FS, the leaves of *Cassia angustifolia* Vahl (Fabaceae), synonymous with *Senna alexandrina* Mill., has been commonly used as a laxative worldwide for the treatment of diet-, stress-, or medication-related constipation [1,2]. Nowadays, it is a component in diets for weight control [3]. FS contains polyphenolic anthranoids including sennosides and a variety of anthraquinones, such as aloe-emodin, rhein, and chrysophanol, which exist in both glycoside and aglycone forms [4,5] (Fig. 1). Sennosides have been found to be hydrolyzed by intestinal enzymes first to sennidin monoglucosides and sennidins, which are further transformed to rhein, rhein anthrone, and aloe-emodin [6–8]. Till now, although the information regarding the pharmacokinetics of senna anthranoids in FS has been reported, only plasma levels of the total amount of S+G from rhein or aloe-emodin were determined [9], while detailed investigation on the serum concentrations of anthraquinone sulfates or glucuronides has yet to be conducted.

### Introduction

FS, the leaves of *Cassia angustifolia* Vahl (Fabaceae), synonymous with *Senna alexandrina* Mill., has been commonly used as a laxative worldwide for the treatment of diet-, stress-, or medication-related constipation [1,2]. Nowadays, it is a component in diets for weight control [3]. FS contains polyphenolic anthranoids including sennosides and a variety of anthraquinones, such as aloe-emodin, rhein, and chrysophanol, which exist in both glycoside and aglycone forms [4,5] (Fig. 1). Sennosides have been found to be hydrolyzed by intestinal enzymes first to sennidin monoglucosides and sennidins, which are further transformed to rhein, rhein anthrone, and aloe-emodin [6–8]. Till now, although the information regarding the pharmacokinetics of senna anthranoids in FS has been reported, only plasma levels of the total amount of S+G from rhein or aloe-emodin were determined [9], while detailed investigation on the serum concentrations of anthraquinone sulfates or glucuronides has yet to be conducted.
A previous study reported that FS infusion decreased the apparent \( P_{\text{app}} \) of propranolol, verapamil, and rho 123 in Caco-2 cells, which are all substrates of P-gp (ABCB1) \[10\], a drug efflux pump. P-gp expels a variety of hydrophobic and cationic drugs, including critical medicines such as digoxin, cyclosporine, tacrolimus, everolimus, etc \[11\]. In this study, we measured the serum concentrations of anthraquiones and relevant metabolites after administration of single dose and multiple doses of FS decoction to rats. In addition, the modulation effect of FS on P-gp was further investigated by using a newly developed model of LS 180 cells, a human colon adenocarcinoma cell line.

**Results**

FS decoction and its acid hydrolysate were analyzed by HPLC method with a gradient elution, and the chromatogram is shown in **Fig. 2**. Before hydrolysis, the concentrations of sennoside A, aloe-emodin, and rhein were 295.8, 242.8, and 1622.1 \( \mu \text{M} \), respectively, whereas chrysophanol, a relatively nonpolar anthraquione, was not detected in FS decoction. In order to estimate the contents of anthraquinone glycosides, FS decoction was hydrolyzed with hydrochloric acid. After hydrolysis, the concentrations of aloe-emodin and rhein were increased by 62% and 28%, respectively, but chrysophanol was still not detected, indicating that the glycosides of aloe-emodin and rhein were present, but in lower concentrations than their aglycone form, whereas chrysophanol glycosides were not present in the FS decoction. **Fig. 3** shows the HPLC chromatograms of a serum specimen before and after hydrolysis with sulfatase after intake of FS. The analysis of a serum sample took 20 min. Good linear relationships were obtained in the concentration ranges of 0.03–1.0 \( \mu \text{g/mL} \) (\( Y = 4.231 \times -0.030, r = 0.9993 \)) for aloe-emodin, and 0.6–20.0 \( \mu \text{g/mL} \) (\( Y = 1.648 \times -0.176, r = 0.9995 \)) for rhein in serum. Validation of the analytical method confirmed that all CVs and the relative errors of intra-day and inter-day analysis were below 14.7% and 11.6%, respectively. The recoveries were 80.3–104.6% and 82.5–85.9% for aloe-emodin and rhein, respectively. The LLOQs were 0.03 and 0.60 \( \mu \text{g/mL} \), and LODs were 0.02 and 0.08 \( \mu \text{g/mL} \) for aloe-emodin and rhein, respectively.

