Functional Role of Thromboxane Production by Acutely Rejecting Renal Allografts in Rats

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Abstract

We investigated the role of thromboxane in mediating the reduction in renal function and renal blood flow characteristic of acute renal allograft rejection. We transplanted kidneys from Lewis rats to Brown-Norway recipients. By the third day after transplantation, histologic changes that were consistent with cellular rejection occurred in the kidney. These changes were associated with a moderate reduction in renal function. By day 6, histologic changes of rejection were advanced and included interstitial and perivascular infiltration by mononuclear cells. The clearances of inulin and para-aminohippuric acid were also markedly reduced.

As renal function deteriorated, thromboxane \(B_2\) (TXB\(_2\)) production by ex vivo perfused renal allografts increased progressively from 2 to 6 % after transplantation. However, prostaglandin (PG) \(E_2\) and 6-keto PGF\(_{1\alpha}\) production remained essentially unchanged. There was a significant inverse correlation between the in vivo clearance of inulin and the log of ex vivo TXB\(_2\) production. Infusion of the thromboxane synthetase inhibitor UK-37248-01 into the renal artery of 3-d allografts significantly decreased urinary TXB\(_2\) excretion and significantly increased renal blood flow (RBF) and glomerular filtration rate (GFR). Although renal function improved significantly after the acute administration of UK-37248-01, GFR and RBF did not exceed 33 and 58% of native control values, respectively. In other animals, daily treatment with cyclophosphamide improved the clearances of inulin and para-aminohippuric acid and reduced thromboxane production by 6-d renal allografts. These studies demonstrate that histologic evidence of rejection is associated with increased renal thromboxane production. Inhibition of thromboxane synthetase improves renal function in 3-d allografts. Cytotoxic therapy improves renal function, reduces mononuclear cell infiltration, and decreases allograft thromboxane production. Thus, the potent vasoconstrictor thromboxane \(A_2\) may play a role in the impairment of renal function and renal blood flow during acute allograft rejection.

Introduction

The process of cellular rejection markedly reduces renal blood flow (RBF)\(^1\) and impairs excretory function in renal allografts.

Several investigators have described a reduction in renal cortical blood flow during rejection that is greater than expected based on the degree of morphologic changes in the kidney (1-4). Hollenberg et al. (3) suggested that infiltrating cells may produce local vasoconstrictors that could impair renal function. Because leukocytes and various renal cells produce locally vasoactive eicosanoids, alterations in prostaglandin (PG) and thromboxane (TX) metabolism may play an important role in renal allograft rejection. For example, Foegh et al. (5, 6) reported that urinary immunoreactive thromboxane \(B_2\) (TXB\(_2\)) increases during episodes of acute rejection in human renal allograft recipients. However, the source of the TXB\(_2\) that is excreted in urine and the physiologic significance of increased urinary TX is currently unknown (7-9).

Our objectives in this study were to evaluate the relationship between renal function in vivo and TXB\(_2\) production in vitro, and to examine whether histologic evidence of acute cellular rejection correlated with increased TX production. To accomplish these objectives, we developed a model of acute renal allograft rejection characterized by a predictable temporal progression. Using a combination of ex vivo renal perfusion studies, histopathologic evidence, and in vivo clearance and hemodynamic studies with both a cytolytic agent and a TX synthetase inhibitor, we have characterized changes in renal function and renal eicosanoid production in this experimental model of acute renal allograft rejection.

Methods

Rat renal transplants. Renal allografts from male Lewis rats weighing 200–300 g were transplanted into female Brown-Norway rats weighing 150–190 g using the technique described by Fabre et al. (10). The left donor kidney of Lewis rats was prepared by freeing the ureter and bladder from all peritoneal attachments. Renal artery and aorta were separated from renal vein and inferior vena cava by blunt dissection. Small arteries not involved in renal circulation were ligated and cut. We infused heparin (1,000 U/kg, Upjohn Co., Kalamazoo, MI) intravenously and then clamped the donor aorta above the left renal artery. The donor kidney was flushed with 20 ml of an iced solution containing 10% mannitol, chloramphenicol (sodium succinate salt; Merrel-National Laboratories, Cincinnati, OH) and 100 U of heparin in half-normal saline. The kidney, ureter, and bladder were removed en bloc, including the renal artery with a 3-mm aortic cuff, and the renal vein with a 3-mm vena cava cuff. The kidney was placed into an iced solution of 10% mannitol in saline.

