Measurement of Renal Artery Pressures by Catheterization in Patients with and without Renal Artery Stenosis

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Surgical Correction of a renal artery stenosis may result in the reduction of the blood pressure to normal levels in some hypertensive patients. Selection of those patients likely to benefit, however, is a difficult problem since the presence of a narrowing may be a coincidence rather than the cause of the hypertension. Furthermore, renal artery stenosis has been shown by angiography or found at autopsy in individuals with normal blood pressure.

Various tests have been used in the selection of patients for surgery, but none is entirely satisfactory. It has been suggested that only patients with a significant decrease in pressure across the stenosis can be expected to benefit. The pressures in the aorta and renal artery are measured at operation, and repair is carried out only if an appreciable pressure gradient is found. Therefore, if these pressures could be measured reliably by percutaneous catheterization, some patients might be spared unnecessary laparotomy. In addition, since correlation of the pressure studies with other clinical data is likely to improve understanding of the relationship between hypertension and renal artery stenosis, availability of such a technique should be of value.

Brief references to the measurement of renal artery pressures by catheterization have appeared, including comments on the technical difficulties, but detailed results have not been given. This report deals with our experience in using this technique and compares the pressures with the angiographic appearance of the renal vessels. The pressures were obtained via a small nylon catheter passed into the renal artery through a larger curved catheter. The method is similar to that originally described by Amplatz.

Methods

Technique

Figure 1 shows the catheters and instruments used. They include a straight radiopaque polyethylene catheter with side holes (red KIF tubing, I.D. 1.2 mm, O.D. 2.2 mm) for a survey aortogram (fig. 1A); a set of single end-hole catheters made of the same tubing as the aortographic catheter, with tips having various degrees of curvature (one of the set is shown in figure 1B); two nylon radiopaque catheters of different thickness (I.D. 0.5 mm, O.D. 0.8 mm, and I.D. 0.5 mm, O.D. 1.1 mm) which can be passed through the curved catheter into the renal arteries (fig. 1C); a short stylet, if needed, to stiffen the proximal part of the nylon catheter in order to facilitate its passage around the bend of the curved catheter (fig. 1D); and a modified Cope adapter or B.D. adapter (615A) to prevent back bleeding and to inject contrast medium around the nylon catheter (fig. 1E).

The nylon catheter and the residual lumen of the outer curved catheter are connected to pressure transducers (Statham P23D) and to a high pressure reservoir of heparinized Ringer's solution used for flushing as described by Wood. The total recording system, including the nylon catheter, metal connectors, the pressure transducer, and an optical oscillograph, has an essentially flat response to at least 9 cps, which is satisfactory for the purpose. To obtain this response, it is important to use stopcock grease at all the connections, to make connections while flushing from the pressure reservoir, and to flush the nylon catheter continuously except when taking the pressure records. Recording of quick

*Obtained from A. E. Afford, 340 Marne Avenue, Haddonfield, New Jersey.
flushes from the pressure reservoir on the arterial pressure records helps to determine whether excessive damping is present. Since pressures recorded via the residual lumen of the outer catheter are often damped, only the pressures recorded through the nylon catheter are used.

Fluoroscopy is carried out by means of an image intensifier. The position of the catheters is confirmed by the injection of small volumes of 50% sodium diatrizoate and documented by spot films. Since multiple renal arteries are common, a survey aortogram is carried out initially to visualize all the renal vessels. For this purpose, the straight polyethylene catheter is introduced into the abdominal aorta by Seldinger's technique. To catheterize the renal artery, the aortographic catheter is replaced by a curved catheter whose tip is positioned in the ostium of the renal vessel. Its location is confirmed by injection of 1 to 2 ml of the contrast medium. During manipulation of the curved catheter, the pressure at its tip is monitored to avoid wedging. In some cases, it may be possible to pass the tip of the curved catheter past the stenosis, and a withdrawal pressure record using this catheter alone may show no significant pressure gradient across the lesion. More often, however, there is a pressure gradient, which could be due to the presence of this relatively large catheter in the narrowing, or the curved catheter cannot be passed across the stenosis. In such cases, a small nylon catheter is passed through the curved catheter for the pressure measurements. The nylon catheter with the thinner wall is usually used, and contrast medium is injected around it to document its position in relation to the stenosis. The nylon catheter with the thicker wall, which can be seen better on fluoroscopy, is used in some cases but has the disadvantage that the contrast material has to be injected through it and less satisfactory spot films are obtained than when the thinner catheter is used. A thin stylet, considerably shorter than the nylon catheter, may be put into its proximal part if difficulty is encountered in passing the nylon catheter around the curvature of the outer catheter. The stylet stiffens the small catheter and facilitates this maneuver, but excessive force must not be used when the tip of the inner catheter is in the opening of the outer, since it could be positioned directly against the wall of the vessel.

