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EX VIVO PERFUSION, ARTERIOGRAPHY, AND AUTOTRANSPLANTATION PROCEDURES FOR KIDNEY SALVAGE

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NOT UNCOMMONLY, the need arises for renal arterial surgical procedures but under conditions which would make the use of ordinary vascular reconstructive techniques difficult or impossible, as for example with distally located fibromuscular dysplasia or hilar aneurysm. This study was undertaken to describe a method of renal autotransplantation by which a kidney can be removed, cooled, perfused with asanguineous fluid, studied angiographically in its extracorporeal state, have its structures dissected, and ultimately have it returned heterotopically with the expectation that it will provide prompt function. This approach, first suggested by Belzer and his associates (3), should have wide urologic application for the treatment of a diversity of vascular and nonvascular disorders.

METHODS

The diseased kidney is approached by whatever method gives adequate exposure. In our first two patients, a flank incision was used (Fig. 1a). Dissection of the pedicle structures of the kidney is carried out in the same way as with donor nephrectomy for transplantation (Fig. 1b). The organ is removed with a maximum length of the renal vessels and ureter. It is then flushed with a cold balanced electrolyte solution containing low molecular weight dextran and heparin (Perfudex®) and attached to a Belzer type kidney perfusion machine (Fig. 2), primed with cold, 7 degrees C., deflocculated homologous plasma (2). If a flank approach has been used, the wound is closed while perfusion is being carried out. A decision for autotransplantation can be deferred until all studies are completed, even though this may require several hours. If it is decided to proceed, the patient is placed supine, and a standard anterior lower abdominal extraperitoneal incision is made (16).

If the vascular anatomy has not been defined completely with preoperative angiography (Fig. 4a), an arteriogram of the extracorporeal kidney can be obtained easily and simply (Fig. 4b) by injecting 5 to 10 milliliters of water soluble triiodinated contrast medium (Conray 60®) through an arterial inflow side arm. To eliminate the bolus of contrast material from the perfusate reservoir, the venous effluent is thrown away during the few seconds after the injection.

With the information now available and with the kidney outside the body, the renal vessels are dissected into the hilus to the extent necessary, and these vessels are transected at the site of the proposed anastomosis. In the first two patients, the right kidney was transplanted to the left extraperitoneal space which has become standard for

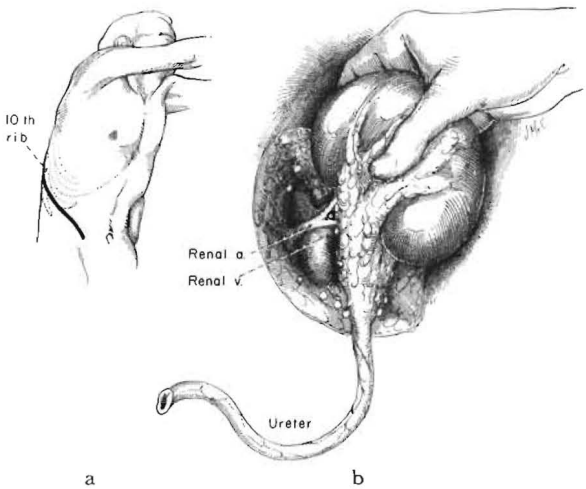

FIG. 1. Technique of mobilization of the diseased kidney. a, Flank incision; b, pedicle structures dissected.

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This work was supported by research grants from the Veterans Administration, by grants No. RR-00051 and No. RR-00069 from the general clinical research centers program of the Division of Research Resources, National Institutes of Health, and by grants No. AI-10176-01, No. AI-AM-08898, No. AM-07772, and No. HE-09110 of the United States Public Health Service.

Reprint from SURGERY, *Gynecology & Obstetrics*, October, 1973, Vol. 137, 659–665

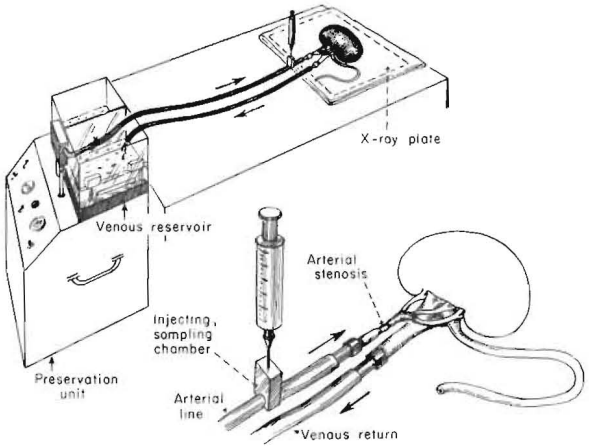


FIG. 2.