We prepared the recipients by carefully separating aorta and vena cava between the origin of the renal vessels and the bifurcation of the iliacs. An anastomosis was created between the recipient's aorta and the donor's aortic cuff; the recipient's vena cava was anastomosed to the donor vena cava cuff. Total ischemic time averaged 40 min.

1. Abbreviations used in this paper: C\(_{\text{in}}\), clearance of inulin; C\(_{\text{PH}}\), clearance of p-aminohippuric acid; GFR, glomerular filtration rate; PAH, p-aminohippuric acid; PG, prostaglandin; PGE\(_1\), prostaglandin \(E_1\); RBF, renal blood flow; TX, thromboxane; TXB\(_2\), thromboxane \(B_2\).
Donor and recipient bladders were attached dome to dome. The recipients' native kidneys were left in situ. Surgical mortality of the recipients was <10%.

**Clearance studies.** We measured clearances of inulin (Cin) and p-aminohippuric acid (CPAH) on days 1 through 6 after transplantation in 32 animals. Animals were anesthetized with inactin, and a polyethylene catheter (PE-240) was inserted into the trachea to facilitate spontaneous respiration. The right carotid artery was cannulated to permit periodic sampling of arterial blood and to measure arterial blood pressure (Gould-Statham strain gauge; Gould Inc., Hato Rey, PR). The right jugular vein was cannulated to infuse carboxy-13C-inulin and glycyl-[3H]PAH (New England Nuclear, Boston, MA) in a solution of 5% mannitol and 0.45% saline at a rate of 0.025 ml·100 g·1·min⁻¹. Allograft and right native kidney uretans were cannulated to measure individual renal function. After a 1-h equilibration period, Cin and CPAH were measured during two 30-min control periods. Arterial blood samples were obtained at the midpoint of each collection.

**Ex vivo perfusion.** After completing in vivo clearance studies, we removed allografts for ex vivo perfusion to assess renal eicosanoid production in 21 animals. In addition to these transplanted kidneys, we perfused nontransplanted kidneys from normal Lewis rats ex vivo (n = 4) and nontransplanted kidneys of Lewis rats subjected to 45 min of renal pedicle cross-clamping. Using a modification of previously described methods (11), a polished metal perfusion catheter was inserted into the left femoral artery and advanced to the transplant anastomosis. The aorta was then ligated around the catheter. The renal vein of the allograft was cannulated with a flared PE-90 catheter. The kidney was removed and placed into a warming chamber (37°C).

We perfused kidneys with a cell-free Krebs-Henseleit buffered solution to avoid prostanoic contamination from nonrenal cells. Perfusion was warmed to 32°C and oxygenated (95% O₂, 5% CO₂) to meet, more adequately, metabolic demands of the ex vivo perfused kidney (12). In other studies, we have demonstrated that morphologic evidence of cellular necrosis is absent with perfusion warmed to 32°C and that there is extensive cortical necrosis when perfusate is delivered at 37°C. At 32°C, oxygen consumption by tubule suspensions from 4-h perfused kidneys is normal and there is no increase in renal venous lactate dehydrogenase activity during perfusion. Perfusate was delivered at a rate sufficient to maintain pressure between 100 and 120 mmHg (8 ml/min).

We collected two control samples of renal venous effluent during the first 30 min of ex vivo perfusion. We then stimulated prostanoic production by the kidney with 1-μg boluses of bradykinin given every 30 min (11, 13). Samples of renal venous effluent were collected on ice at 30-min intervals for a total of 4 h and 5-ml aliquots were stored at −70°C. Samples were thawed, extracted, and then assayed for TXB₂, prostaglandin E₂ (PGE₂), and 6-keto-PGF₁α by radioimmunoassay.

**Cyclophosphamide treatment.** In a second group of animals, we evaluated the effects of immunosuppression on renal allograft function and eicosanoid production. After transplantation, five rats were treated with the alkylating agent cyclophosphamide 20 mg·kg⁻¹·day⁻¹ (Mead Johnson, Evansville, IN). The first dose was injected intravenously during transplantation, and subsequent daily doses were injected intraperitoneally. We performed renal clearance and ex vivo perfusion studies (as described above) in renal allografts after 6 d of cyclophosphamide therapy.