Figure 2A shows an angiogram with narrowing near the origin of the left upper renal artery. Figure 2B shows the relation of the small catheter

**Figure 1**

*Instruments used for angiography and pressure measurement. (A to E) For explanation see text. The syringe contains contrast material.*

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(A) Angiogram. Narrowing near the origin of the left upper renal artery. (B) The nylon catheter was passed across the area of stenosis. Contrast medium shows its relation to the outline of the vessel. (C) The position after withdrawal of the outer catheter and advance of the inner catheter. The tip of the inner catheter is beyond the site of stenosis, while the outer one is in the aorta.

Figure 2

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to the outline of the vessel when a nylon catheter has passed across the stenosis and contrast medium has been injected. Figure 2C illustrates the position after withdrawal of the outer and advance of the inner catheter. The tip of the inner is beyond the narrowing while the outer one is in the aorta. Pressure is then recorded continuously as the two catheters are withdrawn together until the tip of the inner one is in the aorta. An example of a withdrawal pressure record in a patient with severe stenosis is shown in figure 3.

Group Studied

This procedure has been used to measure pressure in 34 renal arteries of 28 patients. Fifteen patients had hypertension and renal artery stenosis. In addition, 13 patients without stenosis of the renal artery, 10 of whom had hypertension, were studied by means of the small catheter to determine the relationship between the pressures in the aorta and the renal arteries in the absence of stenosis. There were six failures among the 34 attempts; five of these were among the 18 attempts at catheterization of the stenosed renal vessels. Two failures were due to inability to pass the nylon catheter beyond the tip of the outer catheter, three were due to failure to advance the nylon catheter past the site of stenosis, and in the sixth case damped pressure records were obtained. Because refinements in the method were introduced during this series of measurements, it is likely that the incidence of technical failures would now be lower.

Two complications developed. In one case, pain in the costovertebral angle was present for 2 days after the test. In the second case, injection of the contrast material through the outer catheter demonstrated perforation of the renal artery by the extravascular position of the nylon catheter. Following removal of the nylon catheter, a spot film showed good filling of the renal vessels and no extravasation of the contrast medium. There were no symptoms referable to the perforation.

Results

The systolic pressures in the aorta and the renal arteries with and without angiographically demonstrated narrowing are compared in figure 4. In the renal arteries without stenosis, the pressures did not differ by more than 13 mm Hg from the aortic pressure. In normotensive subjects, renal artery pressures were equal to, or somewhat lower than, aortic pressures, whereas in patients with hypertension they were equal, lower, or higher than aortic pressure. The normal sys-
Sensitivity

Withdrawal pressure in a patient with severe stenosis in the proximal part of the right renal artery.

Systolic pressures in some hypertensive patients were due to antihypertensive medication.

The degree of stenosis was graded as mild, moderate, or severe, on the basis of approximate narrowing of the diameter of the lumen. Narrowing of not more than a third was considered as mild, narrowing of approximately one half as moderate, and of more than two thirds as severe. This simple grading did not correlate well with the pressure measurements. Pressure relationships within normal limits were encountered in patients with all three grades of stenosis; also abnormal differences in systolic pressure of 20 mm Hg or more between the aorta and the renal artery were seen in all three groups.

The differences between diastolic pressures in the renal artery and the aorta, not shown in the figure, were generally smaller than the differences in the systolic pressures. The greatest diastolic difference, which was only 15 mm Hg, was recorded in the patient with the highest systolic pressure gradient.

An attempt was made to correlate the pressure measurements with various combinations of the following dimensions of the vessels measured on the angiographic films in a frontal projection: the length of the stenosis \( L_s \), the diameter of the lumen of the stenosis \( D_s \), and the diameter of the lumen of the nonstenosed part of the renal artery \( D_N \). The following indices were calculated from these measurements: \( D_s / D_N \), \( D_s / D_N \)^2, \( D_s / D_N \)^4, \( L_s / D_N \), \( L_s / (D_s / D_N)^2 \), and \( L_s / (D_s / D_N)^4 \). These indices for the anatomic obstruction were then plotted against the systolic pressure gradient between the aorta and the renal artery. The correlation with the pressure gradient was good only in the case of the last two indices. Figure 5 shows the systolic pressure gradient between the aorta and the renal artery on the ordinate plotted against \( L_s / (D_s / D_N)^2 \). There is a
linear relationship between the pressure gradient and this index of stenosis except for one case in which severe narrowing was found in the absence of a significant pressure gradient. In this case, the stenotic vessel supplied a small scarred kidney, and the absence of a pressure gradient may have been due to low renal blood flow. The correlation of the pressure measurements with the index $L_s/(D_s/D_N)^4$ was similar to that shown in figure 5.