FIG. 2. Schematic view of the diseased kidney after its removal and during perfusion. Angiography and dissection of the hilar structures are ready to be carried out.

FIG. 3. Patient 1. Kidney autotransplant with three arterial anastomoses was carried out.

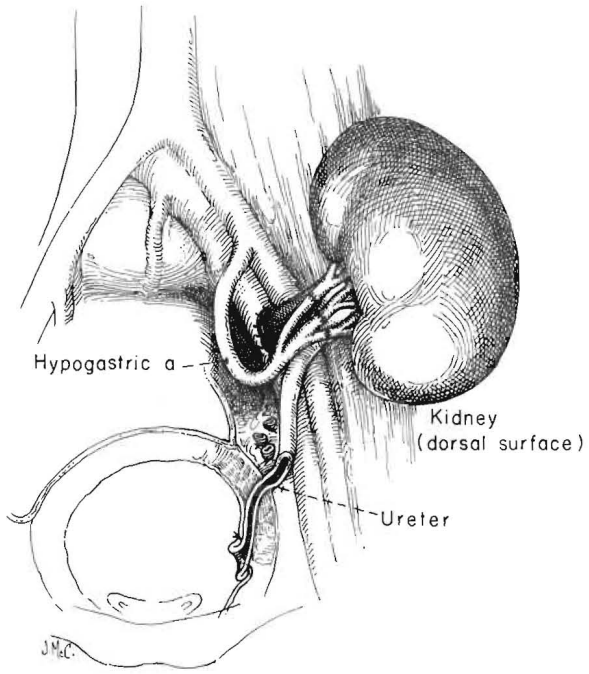
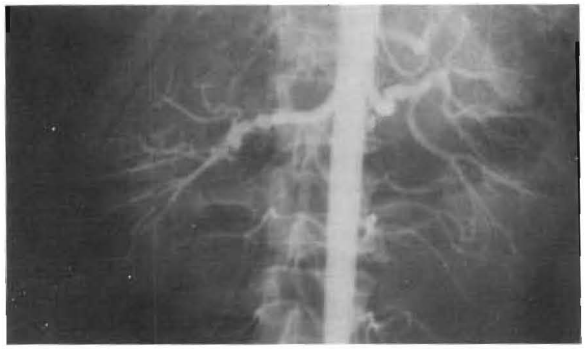


FIG. 3.



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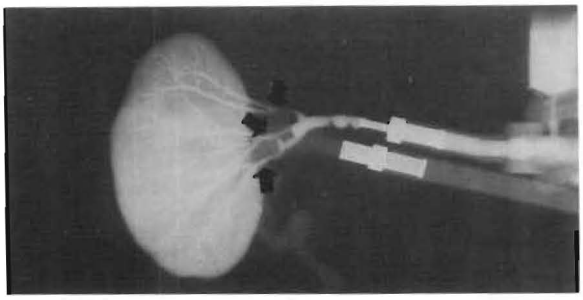

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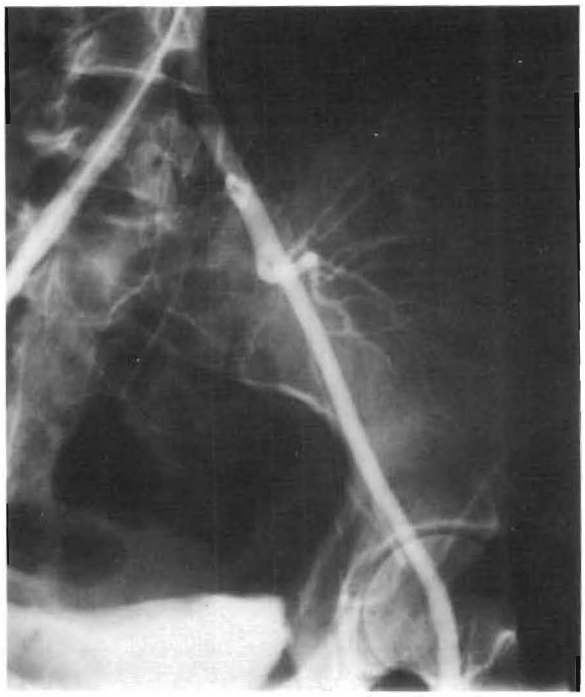