Following oral administrations of single dose and the 7th dose of FS, the serum profiles of \( S+G \) and glucuronides of aloe-emodin and rhein as well as rhein free form are shown in **Fig. 4**. It revealed that the conjugated metabolites of aloe-emodin and rhein emerged rapidly after FS dosing. The pharmacokinetic parameters of aloe-emodin and rhein and their metabolites are listed in **Table 1**, from which it can be seen that AUC\(_{0-\infty} \) of \( S+G \) and G of either aloe-emodin or rhein were comparable. Moreover, the pa-
Parameters including $C_{\text{max}}$, $AUC_{0-720}$, and MRT were not significantly different between single-dose and multiple-dose treatments. Given that the highest serum level of rhein free form was detected at the first sampling time (10 min) in all rats, and the later serum levels of rhein in most rats were below LLOQ, the $AUC_{0-t}$ and MRT of rhein F could not thus be calculated either after single-dose or multiple-dose treatments.

The modulation of FS on P-gp was investigated by using LS 180 cell model. MTT assay indicated that FS and verapamil (a positive control) exerted no significant influence on cell viability at the tested concentrations. In transport study, the intracellular accumulations of rho 123, a typical P-gp substrate, measured after 4-h incubation with various tested agents are shown in Fig. 5. FS at 0.125–5.0 mg/mL significantly enhanced the intracellular accumulation of rho 123 by 16–46% while verapamil at 100 µM, as a positive control, significantly enhanced the intracellular accumulation of rho 123 by 49%.

Discussion

Quantitation of the FS decoction prepared by using boiling water as extraction solvent indicated that rhein was the major anthraquinoid (corresponding to 0.046% of the dried FS), whereas sennoside A and aloe-emodin were comparably minor. In contrast to previous studies reporting that sennosides A and B were the major anthranoids (corresponding to 1–3% of the dried FS) in the methanol-water extract of FS [4,12,13], this discrepancy could be accounted for by the use of different extraction solvents employed in the studies. Based on the solubility character of sennosides, using hot water to prepare FS decoction should solubilize a lower amount of sennoside A from FS.

For the quantitation of anthranoids in serum specimens, an HPLC system with fluorescence detection was developed and optimized in this study. Validation of the analytical method of rhein and aloe-emodin in serum confirmed that the precision, accuracy, and recovery were satisfactory. In order to quantify both the free form and conjugated metabolites of anthraquinones, serum samples were assayed before and after hydrolysis with $\beta$-glucuronidase and sulfatase, individually. Prior to hydrolysis, the free form of rhein was detected in a few specimens. After hydrolysis with sulfatase or glucuronidase, the peaks of aloe-emodin S + G and rhein S + G in the bloodstream. In turn, through hydrolysis with $\beta$-glucuronidase or sulfatase, the concentration of G or

<table>
<thead>
<tr>
<th>Parameters</th>
<th>$C_{\text{max}}$ ($\text{nmol/mL}$)</th>
<th>$AUC_{0-720}$ (nmol · min/mL)</th>
<th>MRT$_{0-720}$ (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single dose</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aloe-emodin S+G</td>
<td>1.2 ± 0.1</td>
<td>252.9 ± 7.4</td>
<td>262.5 ± 22.4</td>
</tr>
<tr>
<td>Aloe-emodin G</td>
<td>1.2 ± 0.1</td>
<td>242.0 ± 7.2</td>
<td>265.4 ± 22.8</td>
</tr>
<tr>
<td>Rhein F</td>
<td>8.4 ± 1.3</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Rhein S+G</td>
<td>15.9 ± 1.0</td>
<td>3056.7 ± 217.1</td>
<td>205.2 ± 36.6</td>
</tr>
<tr>
<td>Rhein G</td>
<td>13.3 ± 1.4</td>
<td>2844.2 ± 290.0</td>
<td>207.7 ± 38.1</td>
</tr>
<tr>
<td>7th dose</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aloe-emodin S+G</td>
<td>1.1 ± 0.2</td>
<td>264.2 ± 57.3</td>
<td>192.6 ± 36.9</td>
</tr>
<tr>
<td>Aloe-emodin G</td>
<td>1.0 ± 0.2</td>
<td>209.9 ± 42.6</td>
<td>179.8 ± 41.8</td>
</tr>
<tr>
<td>Rhein F</td>
<td>10.2 ± 3.5</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Rhein S+G</td>
<td>13.4 ± 2.6</td>
<td>3047.2 ± 806.0</td>
<td>157.6 ± 39.6</td>
</tr>
<tr>
<td>Rhein G</td>
<td>11.0 ± 2.5</td>
<td>2541.3 ± 626.7</td>
<td>163.1 ± 40.9</td>
</tr>
</tbody>
</table>

