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ORIGINAL RESEARCH

Short running header: Nephropreventive effect of meclofenamate in acute kidney injury

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Meclofenamate elicits a nephropreventing effect in a rat model of ischemic acute kidney injury by suppressing indoxyl sulfate production and restoring renal organic anion transporters

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Abstract: Indoxyl sulfate (IS), a putative low-molecular weight uremic toxin, is excreted in the urine under normal kidney function, but is retained in the circulation and tissues during renal dysfunction in acute kidney injury (AKI) and chronic kidney disease (CKD). IS, which is one of the most potent inducers of oxidative stress in the kidney and cardiovascular system, is enzymatically produced in the liver from indole by cytochrome P450-mediated hydroxylation to indoxyl, followed by sulfotransferase (SULT)-mediated sulfate conjugation. We used rat liver S9 fraction to identify inhibitors of IS production. After testing several compounds, including phytochemical polyphenols, we identified meclofenamate as a potent inhibitor of IS production with an apparent IC_{50} value of 1.34 μM. Ischemia/reperfusion (I/R) of rat kidney caused a marked elevation in the serum IS concentration 48 hr after surgery. However, intravenous administration of meclofenamate (10 mg/kg) significantly suppressed this increase in the serum level of IS. Moreover, IS concentrations in both kidney and liver were dramatically elevated by renal I/R treatment, but this increase was blocked by meclofenamate. Serum creatinine and blood urea nitrogen were markedly elevated in rats after renal I/R treatment, but these increases were significantly restored by administration of meclofenamate. Renal expression of both basolateral membrane-localized organic anion transporters rOAT1 and rOAT3 was downregulated by I/R treatment. However, expression of rOAT1 and rOAT3 recovered after administration of meclofenamate, which is associated with the inhibition of I/R-evoked elevation of PGE2. Our results suggest that meclofenamate inhibits hepatic SULT-mediated production of IS, thereby suppressing serum and renal accumulation of IS. Meclofenamate also prevents the PGE2-dependent downregulation of rOAT1 and rOAT3 expression. In conclusion, meclofenamate was found to elicit a nephropreventive effect in ischemic AKI.

Keywords: uremic toxins; hepatic sulfotransferase; renal ischemia/reperfusion; renal tubular cell.

Introduction

The Acute Kidney Injury Network (AKIN) defined Acute Kidney Injury (AKI) as "functional and structural disorders or signs of renal damage including any defect from blood and urine test, or tissue imaging that is less than 3 months".[1,2] AKI develops when the kidney damage is evoked by a decrease in renal blood flow, *i.e.*, renal ischemia from causes including low blood pressure and renal surgery, exposure to nephrotoxic chemicals and drugs, an inflammatory process in the kidney, or an obstruction of the urinary tract that blocks urine flow.[2] Generally, AKI is diagnosed based on laboratory data, such as abnormal blood urea nitrogen (BUN) and serum creatinine (SCr) levels, or failure to produce sufficient amounts of urine. AKI leads to many complications, including metabolic acidosis, high potassium levels, changes in body fluid balance, and uremia with increased serum uremic toxins that cause oxidative stress affecting other organ functions.

Uremic toxins are defined as compounds retained as solutes in the serum that contribute to uremic syndrome (*i.e.*, deterioration of multiple biochemical and physiological functions in association with progressive renal disease), leading to a complex and variable symptomatology.[3,4] These uremic toxins accumulate in patients with chronic kidney disease (CKD), including patients with stage 5 kidney disease or end-stage renal disease (ESRD).[5,6] Some studies have suggested that moderate stages of AKI are independently associated with an increase in mortality.[7-9] Increased mortality is not due to AKI or to direct renal complications associated with AKI but is enhanced by acute lung injury, sepsis or sympathetic nervous system dysfunctions. The precise mechanism by which AKI-induces these deleterious, distant, nonrenal organ dysfunctions is not well understood. Nonetheless, uremic toxins are thought to be one of the key mediators affecting organ dysfunction.[10-12] Uremic toxins can be subdivided into three major groups based upon their chemical and physical characteristics: (i) small, water-soluble, non-protein-bound compounds, such as urea; (ii) small, lipid-soluble and/or protein-bound compounds, such as indoxyl sulfate (IS) and *p*-cresyl sulfate; (iii) larger so-called middle-molecules, such as β2-microglobulin.[3,4]

IS, a putative low-molecular weight uremic toxin, is excreted in the urine under normal kidney function, but is one of a representative group of sulfate-conjugated metabolites that are retained in the circulatory system during renal dysfunction.[3,11,13] Serum IS levels elevate markedly in patients undergoing dialysis treatment, with maximum serum concentrations of > 900 μM.[3] Previous studies demonstrate that IS

induces oxidative stress in the kidney and cardiovascular system.[5,6,14] For example, IS is one of the most powerful inducers of free radicals among various low-molecular weight uremic toxins.[5,6] Indeed, cytotoxic effects induced by IS can be explained by dysregulated oxygen metabolism and induction of oxidative stress in renal proximal tubular cells.[14] IS is exclusively generated in the liver. Dietary protein-derived tryptophan is first metabolized to indole by tryptophanase of intestinal bacteria such as *Escherichia coli*.[5,11] Following intestinal absorption, indole is hydroxylated to indoxyl by cytochrome P450 (CYP) 2E1 or CYP2A6, and subsequently conjugated to IS by sulfotransferase (SULT) 1A1 in the liver.[15,16] IS generated in the liver enters the blood circulation and is efficiently taken up by renal proximal tubular cells *via* basolateral membrane-localized organic anion transporters, OAT1/SLC22A6 and OAT3/SLC22A8, before being excreted into the urine *via* unidentified apical membrane-localized transporters.[17,18]