c

FIG. 4. Patient 1. a, Preoperative arteriogram. b, Intraoperative arteriogram outlining the lesions with high definition. The arrows indicate the level of eventual arterial transection. The three small vessels were individually anastomosed. c, Postoperative arteriogram after autotransplantation to the contralateral extraperitoneal iliac fossa and revascularization to the pelvic vessels.

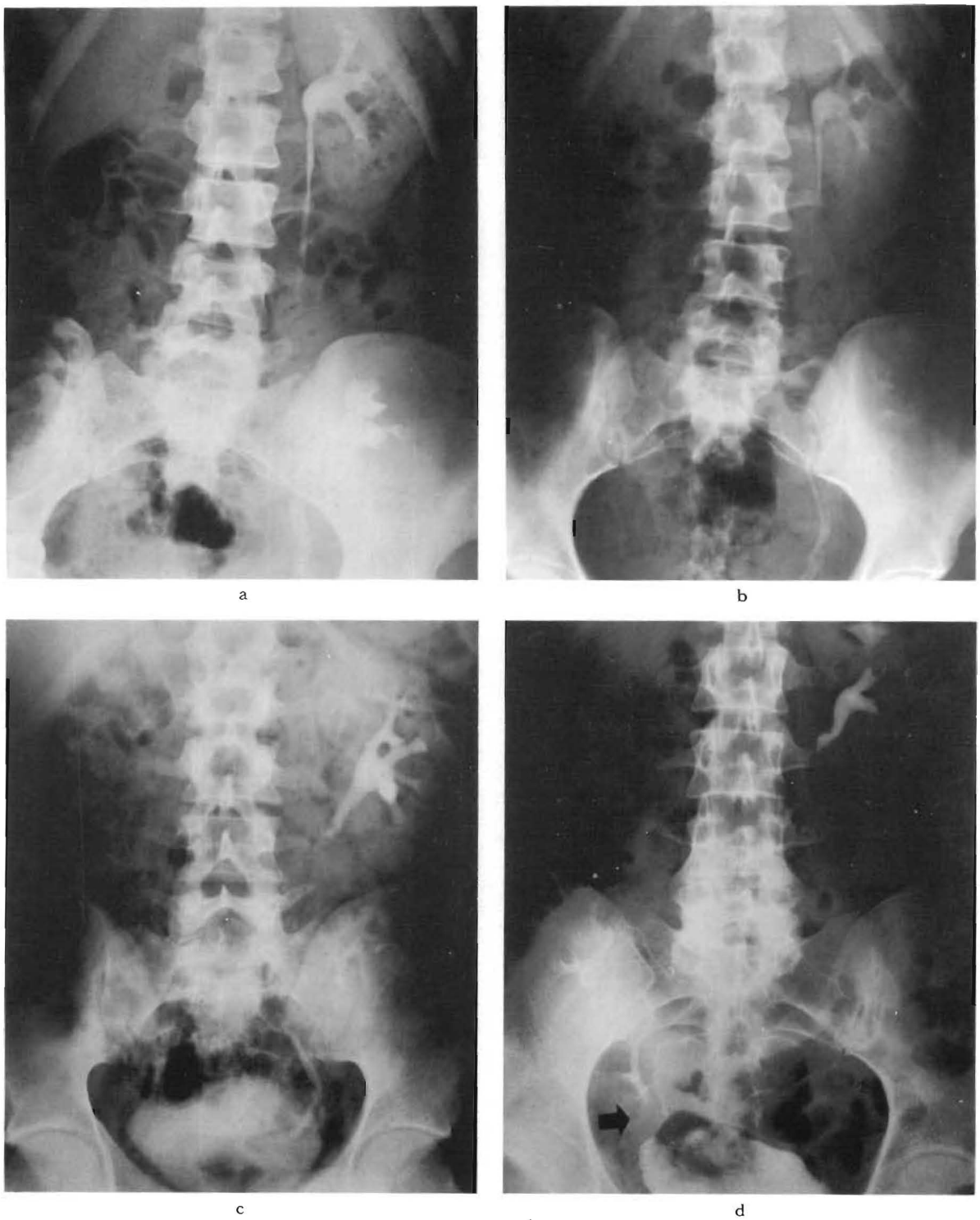
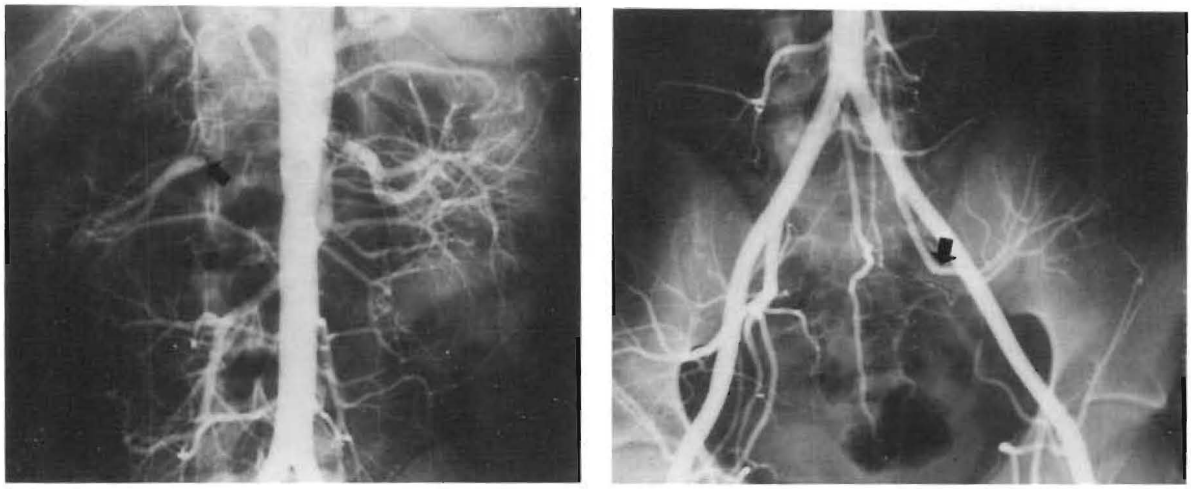