**Effects of TX synthetase inhibition on renal hemodynamics.** In a group of seven animals, we evaluated the effects of increased TX production in vivo renal function in 3-d allografts. Renal clearance studies were performed and RBF was measured in native and donor kidneys before and after administering the TX synthetase inhibitor (14) UK-37248-01 (4-2-[H]-imidazo-[1,2-b]-ethoxy)benzoic acid HCl, Pfizer Inc., New York, NY. In these animals, a tapered PE-10 catheter was inserted into the femoral artery and advanced into the allograft's renal artery cuff (15). Normal saline or a solution of UK-37248-01 in saline was infused into the renal artery at a constant rate of 24 μl·min⁻¹. The renal vein of the allograft was catheterized with a curved 0.965 mm o.d. teflon catheter (Bradford Scientific, Marble Head, MA) to collect samples for the determination of renal venous p-aminohippuric acid (PAH) concentration. RBF was calculated as: 
\[ RBF = \frac{C_{PAH} \cdot E_{PAH} \cdot R}{(1 - Hct)} (\text{PAH extraction; Hct, hematocrit}). \]

After a 45-min equilibration period, we measured Cin, CPAH, and RBF in the allograft and native kidneys during two 30-min control periods. During control periods, normal saline was infused into the renal artery of 3-d allografts. These values were remeasured during two 30-min experimental periods while infusing the TX synthetase inhibitor UK-37248-01 (100 μg·kg⁻¹·min⁻¹). This dose was selected after performing in vivo dose response curves in preliminary renal function studies in 3-d allografts.

In a separate group of four animals with 3-d allografts, we documented that UK-37248-01 inhibited in vivo TXB₂ production. In these animals, the ureter of the transplanted kidney was cannulated and urine was collected on ice before and after UK-37248-01 infusion (100 μg·kg⁻¹·min⁻¹). Urine samples were extracted as described above and TXB₂ was measured by radioimmunoassay and expressed as picograms of TXB₂ produced per minute. In other studies using UK-37248-01 in hydropneumatic rats, we have found that 100 μg·kg⁻¹·min⁻¹ administered into the renal artery inhibits renal TXB₂ production ex vivo, reduces urinary TXB₂ excretion in vivo, and improves Cin and RBF in vivo after 24 h of unilateral ureteral obstruction.

**Histologic studies.** After renal clearance or ex vivo perfusion studies, all kidneys were fixed in buffered formalin for histologic examination. 3-μm sections were prepared and stained with hematoxylin and eosin. Both native and donor kidneys were examined for the presence of cellular infiltrates on days 1 through 6 after transplantation.

**Analytical techniques.** Tritium and ¹⁴C radioactivity were measured in plasma and urine with a dual channel liquid scintillation system (Isocomp 300; Nuclear Chicago-TM Analytic Inc., Elk Grove Village, IL). Plasma and urine Na⁺ and K⁺ were analyzed with a lithium internal standard flame photometer (Instrumentation Laboratory, Inc., Lexington, MA), and U₁₈₀₀ and P₁₈₀₀ with a vapor pressure osmometer (Wescor Inc., Logan, UT).

**Radioimmunoassays (RIAs).** Prostanoids were extracted by passing samples of renal venous effluent through C₁₈ columns (Sep-Pak C₁₈ cartridges; Waters Associates, Milford, MA). Cartridges were washed with distilled water, and samples were eluted with acetonitrile and dried at 35°C with dry nitrogen. Dried samples were resuspended in buffer and assayed for TXB₂, PGE₂, or 6-keto-PGF₁α by RIA. Small amounts of tritiated compound were added to each sample before extraction and RIA to correct for recovery. Using this extraction procedure, 60−70% of [³H]TXB₂, 70−80% of [³H]TXB₂, and 70−80% of [³H]PGE₂ were recovered. All RIA reagents were purchased from Seragen Inc., Boston, MA. Specific antisera were generated in rabbits using immunogen complexed to bovine serum albumin. Antibody to TXB₂ demonstrated 50% binding at a final titer of 1:3,500; cross-reactivity to 2-3 dinor TXB₂ was 60%, and to other prostanoids was <0.1%. Sensitivity of the antibody (50% displacement of radioligand) was 12 pg. Antibody to PGE₂ demonstrated 50% binding at a final titer of 1:1,400; cross-reactivity was 6% for PGA₂, 3% for PGA₁, 1.3% for PGE₂, and <1% to other prostanoids. Sensitivity of the PGE₂ antibody was 73 pg. Antibody to 6-keto-PGF₁α demonstrated 50% binding at a final assay titer of 1:4,500; cross-reactivity was 7.8% for PGI₂, 6.8% for 6-keto-PGE₂, 2.2% for PGE₂, 0.7% for PGE₁, 0.6% to PGE₂, and <0.01% for the other prostanoids. Sensitivity of the 6-keto PGI₂ antibody was 47 pg.