Previously, we used experimental rats with cisplatin-induced AKI to demonstrate oral administration of AST-120 (Kremezin™), a charcoal adsorbent for intestinal organic compounds that accumulate in patients with CKD[6], suppresses serum and renal accumulation of IS as well as significantly reducing the onset of AKI.[19,20] Based on these findings, we proposed that low-molecular weight uremic toxins, which can be removed by AST-120 treatment, contribute to the progression of kidney diseases in not only CKD but also in the development or derangement of AKI. Moreover, we found that phytochemical polyphenol compounds such as resveratrol and quercetin, which show a potent inhibitory effect against SULT1A1, significantly inhibited *in vitro* hepatic production of IS.[21] These phytochemicals displayed a nephropreventive effect in cisplatin-induced AKI rats in association with a decreased accumulation of IS in serum, kidney and liver. We suggested that agents with a potential inhibitory effect on hepatic IS production could be useful for preventing the progression of cisplatin-induced AKI.[21] The pathophysiological role of IS in ischemic AKI has not yet been determined. In the present study we have examined the effect of meclofenamate, a potential SULT inhibitor, on IS accumulation and the development of kidney dysfunction in ischemic AKI rats.

Materials and methods

Chemicals

IS was obtained from Sigma-Aldrich (St. Louis, MO). Apigenin, boldine, catechin-(+,-)-hydrate, diclofenac sodium, esculetin, graveoline, meclofanamic acid, myricetin and naringenin were obtained from Meiji Seika Pharma Co., (Tokyo, Japan). Indole, carboxymethyl cellulose (CMC), methanol and nitric acid (HNO_3) were obtained from Wako Pure Chemical Industries, Ltd. (Osaka, Japan). All chemicals used in this study were of analytical grade and commercially available.

Inhibition experiment of hepatic IS production by rat liver S9 fraction

Rat liver S9 fraction was prepared according to our previous report with some modifications.[21] The liver S9 fraction contains cytosol and microsomes. The microsomal component of the S9 fraction contain CYP isoforms and other enzymes mediating phase I metabolism. The cytosolic component includes transferases mediating phase II conjugation, including SULT. Liver was harvested from male SD rats at 6 weeks of age (Clea Japan, Inc., Tokyo, Japan). The liver homogenate in 50 mM sodium phosphate buffer (pH 7.4) containing 150 mM potassium chloride was centrifuged at 9,000*g* for 20 min at 4°C, and the supernatant was used as the S9 containing microsomal fraction with CYP and cytosol fraction with SULT. The reaction mixture (total volume 250 μl) comprised 50 mM sodium phosphate buffer (pH 7.4) containing the S9 fraction (5-10 mg protein/ml), indole, reduced nicotinamide adenine dinucleotide phosphate (NADPH) (1 mM), adenosine 3'-phosphate 5'-phosphosulfate (20 μM) and uridine diphosphate glucuronic acid (1 mM) with or without test compounds. Incubation of the reaction mixture was performed in a shaking water bath maintained at 37°C for 30 min. The reaction was terminated by addition of 250 μl of ice-cold methanol. The reaction mixture was then centrifuged at 9,000*g* for 10 min and the supernatant obtained was used for liquid chromatography (LC) / mass spectrometry (MS) / MS analysis of IS concentration.

Animal experiments

All procedures for animal experiments were approved by Kumamoto University ethical committee concerning animal experiments, and animals were treated in accordance with the Guidelines of the United States National Institutes of Health regarding the care and use of animals for experimental procedures, and the Guidelines of Kumamoto University for the care and use of laboratory animals. Male Sprague-Dawley (SD) rats at 6 weeks of age were housed in a standard animal maintenance facility at a constant temperature (22 ± 2°C) and humidity (50-70 %) and a 12/12 hr light/dark cycle for about a week before the day of the experiment, with food and water available *ad libitum*. Rats were anesthetized using sodium pentobarbital (50 mg/kg intraperitoneally), and placed on a heating plate (39°C) to maintain a constant temperature. All surgery was conducted under anesthesia with pentobarbital, and all efforts were made to minimize animal suffering. The kidneys of male SD rats at 6 weeks of age were exposed *via* midline abdominal incisions. Renal I/R was induced by vascular clamps (AS ONE, Osaka, Japan) over both pedicles for 30 min, followed by release of the clamps as reported previously.[22] Sham animals (control) underwent anesthesia, laparotomy, and renal pedicle dissection only. Rats were divided into three different groups as follows: sham-operated rats (control rats), saline-administered rats with I/R treatment and meclofenamate-administered rats with I/R treatment. Meclofenamate (10 mg/kg) were intravenously administered to rats 6, 12 and 18 hr after renal I/R treatment. Blood was collected 48 hr after I/R treatment from the abdominal aorta and centrifuged at 3,000*g* for 10 min to obtain the serum sample. Acetonitrile (100 μl) was added to serum (25 μl) and the mixture was centrifuged at 9,000*g* for 10 min at 4°C. The obtained supernatant (50 μl) was diluted with LC/MS/MS mobile phase solution (300 μl) and centrifuged at 9,000*g* for 10 min at 4°C. The supernatant was used for LC/MS/MS determination of IS concentration. Kidney was harvested 48 hr after I/R treatment and homogenized in phosphate-buffered saline (pH 7.4) using a Polytron PT3000 (Kinematica AG, Lucerne, Switzerland). After centrifugation at 3,000*g* for 10 min at 4°C, the obtained supernatant was used for LC/MS/MS assay of IS concentration. Levels of SCr (enzymatic method) and BUN (uricase ultraviolet (UV) method) were then measured.