FIG. 5. Postoperative excretory urograms. All were taken ten minutes after contrast material had been injected. a, Patient 1. One week postoperative the two kidneys can be seen functioning on the left side, but with some degree of obstruction of the collecting system of the autotransplant due to edema of the bladder wall. b, Patient 1. Six weeks later. c, Patient 2. Both kidneys are on the left. d, Patient 3. After autotransplantation to same side as in Figure 9. Note ureteropelvic duplication.



a b

FIG. 6. Patient 2. a, Preoperative arteriogram shows revascularization, at arrow, of the occluded renal artery by collaterals. b, Postoperative arteriogram shows the same kidney after its autotransplantation to the left iliac fossa. The arrow indicates the renal artery hypogastric anastomoses.

renal homotransplantation (16), using one or more anastomoses, as required (Fig. 3). Ureteroneocystostomy was used to complete the procedure (Fig. 3) in the first two patients, but ureteroureterostomy or ureteropyelostomy could be considered.

In the third patient, the diseased organ was approached through a midline incision, perfusion and angiography were carried out on the anterior abdominal wall, the treated kidney was turned upside down without ureteral division, and an ipsilateral vascular transplantation was performed.

PATIENT REPORTS

PATIENT 1. This 23 year old woman with severe hypertension was proved to have bilateral medial fibroplasia with the right renal artery being most severely involved as proved by excretion urography, arteriography (Fig. 4a), and by the right to left ratio of plasma renin activity of 45.01:20.64 nanograms of angiotensin I per milliliter of plasma per hour.

After removal of the kidney and more precise definition of the vascular disease by extracorporeal renal arteriography (Fig. 4b), the three relatively uninvolved terminal hilar vessels were anastomosed to branches of the contralateral hypogastric artery (Fig. 3), the transplantation being completed in the usual way. The extracorporeal kidney time was five hours and 50 minutes.