**Discussion**

In the present study, adequate pressure records across renal artery stenosis were obtained in about 70% of cases. It is likely that this rate of success may be improved by exploring the use of catheters made of different materials and curved catheters of various shapes. One of the main causes of technical failure was inability to pass the small nylon catheter out into the renal artery or past the narrowing. This was presumably due to the curvature of the outer catheter which directed the tip of the inner catheter against the wall of the vessel. Addition of a second curvature on the last few millimeters of the outer catheter and converting its end into a “shepherd’s crook” may overcome this difficulty. Neither of the two complications encountered in the present series appeared to be serious. Experience in larger numbers of patients will be needed before the incidence of complications can be adequately evaluated.

The pressure records obtained through the small inner catheter are adequate if meticulous attention to technical details is exercised. Although theoretically the presence of any catheter in the narrowed portion of the renal artery may result in or exaggerate the pressure gradient, the small diameter of the nylon catheter used in these measurements is not likely to alter the pressure significantly in most cases. Good agreement between measurements obtained by catheterization and at operation, mentioned by others and seen in one of our cases which came to surgery, supports the validity of the measurements obtained at catheterization.

Measurements obtained in the vessels without stenosis indicate that the pressures in the aorta and the renal arteries are similar and that a difference of more than 15 mm Hg between the systolic pressures is probably abnormal. The finding of higher systolic pressures in the renal arteries than in the aorta in some hypertensive patients could be related to a greater degree of reflection of the pulse wave in the presence of high peripheral resistance in the renal vascular bed in hypertension.

The pressure measurements correlated poorly with casual angiographic evaluation of the stenosis, based simply on the degree of narrowing of the lumen by the lesion, but a good correlation was obtained with indices which incorporated the length of the narrowing and a power of the ratio of the diameters of the stenosed and normal segments of the renal artery, for example $L_s/(D_s/D_N)^2$. If further experience should confirm these findings, based so far on only a few cases, then such indices could be used to evaluate functional significance of the angiographically
demonstrated stenosis. Formulas which relate pressure gradient to the dimensions of the vascular narrowing\textsuperscript{18} show that the pressure gradient depends on the length of the stenosis and on complex powers of the diameters of the stenosis and of the normal segment of the vessel. Consequently, there is a theoretical basis for the use of the indices which incorporate these dimensions to evaluate the functional significance of the angiographically demonstrated stenosis.

The pressure gradient across the narrowing is also affected by the flow which in turn may be influenced by changes in the peripheral resistance of the small renal vessels. Although under normal conditions the renal vascular bed is usually dilated,\textsuperscript{19,20} renal vasoconstriction mediated by the adrenergic system occurs readily as a result of various stresses such as trauma,\textsuperscript{21} anesthesia,\textsuperscript{22,23} or surgery.\textsuperscript{23} Therefore, measurements of pressures across renal artery stenosis at operation may not provide a valid index of the functional significance of the lesion. This may explain the lack of correlation between such pressure measurements and the clinical course of patients after corrective surgery.\textsuperscript{24} Whether arterial catheterization and angiography are associated with much renal vasoconstriction remains to be determined. These questions might be answered by measurements of pressures and flows across renal artery stenosis at surgery and at catheterization before and after administration of an adrenergic blocking agent, such as phenoxybenzamine, into the renal artery.

Although more experience with measurements of renal artery pressures by catheterization is needed, the preliminary results reported herein warrant its use in a larger number of patients. Preoperative measurement of pressures in the renal arteries may be of value in the selection of patients with renal artery stenosis for surgery.\textsuperscript{1-7,8,12,25} Also, correlation of the pressure measurements with measurements of renal blood flow, split renal function tests, assays of the renal vein blood for pressor activity,\textsuperscript{26} and the results of surgery may lead to a better understanding of the relationship between hypertension and renal artery stenosis.

Summary

Pressures were successfully measured by catheterization in 13 out of 18 renal arteries with stenosis and in 15 out of 16 vessels without stenosis. The pressures were measured via a small-bore, radiopaque nylon catheter threaded through a curved polyethylene catheter whose tip was placed in the renal vessel. The position of the catheters was confirmed by injections of small volumes of angiographic dye and documented by spot films. Use of the small-bore catheter was necessary to avoid alteration of the measured pressure. Strict attention to technical details is mandatory in order to obtain satisfactory pressure recordings.

In patients without angiographic evidence of stenosis, pressure in the renal arteries did not differ consistently from the aortic pressure. Differences of more than 15 mm Hg in the systolic pressure are probably abnormal.

Abnormal systolic pressure gradients between the aorta and the renal artery were found in some patients with renal artery stenosis, but not in others. In the patients with gradients, good correlation was obtained between the gradient and the dimensions of the stenosis measured on the angiographic films and expressed as $L_s/(D_s/D_N)^2$,\textsuperscript{5} where $L_s$ is the length of the narrowing, and $D_s$ and $D_N$ are respectively the diameters of the lumen of the stenotic and nonstenotic parts of the vessel in a frontal projection.

Our experience suggests that more preoperative pressure measurements by catheterization across renal artery stenosis and correlation with angiographic and renal function studies and with the results of operation are warranted.

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References

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