LC/MS/MS assay of IS concentration

Aliquots of the extracts (5 µL) were separated on a Symmetry™ C18 (5 µm, 3.9 mm x 150 mm) column (Waters Corp., Milford, MA) interfaced with API3200™ LC/MS/MS system (AB SCIEX, Foster City, CA) operating in negative TurboIonSpray mode. Samples were eluted at a flow rate of 0.2 mL/min using a mobile phase consisted of 10 mM ammonium acetate:acetonitrile (73:27 v/v) at 40°C. Relevant MS/MS settings were: CAD gas at 3.0 psig; CUR at 40 psig; GS1 at 50 psig; GS2 at 30 psig; IS at -4500 V and TEM at 500°C.

Western blot analysis

Western blot analysis for organic anion transporters, rOAT1 and rOAT3, was performed according to a previous report with some modifications.[21,22] Briefly, kidneys were homogenized in an ice-cold homogenization buffer consisting of 230 mM sucrose, 5 mM Tris (hydroxymethyl) aminomethane hydrochloride (Tris–HCl) (pH 7.5), 2 mM ethylenediaminetetraacetic acid, 0.1 mM phenylmethanesulfonyl fluoride, 1 µg/ml leupeptin and 1 µg/ml pepstatin A. After measuring of protein content using a bicinchoninic acid (BCA) protein assay reagent (Thermo Fisher Scientific, Rockford, IL), each sample was mixed in loading buffer (2 w/v% sodium dodecyl sulfate (SDS), 125 mM Tris–HCl pH 7.2, 20 v/v% glycerol and 5 v/v% 2-mercaptoethanol) and heated at 95°C for 2 min. The samples were subjected to sodium dodecyl sulfate-polyacrylamide gel (SDS-PAGE) electrophoresis using a 7.5% gel and transferred onto a polyvinylidene difluoride (PVDF) membrane (Immobilon-P; Millipore, Bedford, MA) by semi-dry electroblotting. The membrane was blocked overnight at 4°C with 2 v/v% ECL Advance Blocking Agent (GE Healthcare, Little Chalfont, UK) in 50 mM Tris-buffered saline (pH 7.6) containing 0.3 v/v% Tween 20, and then incubated for 1 h at room temperature with a primary antibody specific for rOAT1 or rOAT3 (gift from Dr. Inui Kyoto University Hospital). The blots were then washed with Tris-buffered saline containing Tween 20 before incubation with the secondary antibody (horseradish peroxidase-linked anti-rabbit immunoglobulin F(ab)2 or horseradish peroxidase-linked anti-mouse immunoglobulin F(ab)2 (GE Healthcare) for 1 hr at room temperature. Immunoblots were visualized with an ECL system (ECL Advance Western Blotting Detection Kit; GE Healthcare).

Measurement of prostaglandin (PG) E2 concentration in kidneys

Kidney was harvested 48 hr after IR treatment and homogenized in 100 mM phosphate buffer containing 1 mM EDTA and 10 μM COX inhibitor™ (pH 7.4) using a Polytron PT3000 (Kinematica AG, Lucerne, Switzerland). After centrifugation at 8,000*g* for 10 min at 4°C, the obtained supernatant was used to assay PGE2 concentration using a Prostaglandin E2 Express EIA Kit (Cayman Chemical Co., San Diego, CA).

Statistical analysis

Data were analyzed statistically by analysis of variance, followed by Scheffé's multiple comparison test. A P value of <0.05 was considered statistically significant. All data are represented as the mean ± SD.

Results

In vitro inhibitory effects of several compounds on IS production using the rat hepatic S9 fraction

In our previous study,[21] we found that quercetin, curcumin and resveratrol, well-known potent inhibitors of SULT, showed strong inhibitory effects on IS production. The apparent inhibition constant (*Ki*) values of quercetin, curcumin and resveratrol for IS production were 1.0, 1.8 and 1.5 μM, respectively.[23] By contrast, the apparent *Ki* values of tranylcypromine, a CYP2A6 inhibitor, and diethyldithiocarbamate, a CYP2E1 inhibitor, were 148 and 1,859 μM, respectively.[21] Based on these findings, we further examined the inhibitory potencies of several compounds, including other phytochemical polyphenols and clinically used drugs (chemical structures shown in Figure 1), on hepatic IS production by using the liver S9 fraction. Among the compounds examined, polyphenol derivatives showed relatively potent inhibitory effects on hepatic IS production; % of inhibition, esculetin (84.9 ± 0.3%), apigenin (84.2 ± 3.3%) and myricetin (75.6 ± 1.0%) (Figure 2). Meclofenamate, a non-steroidal anti-inflammatory drug, also exhibited strong inhibition (83.3 ± 1.9%) of IS production. Another non-steroidal anti-inflammatory drug diclofenac showed a moderate inhibitory effect (31.8 ± 8.8%). The apparent inhibitory constant (IC_{50}) values for these compounds on IS

production were kinetically determined based on the data of concentration-dependent inhibition experiments (Figure 3). Among these compounds, meclofenamate showed the most potent inhibitory effect on IS production (apparent IC_{50} of 1.34 μM).

Effect of meclofenamate on IS concentrations in rats treated with renal I/R

The effect of meclofenamate on IS concentrations in serum, kidney and liver was examined in rats treated with renal I/R. Meclofenamate was administered three times to rats by intravenous injection at a dose of 10 mg/kg. Serum IS concentration was markedly increased in I/R rats 48 hr after surgery compared to that in control rats (Figure 4). However, meclofenamate administration significantly suppressed this increase in serum IS concentration (Figure 4). Furthermore, the IS concentration in both kidney and liver were dramatically elevated after renal I/R treatment, but this elevation in IS level in these organs was significantly reduced by administration of meclofenamate (Figure 4).