Preoperatively, the diastolic blood pressure had risen to 110 to 130, despite the administration of large dosages of several antihypertensive drugs. Postoperatively, the blood pressure fell during a period of two weeks to 115/76 after discontinuance of all drug treatment. Excretion urography (Fig. 5a and b) showed good function of two kidneys on the left side. A transfemoral iliac arteriogram

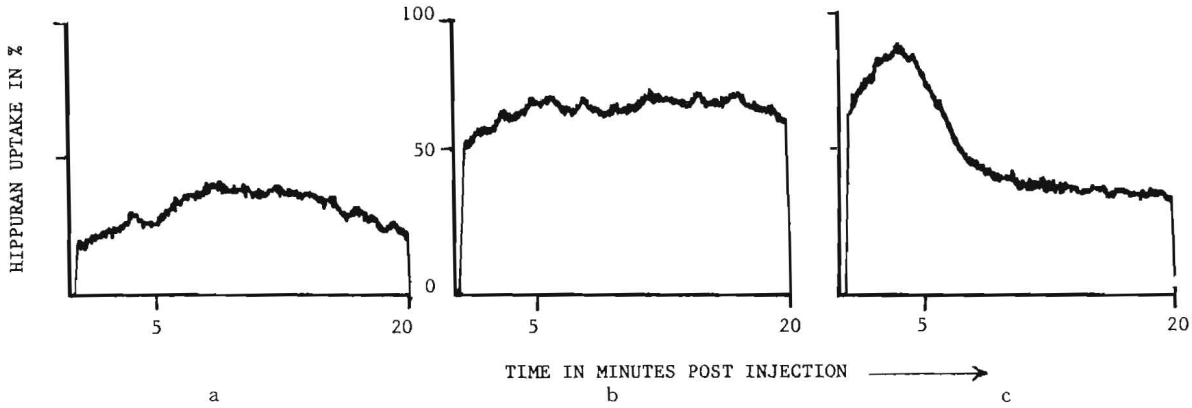
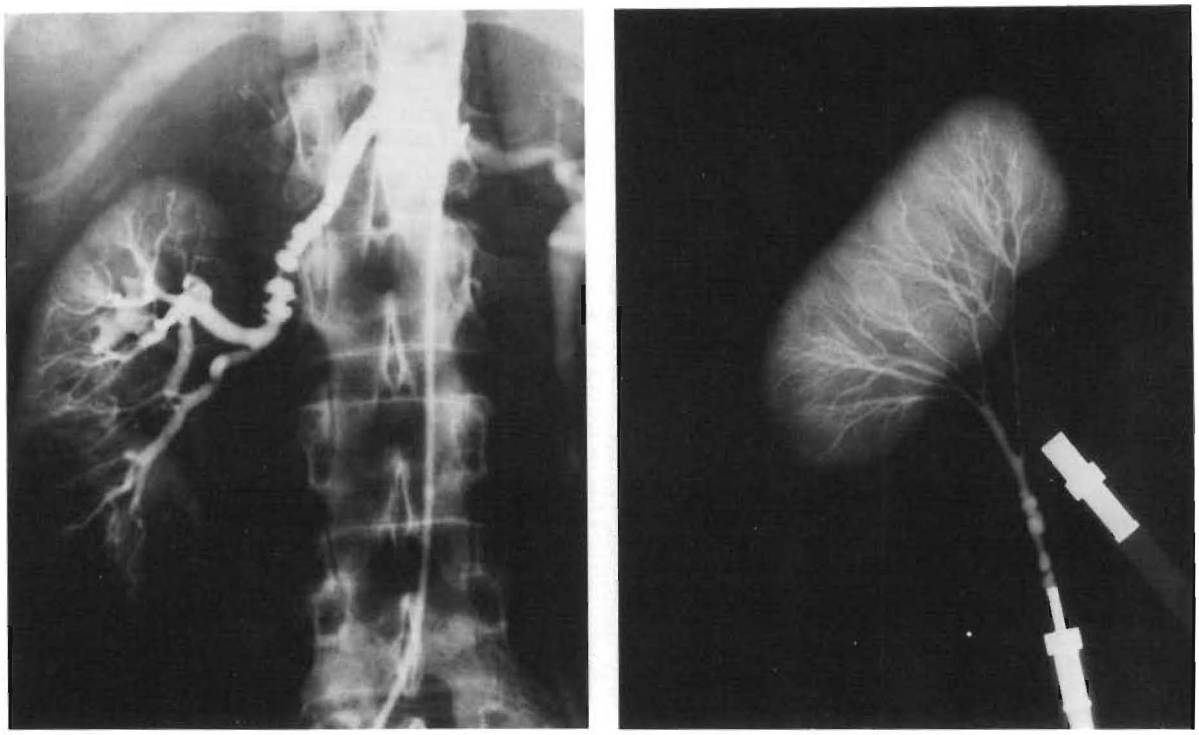