Samples and standards were incubated with a mixture of antisera and a known amount of tritiated standard at 4°C for 20 h. Specific activity of the [³H] standards ranged between 110 and 165 Ci/mM. After incubation, we adsorbed free prostanoid with dextran-coated charcoal and measured [³H] remaining in the supernatant with a liquid scintillation counter. The unknowns, corrected for [³H] recovery from the extraction procedure, were compared with the standard curve in which the logarithm of the concentration was plotted against the log of the B/B₀ value. The results are expressed as picograms per minute of prostanoid.

**Statistics.** Data are presented as means±standard error. Statistical.
significance was assessed between groups with an unpaired t test, and within groups with a paired t test. The correlation between the log of TXB₂ produced ex vivo and C_in measured in vivo was determined by linear regression analysis.

**Results**

The clearances of inulin and PAH by native kidneys and allografts on days 1 through 6 after transplantation are depicted in Fig. 1. Native kidney C_in and C_PAH remained unchanged throughout most of the 6 d after transplantation with the exception of day 2. On day 2, both C_in and C_PAH increased slightly but not significantly above basal values. On the first day after transplantation, C_in and C_PAH of renal allografts were significantly reduced compared with native kidneys. On the second day after transplantation, function of the allografts improved and C_PAH was not different from that of the native kidneys (7.82±1.82 ml·min⁻¹·kg⁻¹ vs. 9.69±1.45 ml·min⁻¹·kg⁻¹). Allograft C_in also improved but was still less than that of native kidneys (2.35±0.45 ml·min⁻¹·kg⁻¹ vs. 4.20±0.48 ml·min⁻¹·kg⁻¹; P < 0.025). Allograft function declined progressively from days 3 through 6; native kidney function remained unchanged. On day 3, allograft C_in was significantly reduced when compared with day 2 (0.9±0.3 vs. 2.35±0.45 ml·min⁻¹·kg⁻¹, P < 0.025). C_PAH was also significantly reduced from 7.82±1.26 ml·min⁻¹·kg⁻¹ on day 2 to 2.91±0.88 ml·min⁻¹·kg⁻¹ on day 3 (P < 0.025). By day 6, C_in and C_PAH of donor kidneys decreased to 0.04±0.04 and 0.24±0.21 ml·min⁻¹·kg⁻¹, respectively (P < 0.005 vs. day 3 values).

Histologic examination of allografts on the first day after transplantation demonstrated patchy acute tubular necrosis with no evidence of acute cellular rejection. There were focal areas of brush border loss, sloughed epithelial cells, and occasional intraluminal casts. On day 2, tubules and glomeruli appeared histologically normal and there was only minimal cellular infiltration. However, on the third day after transplantation, there was marked infiltration of the interstitium by inflammatory cells, especially in perivascular areas, with sparing of glomeruli. 6 d after transplantation, there was marked progression of mononuclear cell infiltration throughout the interstitium of the allograft as well as glomerular capillary involvement.

To evaluate the rejecting allograft's capacity for eicosanoid production without contamination by other tissues, we perfused allografts ex vivo with a cell-free perfusate and measured renal venous 6-keto-PGF₁α, PGE₂, and TXB₂. Fig. 2 depicts renal TXB₂ production by ex vivo perfused kidneys 2, 3, and 6 d after transplantation and by nontransplanted kidneys from normal Lewis rats. Unstimulated TXB₂ production by Lewis control kidneys and 2-d allografts did not differ (28±8 pg/min vs. 10±8 pg/min; n = 8). 3-d allografts produced significantly greater amounts of TXB₂ than 2-d allografts or normal Lewis control kidneys. TXB₂ production by 6-d transplanted kidneys was significantly greater than the values of all other groups. Bradykinin stimulation produced a significant and immediate increase in TXB₂ production by all transplanted kidneys, but not by Lewis control kidneys. Unstimulated TXB₂ production by cross-clamped control kidneys and by 1-d allografts was <40 pg/min. In these kidneys, acute tubular necrosis was the predominant morphologic feature and there was no response to bradykinin stimulation.