Effect of meclofenamate on renal function of rats treated with renal I/R

Figure 5 illustrates SCr and BUN levels in rats treated with renal I/R. SCr and BUN were markedly elevated by renal I/R treatment, but these increases were significantly restored by the administration of meclofenamate, suggesting this compound elicits a nephropreventing effect.

Effect of meclofenamate on the expression of rOAT1 and rOAT3 and the level of prostaglandin E2 (PGE2) in an ischemic kidney

In our previous study, we reported that expression of organic anion transporters rOAT1 and rOAT3, located on the basolateral membrane of renal proximal tubular cells, was markedly downregulated after renal I/R treatment in rats.[22] As shown in Figure 6, the expression levels of both rOAT1 and rOAT3 were markedly decreased in the kidney of I/R-treated rats. However, the expression levels of these two transporters were largely restored by administration of meclofenamate.

PGE2 can be transiently produced by an increased cyclooxygenase 2 activity in response to oxidative stress. In the ischemic kidney of rats, PGE2 is reported to induce downregulation of rOAT1 and

rOAT3.[23] Thus, the PGE2 level in rats after renal I/R treatment was assayed. Renal I/R treatment caused a marked elevation in the level of PGE2, but this increase was prevented partially by administration of meclofenamate with no significant level compared to that of control (sham) (Figure 7).

Discussion

Based on an *in vitro* indoxyl sulfate production assay using rat liver S9 fraction, we found that phytochemical polyphenols showed a relatively potent inhibitory effect on hepatic IS production. Among the compounds tested, esculetin, apigenin and myricetin displayed strong inhibitory effects on IS production (Figure 2). In our previous study, the inhibitors of SULT activity, such as resveratrol, quercetin and curcumin, showed potent inhibitory effects on IS production compared with the inhibitors of CYP2E1 and CYP2A6, including diethyldithiocarbamate or tranylcypromine.[21] These results suggested that SULT-mediated sulfation of indoxyl could be the inhibitor-sensitive target step in hepatic IS production. Flavonoid compounds have been reported to inhibit SULT activity.[24] Apigenin and myricetin were reported to have potent inhibitory effects on CYP3A4 and CYP2C9.[27,28] In addition, myricetin and apigenin were found to be potent inhibitors of phenolsulfotransferase-mediated sulfoconjugation of acetaminophen and minoxidil with IC_{50} values < 1 μM or resveratrol with IC_{50} values < 3 μM.[27,28] The inhibitory potency of esculetin against CYP or SULT enzymes has not been reported. Based on these findings, the observed inhibition of hepatic IS production by esculetin, myricetin and apigenin could predominantly depend on inhibition of SULT activity rather than CYP2E1 or CYP2A6.

Meclofenamate, a non-polyphenolic and non-steroidal anti-inflammatory drug, also exhibited a strong inhibition of hepatic IS production with an apparent IC_{50} of 1.3 μM. Previous reports suggest that non-steroidal anti-inflammatory agents including meclofenamate, nimesulide, priroxicam and aspirin competitively inhibit human phenol SULT with IC_{50} values ranging from 0.1 μM to 3,800 μM.[29] In addition, among non-steroidal anti-inflammatory drugs, fenamic compounds including mefenamic acid, flufenamic acid, niflumic acid and meclofenamic acid were reported to impair human liver SULT activity without phenolic hydroxy group in their molecules.[30] However, the effect of meclofenamate on SULT-mediated IS production was not examined. We previously reported that oral administration of phytochemical polyphenols showed a

nephropreventive effect on cisplatin-induced AKI in rats.[21] These effects were associated with a significant suppression of serum and renal accumulation of IS. Thus, the potent inhibitory effect of meclofenamate on IS production encouraged us to examine its *in vivo* effects on IS accumulation and ischemic AKI in rats. An increase in IS concentration in the kidney and liver of I/R-treated rats was largely blocked by the intravenous administration of meclofenamate (see Figures 4 and 5). Furthermore, treatment with meclofenamate significantly restored the increased levels of SCr and BUN in I/R-treated rats (Figure 5). The administration of meclofenamate was associated with the restoration of renal basolateral membrane organic anion transporters mediating cellular accumulation of IS, rOAT1 and rOAT3, which were markedly downregulated by renal I/R treatment (Figure 6). Sauvant *et al.* demonstrated that PGE2 leads to downregulation of both rOAT1 and rOAT3 in the rat proximal tubular cell line NRK-52E after long-term exposure.[31] Furthermore, PGE2 levels have been reported to increase in the kidney cortex after acute renal ischemia[32,33] or during chronic renal ischemia.[34] Notably, Shneider *et al.* reported that administration of a low-dose of indomethacin, a non-steroidal anti-inflammatory agent, after renal I/R treatment prevented I/R-induced downregulation of rOAT1 and rOAT3 during reperfusion and elicited a nephropreventive effect on kidney function.[23] They concluded that a low-dose of indomethacin (1 mg/kg) applied directly after ischemia has a beneficial effect on renal outcome after ischemia, and that PGE2 plays an important role in the development or maintenance of renal damage. Pharmacological intervention of COX activity may be a therapeutically relevant option after acute ischemic injury of the kidney.[23] Based on these findings and the present results, the restorative effect of meclofenamate on rOAT1/3 may be caused by suppressing COX2-mediated PGE2 production in the kidney. The substantial restoration or maintenance of these transporters should enhance renal excretion of IS, thereby reducing IS-induced cytotoxicity in the kidney. Thus, meclofenamate could have two pathways for its nephropreventive effect in ischemic AKI: (i) the potent inhibition of hepatic IS production followed by suppression of IS accumulation in serum and kidney, and (ii) the prevention of renal COX2-mediated PGE2 production, that could be induced by renal I/R treatment and/or IS accumulation in the kidney, followed by secondary restoration of OATs expression.