FIG. 7. Patient 2. Hippuran renograms show the progressive improvement of the autograft function. a, Preoperatively; b, three days postoperatively; and c, three months postoperatively.



a b

FIG. 8. Patient 3. a, Preoperative arteriogram; and b, intraoperative arteriogram.

revealed a good arterialization of the pelvic autograft (Fig. 4c). All three arterial anastomoses were patent.

PATIENT 2. This 20 year old man was stabbed in the abdomen with a knife in April 1972, with perforations of the ascending colon and the right renal artery near its origin. Colostomy was performed, and the arterial laceration was sutured. He became anuric on the tenth postoperative day. Aortography revealed a patent left renal artery and an appearance of the left kidney consistent with acute tubular necrosis but complete occlusion of the proximal right renal artery. The right renal artery had distal filling by collaterals (Fig. 6a). Hemodialysis was required for four weeks. By early July, the creatinine clearance value was 22 milliliters per minute and his blood pressure had risen to 190/130. Results of selective ureteral catheterization showed that the right kidney was still anuric with no urine production during the two hour examination. He had two episodes of severe hypertensive encephalopathy. Closure of the colonic stoma was carried out on 28 July 1972.

On 18 September 1972, the damaged right kidney was exposed through the flank. The organ was soft and pink, and after its removal, it weighed 75 grams. After 220 minutes of combined perfusion and cold ischemia time, it was transplanted to the left extraperitoneal space, the single renal artery being connected end-to-end to the hypogastric artery; the renal vein, end-to-side to the iliac vein; and the ureter, to the bladder (Fig. 3).

Three second sequential images of renal perfusion obtained using the scintillation camera and ^{99m}Tc pertechnetate demonstrated good blood flow to the autograft at all times postoperatively. A renal scan, using ^{197}Hg, and serial Hippuran® (sodium *o*-iodohippurate) renograms were grossly abnormal during the immediate postoperative period but showed progressive improvement (Fig. 7). Serial excretory urograms showed increasing function of the transplanted kidney (Fig. 5c). A transfemoral-iliac arteriogram after six weeks revealed a well vascularized renal autograft (Fig. 6b). Postoperatively, no antihypertensive drugs were required, the diastolic pressure being 85 to 90. Six weeks later, the blood pressure had returned to normal, and during the first 14 postoperative weeks, the creatinine clearance value rose from 22 to 47 milliliters per minute.

PATIENT 3. This 42 year old woman with hypertension of six years' duration had medial fibroplasia of both renal arteries, being more advanced on the right where it seemed to involve the entire length of the main renal artery (Fig. 8a). The right to left ratio of plasma renin activity in the renal veins was 6.26:4.72 nanograms of angiotensin I per milliliter of plasma per hour. The preoperative excretory urogram revealed a right complete ureteropelvic duplication.

At operation, the right kidney was brought out of the abdomen through a midline incision without ureteral division. It was perfused for 33 minutes extracorporeally, while an arteriogram was performed (Fig. 8b) and while the renal artery was dissected. The renal artery was

