have been correct after all.

Regarding the reconstructions without postoperative confirmatory study, most postoperative complications could be explained by additional information and were most likely not the result of problematic reconstruction. In only one case were postoperative complications possibly caused by technical problems missed by intraoperative duplex. In this case a second operation, because of postoperative lack of diuresis, showed a weakly pulsating, though open, bypass graft with again no signs of stenosis revealed by intraoperative duplex. After a new reconstruction was made diuresis started to get better, indicating that the first reconstruction was not as successful as the second one. Nevertheless, because there was no reliable confirmation that the first reconstruction was problematic, the question whether or not technical problems were missed by intraoperative duplex could not be answered.

Haemodynamic intraoperative duplex data were used to add information in cases where no B-mode information was available. However, where B-mode information was available, haemodynamic data was not used. There was no reconstruction in which B-mode findings were abnormal and haemodynamic information prevented re-exploration, or in which B-mode findings were normal and haemodynamic information caused re-exploration. This is in agreement with the intraoperative duplex criteria used in the patients that we studied. However, this is not in agreement with other studies,[1,2] in which haemodynamic information was used to refine the prediction of intraoperative duplex based on B-mode imaging alone and resulted in an improved ability of intraoperative duplex to detect technical problems. Nevertheless, in our study the ability of intraoperative duplex to detect technical problems could not be improved by the use of other criteria. Furthermore, PSV measurements over 1.8 m/s in reconstructions considered normal by confirmatory study may have been caused by: (1) insignificant stenosis that remained after reconstruction, especially at the distal end of an endarterectomy (focal) or (2) the effects of revascularisation after ischaemia of the kidney during surgery (diffuse). The latter reason for high flow measurements has not yet been properly studied. Nevertheless, we could not obtain enough information to study the relationship between PSV and the amount of time that the kidney was ischaemic.

Finally, it should be pointed out, that our study and all the other above-mentioned studies[1–4] suffer from a serious limitation; that is, intraoperative duplex was compared with confirmatory studies of varying sensitivity and specificity. The use of our most frequently used confirmatory study, angiography, as the "gold standard" of arterial evaluation, and the use of postoperative surface duplex scanning are both controversial because they are known to be less sensitive methods of studying arterial reconstructions than is intraoperative duplex scanning.[1,2] Therefore, one might expect a high false-positive rate from postoperative angiography and postoperative surface duplex. However, this was not the case in our study.

In conclusion, our experience with intraoperative duplex suggests that it is a specific but insensitive method for detection of technical problems in renal artery reconstructions. Haemodynamic information appeared less important than B-mode revaluation in discriminating between satisfactory and unsatisfactory reconstructions.

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