Fig. 3 illustrates the relationship between C_in and unstimulated TXB₂ production in 3- to 6-d allografts. C_in was determined in vivo and the same kidneys were then removed and perfused ex vivo to determine unstimulated and bradykinin-stimulated TXB₂ production. There was a significant inverse linear correlation between the log of ex vivo TXB₂ production and in vivo inulin clearance (r = 0.74, P < 0.05).

The effects of daily cyclophosphamide treatment on renal allograft function and ex vivo TXB₂ production are shown in
Fig. 4 and Fig. 5. Clearances of inulin and PAH measured in cyclophosphamide-treated animals 6 d after transplantation were significantly greater than values from untreated animals (Cin, 0.71±0.16 vs. 0.04±0.04 ml·min⁻¹·kg⁻¹, P < 0.001; CPAM, 2.87±0.72 vs. 0.24±0.21 ml·min⁻¹·kg⁻¹, P < 0.001). 6-d cyclophosphamide-treated allografts produced significantly less TXB₂ than untreated 6-d allografts both before and after bradykinin stimulation. Furthermore, cyclophosphamide treatment significantly reduced the interstitial infiltration of inflammatory cells in 6-d allografts.

Fig. 6 depicts 6-keto PGF₁α production by three groups of kidneys: (a) nontransplanted Lewis control kidneys; (b) allografts 2, 3, and 6 d after transplantation; and (c) 6-d cyclophosphamide-treated allografts. Ex vivo 6-keto PGF₁α production before bradykinin stimulation was similar in each group. However, after 180 and 240 min of bradykinin stimulation, 6-keto PGF₁α production by 2-, 3-, and 6-d allografts was greater than the values of either Lewis controls or the cyclophosphamide-treated rats.

As demonstrated in Fig. 7, there was no clear relationship between the number of days after transplantation and ex vivo PGE₂ production. Unstimulated PGE₂ production by 2-d allografts was significantly less than values of nontransplanted Lewis control kidneys (178±27 pg/min vs. 324±63 pg/min, P < 0.05) and 3-d allografts (402±118 pg/min, P < 0.05). After 240 min of bradykinin stimulation, PGE₂ production by both Lewis control kidneys (1,915±283 pg/min, P < 0.005) and 2-d allografts (1,813±456 pg/min, P < 0.025) was significantly greater than that of cyclophosphamide-treated rats (533±189 pg/min).

Because ex vivo TXB₂ production by allografts correlated inversely with Cin, we explored the functional significance of increased TX production in vivo. We acutely infused the TX synthetase inhibitor UK-37248-01 into renal arteries of seven donor kidneys 3 d after transplantation. As demonstrated in Fig. 8, in vivo RBF increased from 16.53±5.21 ml·min⁻¹·kg⁻¹ before infusion to 26.19±3.45 ml·min⁻¹·kg⁻¹ during infusion of UK-37248-01 (P < 0.025). Cin also increased from 1.06±0.38 ml·min⁻¹·kg⁻¹ to 1.37±0.39 ml·min⁻¹·kg⁻¹ (P < 0.05). The intra-arterial infusion of UK-37248-01 significantly reduced urinary TXB₂ excretion by allografts from 1.18±0.26 pg/min to 0.50±0.22 pg/min (P < 0.05).

Other renal excretory data from the acute UK-37248-01 infusion studies are displayed in Table I. Mean arterial pressure was not altered by UK-37248-01 infusion (101±4 vs. 98±5 mmHg). Neither were allograft urine flow rate, percent fractional excretion of sodium, sodium excretion, potassium excretion, or percent free water clearance/osmolar clearance altered by UK-37248-01 infusion. However, as measured during the control period before UK-37248-01 infusion, native kidney Cin, CPAM, sodium excretion, potassium excretion, and percent free water clearance/osmolar clearance were all significantly greater than values measured in the allograft. In native kidneys, acute administration of UK-37248-01 had no significant effect on any of these parameters.