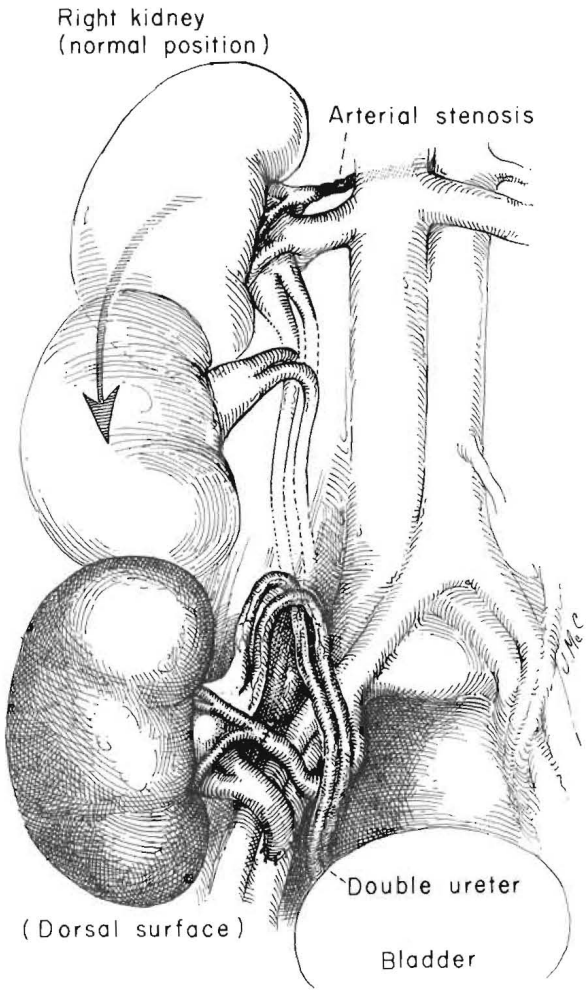


FIG. 9. Patient 3. The procedure used for autotransplant. The organ was turned down and revascularized in the ipsilateral iliac fossa without division of the double collecting system.

transected just proximal to the trifurcation. The organ was then passed inferiorly and revascularized in the right extraperitoneal space after having been turned upside down (Fig. 9). Although there was 47 minutes of cold ischemia in addition to the 33 minutes of perfusion time, the kidney autograft produced urine immediately, and eight days later, both kidneys were functioning according to excretion urography (Fig. 5d). The hypertension was relieved within five days.

DISCUSSION

It is almost superfluous to point out that most renal artery lesions can be repaired by standard methods and without recourse to partial or complete autotransplantation. The techniques described herein with particular reference to the ex vivo perfusion, should be reserved for the more difficult patients in whom, in view of the operator, there is otherwise an unacceptably high risk of losing the organ. There would also be a special inducement for autotransplantation in a patient with extensive arterial disease of a single kidney. Finally, autotransplantation would be indicated if the nature and extent of the vascular lesions could not be delineated in advance. Here, the high quality resolution of extracorporeal angiography becomes an overwhelming advantage, as has been pointed out by Alfidi and Magnusson (1).

The technique of renal autotransplantation is relatively simple and has been summarized on several occasions by Clunie (5), Gil-Vernet (7), Kaufman (10), Kuss (11), Marshall (12), Martinez-Pineiro (13), Ota (14), and Serrallach-Mila (15) and their associates since the original description of a patient by Hardy (9). However, there are many details of the procedure that can be varied. It may be desirable to leave the ureter intact and to transfer only the blood supply, as was done in Patient 3 after turning the kidney upside down. In most patients, a full autotransplantation will be the easiest, carrying the kidney into the iliac fossa of the same or opposite side, with ureteroneocystostomy for restoration of urinary tract continuity.

If the indication for operation is renal arterial disease extending unusually far distally, there is a special advantage in reversing the anteroposterior relationships of the hilar structures. Normally, the vein lies anterior to the artery, but when the kidney is turned over and placed contralaterally, as in Patients 1 and 2, or if it is turned upside down, as in Patient 3, the artery is brought anterior where it can be more easily anastomosed.

The degree of protection afforded by ex vivo hypothermic perfusion has been well characterized by Belzer and his associates (2) as well as by many others, including ourselves who have acquired an unusually extensive cumulative experience in renal homotransplantation. The time of perfusion, after which good renal function can be expected, is well in excess of a half day and, in many instances, may exceed 24 to 48 hours. Consequently, there are no practical limits to the extent of arteriographic and other studies, dissections, or other instrumentations during the extracorporeal interval.

Appreciation of the long periods that this kidney can spend outside the body should be an inducement to extend the use of such a bloodless field technique to the treatment of nonvascular kidney diseases, as has been suggested by several authors including Guerriero and his co-workers (8), Gelin and his colleagues (6), and Calne (4). It is not difficult to envision the removal of a malignant

lesion from a patient's sole kidney during the asanguineous hypothermic perfusion with subsequent return of the reconstructed remnant. The same principle should apply equally in treating advanced staghorn calculous diseases or lesions of the ureter or of the pelvis, in which the kidney could be saved were it not for a deficient length of the collecting system. Other potential indications could be cited, but the foregoing examples should suffice to illustrate the potential value of this general approach.