Conclusion

Meclofenamate inhibits hepatic production of IS, which results in decreased serum and renal accumulation of IS, and protects I/R-induced downregulation of rOAT1 and rOAT3 expression *via* COX2-mediated PGE2 production, thereby eliciting a nephropreventive effect in ischemic AKI. These findings will help in the development of novel therapeutic drugs that prevent acute kidney injury.

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Author contributions

H.S. contributed to the conception and design of the work. C.S., Y.N., Y.Y., M.S. and R.M. contributed to the animal experiments as well as the acquisition and analysis of data. K.N. and H.J contributed to the interpretation of data and statistical analysis.

Disclosure

The authors report no conflicts of interest in this work.

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Abbreviations: AKI, acute kidney injury; BUN, blood urea nitrogen; CKD, chronic kidney disease; CYP, cytochrome P450; I/R, ischemia/reperfusion; IS, indoxyl sulfate; OAT, organic anion transporter; SCr, serum creatinine; SDS, sodium dodecyl sulfate; SDS-PAGE, SDS-polyacrylamide gel electrophoresis; SULT, sulfotransferase.

Figure 1 Chemical structures of compounds examined for their inhibitory effect on hepatic IS production.

Figure 2 *In vitro* inhibitory effect of several compounds on IS production using the rat liver S9 fraction. The reaction mixture (total volume 250 μl), containing 50 mM sodium phosphate buffer (pH 7.4), rat liver S9 fraction (5-10 mg protein/ml), indole (100 μM), NADPH (1 mM), adenosine 3'-phosphate 5'-phosphosulfate (20 μM) and uridine diphosphate glucuronic acid (1 mM), was incubated with or without test compound (10 μM) at 37°C for 30 min. Each column represents the mean ± S.D. for three independent measurements.

Figure 3 Dose-dependent inhibition of IS production by several compounds using rat liver S9 fraction. The reaction mixture containing 50 mM sodium phosphate buffer (pH 7.4), rat liver S9 fraction, indole (100 μM), NADPH (1 mM), adenosine 3'-phosphate 5'-phosphosulfate (20 μM) and uridine diphosphate glucuronic acid (1 mM) was incubated at 37°C for 30 min with or without test compounds at various concentrations. Each point represents the mean of three independent measurements. The apparent IC_{50} values are indicated for each graph for compound tested.

Figure 4 Effect of meclofenamate on IS concentration in rats treated with renal I/R. **A**, serum IS concentration in control rats (open circle) and renal I/R-treated rats with (closed rhombus) or without (closed circle) intravenous administration of meclofenamate (10 mg/kg) 6, 12 and 18 hr after renal I/R treatment. Each point represents the mean ± S.D. for three to four rats in each group. Renal (**B**) and hepatic (**C**) IS concentration in control rats (sham) and renal I/R-treated rats with (IR+Mecl) or without (IR) intravenous administration of meclofenamate. $^{**}P<0.01$ versus sham (control); $^{\#\#}P<0.01$ versus I/R.

Figure 5 Effect of meclofenamate on renal function of rats treated with renal I/R. Serum BUN (**A**) and creatinine (**B**) levels in control rats (sham), renal I/R-treated rats with (IR+Mecl) or without (IR) intravenous administration of meclofenamate. $^{**}P<0.01$ versus sham (control); $^{\#\#}P<0.01$

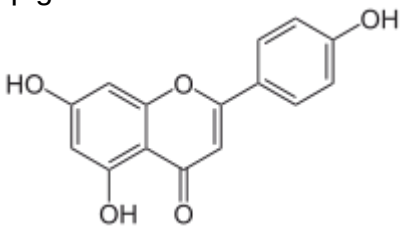
versus I/R.

Figure 6 Expression of rOAT1 and rOAT3 in the kidney of rats treated with I/R. Meclofenamate (10 mg/kg) was intravenously administered to rats 6, 12 and 18 hr after renal I/R. Renal tissue samples were collected 48 hr after I/R treatment, and used for immunoblotting of rOAT1 and rOAT3. Panels A and B show the representative blots for rOAT1 and rOAT3, respectively. The band density of rOAT1 and rOAT3 were determined densitometrically and the relative density ratio to control (sham) is represented as columns with the mean ± S.D. for three to four rats in each group. $^{*}P<0.05$ versus control (sham); $^{\#}P<0.05$ versus I/R.

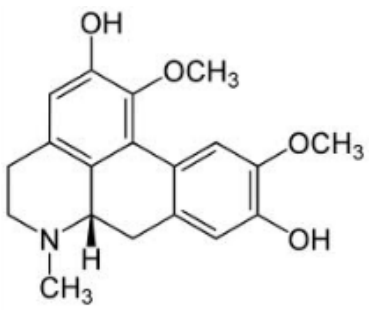
Figure 7 Effect of meclofenamate on PGE2 level in the kidney of control rats (sham) and renal I/R-treated rats with (IR+Mecl) or without (IR) intravenous administration of meclofenamate (10 mg/kg). Each column represents the mean ± S.D. for three to four rats in each group. $^{*}P<0.05$ versus control (sham).