Discussion

The mechanisms that reduce renal function during renal allograft rejection are unknown. Focal perivascular mononuclear cell infiltrates are a prominent morphologic feature of rejection, but the role that these cells play in altering renal hemodynamics is unclear. Various renal, endothelial, and hematopoietic cells are important sources of vasoactive hormones. In particular, both monocytes and macrophages release locally active cyclooxygenase and lipoxygenase products (16–22). These infiltrating cells may release vasoconstrictor eicos-
anoids or stimulate renal production of vasoconstrictors, which reduce RBF and glomerular filtration rate (GFR). This hypothesis has been suggested for other models of renal disease including unilateral ureteral obstruction (11), renal vein constriction (23), and acute nephrotoxic serum nephritis (24). Because mononuclear cell infiltration is so impressive in rejecting allografts, renal transplantation rejection provides an ideal setting in which to study the effects of these cells on renal function.

In this study, we developed a model of renal transplantation rejection that was predictable in progression and severity of renal impairment. In this model, we demonstrated that TX synthetic capacity of rejecting kidneys was significantly increased. The in vivo TX synthetase inhibitor studies suggested that increased TXA2 production may have a role in determining renal function during allograft rejection. TX synthetase inhibition had no effect on native kidney function. Therefore, improvement in allograft function probably resulted from local rather than systemic effects of the drug. The acute infusion of UK-37248-01 into allograft renal arteries increased RBF by 58% and C\textsubscript{in} by 29%. However, despite this improvement in allograft function with UK-37248-01, RBF and C\textsubscript{PAS} remained below normal. Thus, increased TX synthesis is only one of several factors that reduce renal function during acute rejection.

The cellular source of increased TX production by rejecting kidneys cannot be determined from these studies. In our model, increased TX production by allografts correlated with progressive interstitial accumulation of chronic inflammatory cells. Stimulated macrophages, lymphocytes, and leukocytes can synthesize TXA2, PGE\textsubscript{2}, 6-keto-PGF\textsubscript{1\alpha} as well as a number of lipoxygenase products (16-22). Thus, inflammatory cells that infiltrated the allograft could have been the primary source of increased eicosanoid production. In addition, lipoxygenase products released by leukocytes can stimulate TX synthesis in other cells. Feuerstein et al. (25) reported that incubation of rat peritoneal macrophages with leukotrienes C\textsubscript{4} and D\textsubscript{4} enhances the release of PGE\textsubscript{2}, 6-keto-PGF\textsubscript{1\alpha}, and TXB\textsubscript{2} in a dose dependent manner. Therefore, in this study, leukotrienes from infiltrating leukocytes could have stimulated production of eicosanoids by inflammatory cells or renal parenchymal cells. Finally, platelet aggregation may also occur in the vessels of rejecting kidneys. Platelets produce large quantities of TXA2 (26), and they too could have contributed to the increased TX production by ex vivo perfused allografts.

In other models of acute renal failure, leukocytes have been implicated as a potential source of eicosanoids or as stimulators of increased eicosanoid production. Okwega et al. (11) have suggested that infiltrating mononuclear cells are instrumental in the exaggerated renal TX and PG synthesis that occurs with ureteral obstruction in rabbits. Schwartz et al. (23) have demonstrated in the same species a similar phenomenon associated with renal vein constriction. Leftkowitz et al. (27) have reported that treatment of hydronephrotic rabbits with nitrogen mustard decreases leukocytic infiltration and inhibits bradykinin-stimulated thromboxane production. Davis and Needleman (28) demonstrated that pretreatment with cyclophosphamide inhibits TX synthesis in hydronephrotic rabbit kidneys. In our study, cyclophosphamide treatment reduced both bradykinin-stimulated and unstimulated TBX2 production. This inhibition of TX production was associated with a marked decrease in interstitial mononuclear cell infiltration and an improvement in both C\textsubscript{in} and C\textsubscript{PAS}.

Renal tissue may also be an important source of enhanced prostanooid production by rejecting kidneys. Isolated glomeruli from normal rats synthesize PGE\textsubscript{2}, 6-keto-PGF\textsubscript{1\alpha}, and TXB\textsubscript{2} (29). Isolated glomeruli produce increased amounts of TXB\textsubscript{2} during ureteral obstruction (30), acute nephrotoxic serum nephritis (24), and glycerol-induced acute renal failure (31). We have also shown that isolated proximal tubule suspensions from normal rats can produce PGE\textsubscript{2} and TXB\textsubscript{2} (32). Thus, altered prostanooid synthesis by the kidney, by infiltrating cells, or by an interaction between these tissues may play a role in the vasoconstriction of allograft rejection.