In Patient 2, the results were of particular interest because of the extreme atrophy which had afflicted the right kidney by the time of its autotransplantation. Although it was only one-third of the normal weight of a normal adult kidney, weighing 75 grams, and although it was anuric prior to operation, it resumed a significant function soon after it was given a normal blood supply. According to accepted criteria for revascularization, this organ should not have been salvable, but, in fact, this kidney now has become an important factor in this patient's hope of avoiding chronic renal disease.

A special precautionary note is in order about ex vivo arteriography. As Alfidi and Magnusson (1) have emphasized, kidneys into which contrast media is injected, especially under hypothermia, should be immediately washed out with electrolyte solution. Otherwise, the organ may be rendered unuseable by the toxicity of these agents or by their precipitation due to cold. We have confirmed this in canine experiments and have demonstrated the tri-iodinated contrast medium Conray 60® (meglumine iothalamate) used in our patients to be the most satisfactory of the commonly used contrast media under hypothermia.

SUMMARY

Three kidneys with arterial lesions that would have been difficult or impossible to repair by standard vascular reconstruction were removed, perfused by the Belzer technique, and returned to host after partial or complete autotransplantation. The fact that kidneys can be studied, dissected, repaired, and constantly salvaged with this technique should have important implications in several aspects of urologic operations.

REFERENCES

1. Alfidi, R. J., and Magnusson, M. O. Arteriography during perfusion preservation of kidneys. Am. J. Roentgenol. Radium Ther. Nucl. Med., 1972, 114: 690.
2. Belzer, F. O., Ashby, B. S., and Dunphy, J. E. Twenty-four hour and 72 hour preservation of canine kidneys. Lancet, 1967, 2: 536.
3. Belzer, F. O., Keaveny, T. V., Reed, T. W., and Pryor, J. P. A new method of renal artery reconstruction. Surgery, 1970, 68: 619.
4. Calne, R. Y. Tumour in a single kidney; nephrectomy, excision and autotransplantation. Lancet, 1971, 2: 761.
5. Clunie, G. J. A., Murphy, K. H., Lukin, L., and others. Autotransplantation of the kidney in the treatment of renovascular hypertension. Surgery, 1971, 69: 326.
6. Gelin, L. E., Claes, G., Gustafsson, A., and Storm, B. Total bloodlessness for extracorporeal organ repair. Surgery, 1971, 28: 305.
7. Gil-Vernet, J. M., Caralps, A., Revert, L., and others. Autotransplantation du rein pour hypertension arterielle de cause vasculaire. J. Urol. Nephrol., 1969, Suppl. 12, 75, 469.
8. Guerriero, W. G., Scott, R., Jr., and Joyce, L. Development of extracorporeal renal perfusion as an adjunct for Bench renal surgery. J. Urol., 1972, 107: 4.
9. Hardy, J. D. High ureteral injuries; management by autotransplantation of the kidney. J. A. M. A., 1963, 184: 97.
10. Kaufman, J. J., Alferez, C., and Vela Navarrete, R. Autotransplantation of a solitary functioning kidney for renovascular hypertension. J. Urol., 1969, 102: 146.
11. Kuss, R. A propos de trois cas d'hypertension arterielle par sténose de l'artere rénale. Fourteenth Congress for the International Society of Urology. Vol. II, p. 88. Paris: G. & R. Joly, 1967.
12. Marshall, V. F., Whitsell, J., McGovern, J. H., and Miscall, B. G. The practicality of renal autotransplantation in humans. J. A. M. A., 1966, 196: 1154.
13. Martinez-Pineiro, J. A., and Sicilia, L. S. Kidney autotransplantation for the treatment of renal artery stenosis; report of two cases. J. Urol., 1972, 108: 35.
14. Ota, K., Mori, S., Awane, Y., and Ueno, A. Ex situ repair of renal artery for renovascular hypertension. Arch. Surg., 1967, 94: 370.
15. Serrallach-Mila, N., Paravisini, J., Alberti, J., and others. Nuevo método de revascularización en la cirugía de la hipertensión renovascular; el autotransplante renal. Angiologia, 1966, 18: 93.
16. Starzl, T. E. Experience in Renal Transplantation. Philadelphia: W. B. Saunders Co., 1964.