Figure 1

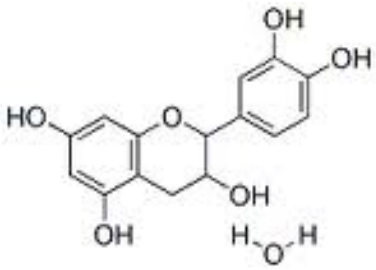
Apigenin



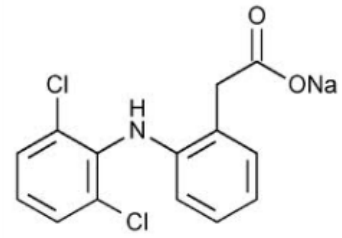
Boldine



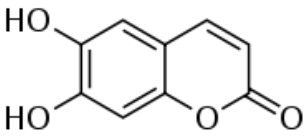
Catechin-(+,-) hydrate



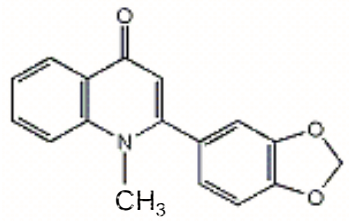
Diclofenac sodium



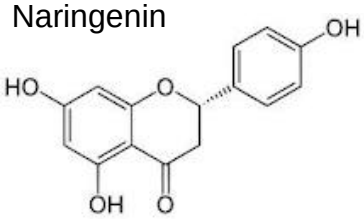
Esculetin



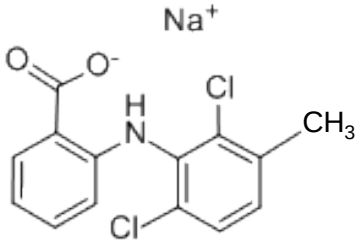
Graveoline



Naringenin



Meclofenamic acid



Myricetin

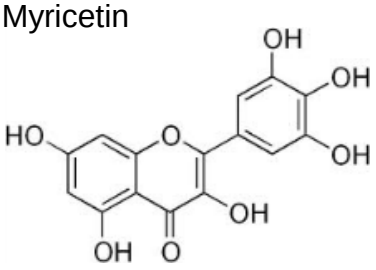


Figure 2

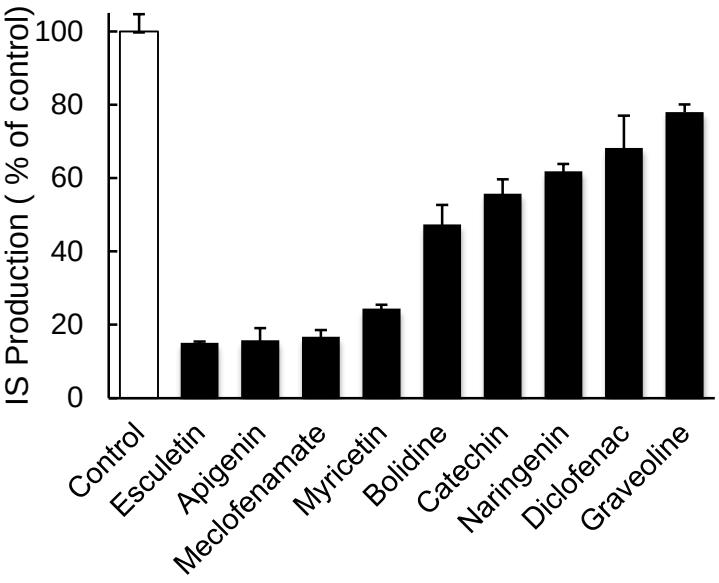

IS Production (% of control)
100
80
60
40
20
0
Control
Esculetin
Apigenin
Meclofenamate
Myricetin
Bolidine
Catechin
Naringenin
Diclofenac
Graveoline