Acute allograft rejection has become an important clinical problem because of the frequent use of renal transplantation as a mode of therapy for end-stage renal disease. One of the major problems in evaluating nonfunctioning allografts has

**Table I. Excretory Function of 3-d Transplant and Native Kidneys Before and After Administration of UK-37248-01**

<table>
<thead>
<tr>
<th></th>
<th>C\textsubscript{in} (ml/min/kg)</th>
<th>C\textsubscript{PAS} (ml/min/kg)</th>
<th>V (ml/min/kg)</th>
<th>%R\textsubscript{FE}</th>
<th>U\textsubscript{1} (ueq/min/kg)</th>
<th>U\textsubscript{2} (ueq/min/kg)</th>
<th>%TCH\textsubscript{O} (ueq/min/kg)</th>
</tr>
</thead>
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<tr>
<td>Allograft control±SE</td>
<td>1.06±0.38</td>
<td>4.10±1.45</td>
<td>18.1±3.69</td>
<td>2.44±1.00</td>
<td>1.84±0.48</td>
<td>1.50±0.36</td>
<td>38.14±11.85</td>
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<tr>
<td>Allograft + UK-37248±SE</td>
<td>1.37±0.39*</td>
<td>5.21±1.54*</td>
<td>19.67±2.58</td>
<td>1.70±0.47</td>
<td>1.90±0.41</td>
<td>1.99±0.56</td>
<td>40.79±8.99</td>
</tr>
<tr>
<td>Native control±SE</td>
<td>4.16±0.50</td>
<td>10.75±1.50</td>
<td>25.86±4.04</td>
<td>0.72±0.14</td>
<td>4.21±0.97*</td>
<td>5.14±0.84*</td>
<td>81.38±0.78$</td>
</tr>
<tr>
<td>Native + UK-37248±SE</td>
<td>4.35±0.35</td>
<td>10.94±1.30</td>
<td>26.86±4.09</td>
<td>0.81±0.11</td>
<td>4.68±0.70</td>
<td>4.84±0.48</td>
<td>80.48±0.98$</td>
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* P < 0.05 vs. allograft control; $P < 0.005 vs. allograft control.
been the difficulty in differentiating acute tubular necrosis from acute cellular rejection. In this study, allografts with acute tubular necrosis 1–2 d after transplantation produced minimal amounts of TXB₂, as did cross-clamped controls. However, kidneys 3–6 d after transplantation produced significantly increased amounts of TXB₂. This observation suggests that, under these experimental conditions, increased renal TXB₂ production may differentiate acute cellular rejection from acute tubular necrosis. Furthermore, as much as 10–20% of the reduced GFR and RBF measured in 3-day allografts could be attributed directly to increased TX production. This observation may have implications for the possible use of specific TX synthetase inhibitors in the future therapy of acute rejection. In this study, cyclophosphamide profoundly reduced renal prostanoid production by the rejecting kidney. Corticosteroids, which are currently used in treating acute cellular rejection, also alter eicosanoid metabolism by inhibiting phospholipase A₂ (33). Therefore, one of the beneficial effects of corticosteroids on renal function during allograft rejection may be related to reduced TXA₂ synthesis. Since much of the morbidity of acute rejection is attributable to drug therapy, improving function with TX synthetase inhibitors may permit reduced immunosuppressive therapy.

We were unable to detect a clear relationship between rejection and PGE₂ and 6-keto PGF₁α production by ex vivo perfused allografts. There was a tendency for the ratios of PGE₂/TXB₂ and 6-keto PGF₁α/TXB₂ to decrease progressively from days 2–6 after transplantation. These ratios were also lower in rejecting kidneys compared with nontransplanted, normal Lewis kidneys. The marked differences in the observed renal synthetic capacity of TXB₂, PGE₂, and 6-keto PGF₁α, and the different responses to bradykinin stimulation and cytolytic therapy suggest that these eicosanoids may be produced by several different tissue types.

In summary, we developed a model of renal allograft rejection that was predictable in onset and degree of functional impairment. Renal TX synthesis in rejecting rat renal allografts was increased and this increase played a role in decreasing RBF and GFR. Although TX was not clearly the sole mediator of this decrease in renal function, its effects may be significant. The exact cellular source of increased TX production and the mechanism of its release were not addressed in this study nor did we study other important vasoconstrictors that may contribute to altered renal hemodynamics. Our data suggest that specific pharmacologic interventions that decrease TXA₂ production during acute rejection may be useful in preserving allograft function.

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