Figure 3

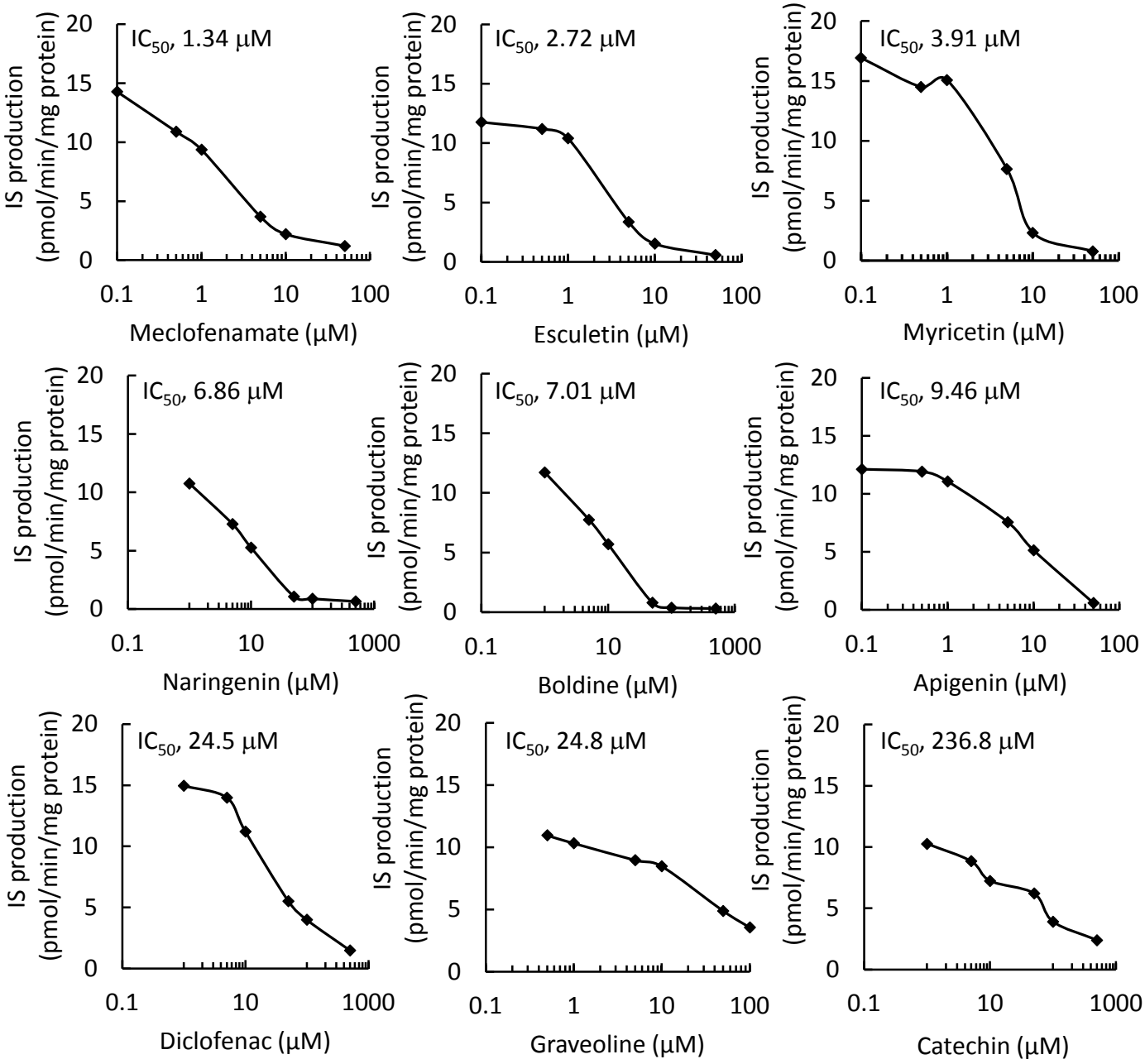

IC50, 1.34 μM
IS production (pmol/min/mg protein)
Meclofenamate (μM)
IC50, 2.72 μM
Esculetin (μM)
IC50, 3.91 μM
Myricetin (μM)
IC50, 6.86 μM
Naringenin (μM)
IC50, 7.01 μM
Boldine (μM)
IC50, 9.46 μM
Apigenin (μM)
IC50, 24.5 μM
Diclofenac (μM)
IC50, 24.8 μM
Graveoline (μM)
IC50, 236.8 μM
Catechin (μM)

Figure 4

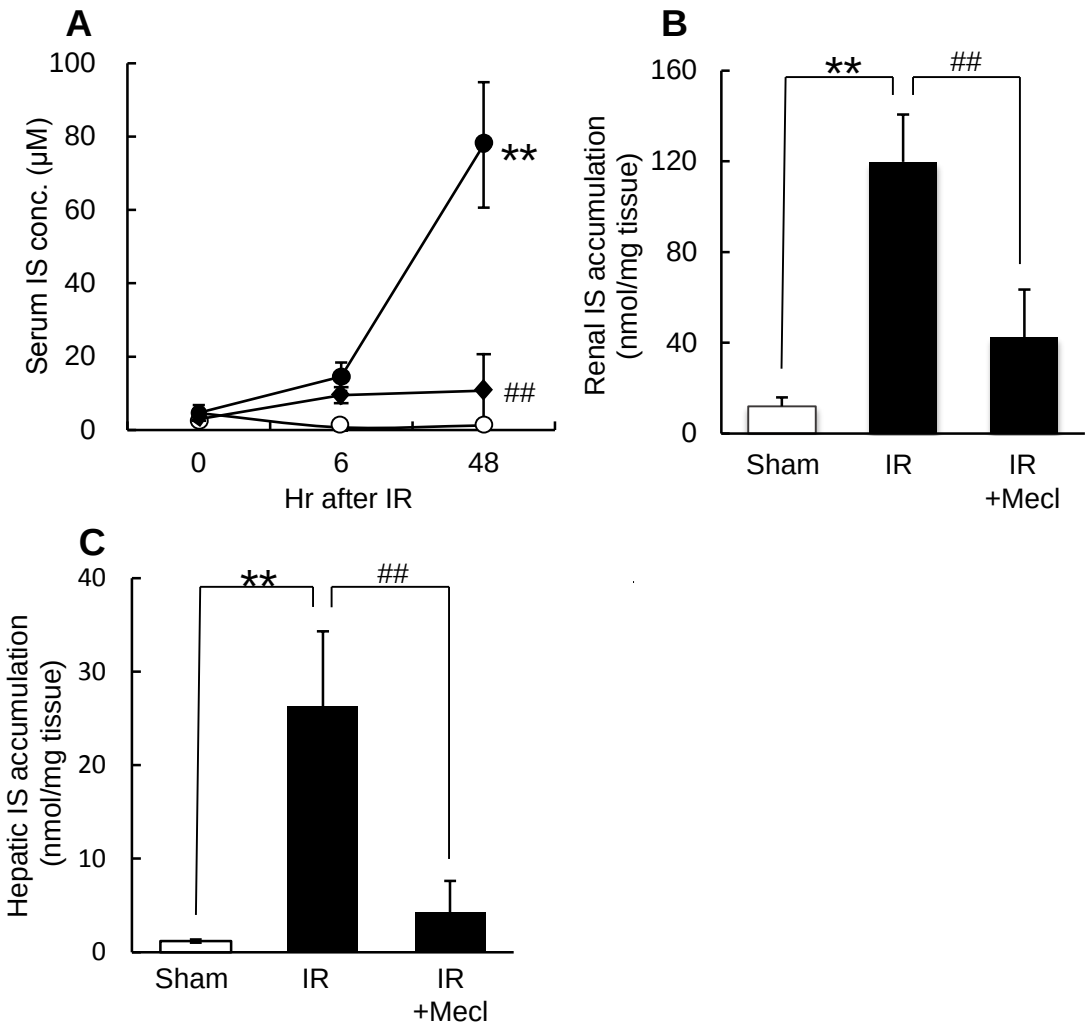

A
Serum IS conc. (μM)
100
80
60
40
20
0
0
6
48
Hr after IR
**
##
B
Renal IS accumulation (nmol/mg tissue)
160
120
80
40
0
**
##
Sham
IR
IR +Mecl
C
Hepatic IS accumulation (nmol/mg tissue)
40
30
20
10
0
**
##
Sham
IR
IR +Mecl

Figure 5

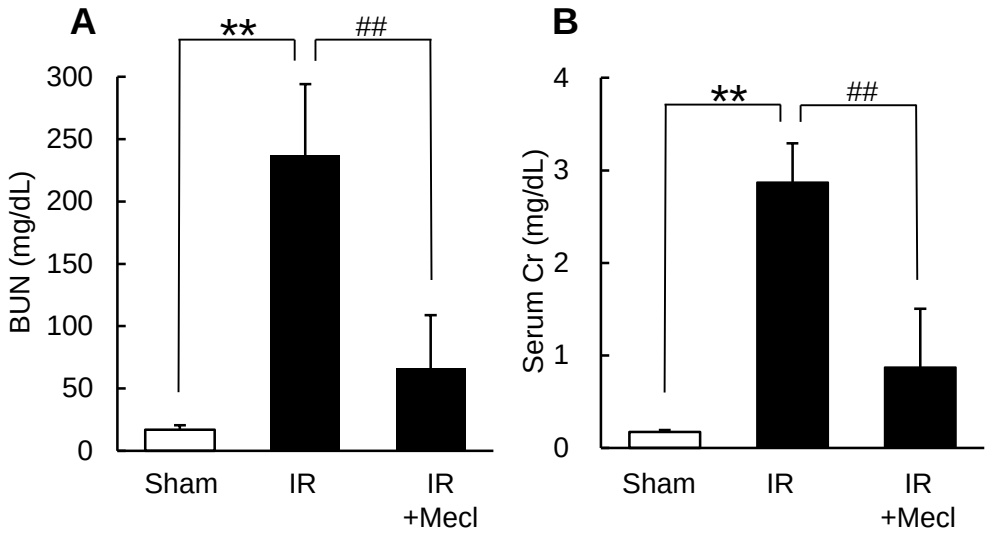

A
**
##
300
250
200
150
100
50
0
BUN (mg/dL)
Sham
IR
IR
+Mecl
B
**
##
4
3
2
1
0
Serum Cr (mg/dL)
Sham
IR
IR
+Mecl

Figure 6

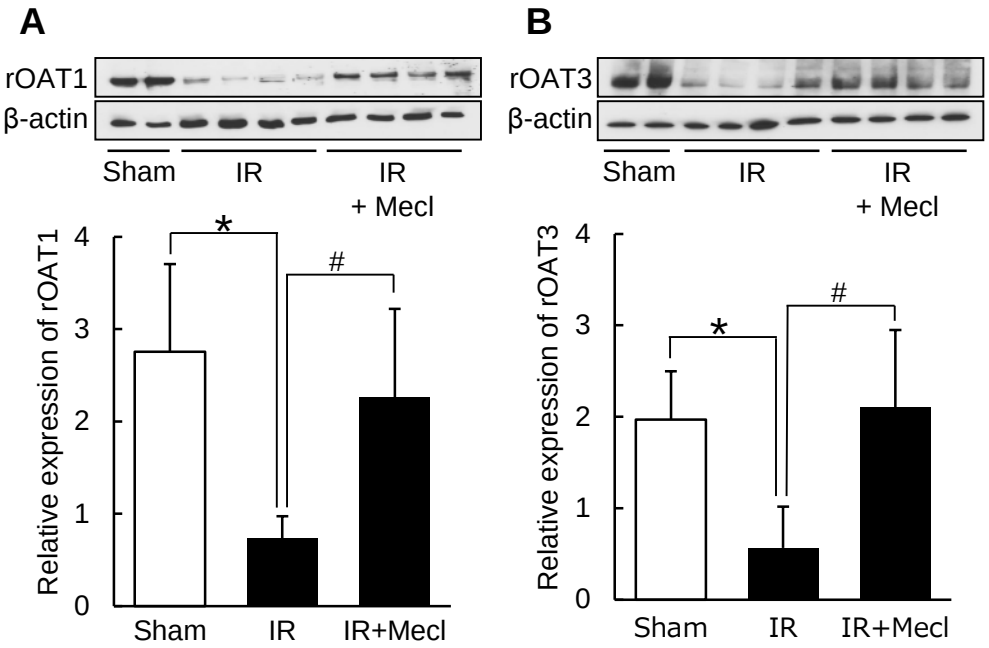

A
rOAT1
β-actin
Sham
IR
IR
+ Mecl
Relative expression of rOAT1
4
3
2
1
0
*
#
Sham
IR
IR+Mecl
B
rOAT3
β-actin
Sham
IR
IR
+ Mecl
Relative expression of rOAT3
4
3
2
1
0
*
#
Sham
IR
IR+Mecl

Figure 7