Data expressed as mean ± SE; $C_{\text{max}}$ (nmol/ml): maximum serum concentration; $AUC_{0-720}$ (nmol · min/ml): area under concentration-time curve to the last time; MRT$_{0-720}$ (min): mean residence time.

Fig. 5 HPLC chromatograms of a serum sample before (a) and after hydrolysis with sulfatase (b). 1: aloe-emodin, 2: rhein, 3: 1,8-dihydroanthraquinone (IS).
S + G was calculated. Owing to considerable amount of glucuroni-
dase present in the sulfatase used in this study (Type H-1), treat-
ment of sulfatase hydrolyzed both S+G. Accordingly, the differ-
ence between the concentrations of S+G and G could estimate
the concentration of sulfates.

The serum profiles of aloe-emodin S+G and rhein S+G revealed
that these conjugated metabolites appeared rapidly in the circu-
lation, suggesting that aloe-emodin and rhein were quickly ab-
sorbed and intensively metabolized by conjugation reaction. The
profiles of S+G and G of aloe-emodin or rhein were essentially
superposable following either single-dose or multiple-dose
 treatments, implying that the major metabolites of aloe-emodin
and rhein were glucuronides, whereas their sulfates were very
minor. The total systemic exposure of rhein G was greater than
that of aloe-emodin G by 12 folds after either single or repeated
dosing of FS, suggesting that rhein glucuronides were the major
metabolites. The AUC0-t of S+G and G of aloe-emodin or rhein
after single dose and multiple doses were comparable, implying
that these conjugated metabolites were not accumulating in the
blood under such dosage regimen.

The free form of rhein was detected at the first sampling time
after both single-dose and multiple-dose administrations, indi-
cating that rhein was transiently existing as free form in the cir-
culation during the very early phase and turned over rapidly to
its conjugate forms, which was in good agreement with an in vi-
tro study reporting relatively low glucuronidation activity of
UDP-glucuronyltransferase toward carboxylic acids [14]. Regard-
ing aloe-emodin, the free form was not detected in all serum
samples. These results were consistent with a previous study re-
porting the biological fates of aloe-emodin and rhein after rhu-
barb administration to rats [15].

P-gp has been thought to play an important role in the barrier
function of intestine for drug absorption [16]. In order to evaluate
the effect of FS on P-gp activity, transport assay of rho 123, a typ-
ical P-gp substrate, was conducted by using LS 180 cells. As
shown in Fig. 5, similarly to verapamil (a positive control of
P-gp inhibitor), FS markedly increased the intracellular accumu-

![Fig. 4](image_url) Mean (± SE) serum concentration-time profiles of free form, sulfates
and glucuronides (S+G), and glucuronides (G) of aloe-emodin and rhein after
oral administration of (a) single dose and (b) the 7th dose of FS decoction
(10 g/kg) to six rats.
lation of rho 123, indicating that the efflux function of P-gp was suppressed by FS. This finding of FS as an inhibitor of P-gp was in good agreement with a previous study using Caco-2 cells [10]. This LS 180 model was newly developed and superior to Caco-2 model because of much shorter time needed to reach confluency before a transport study.

It has been reported that senna led to toxicity in digoxin users [17]. Moreover, a recent population-based, nested, case-control study has furnished further evidence that the combined use of digoxin and sennosides for less than 14 days increased the risk of digoxin toxicity in heart failure patients [18]. However, no pharmacokinetic relevant mechanism has been proposed by these investigators. Based on our result showing that the transport of rho 123 was inhibited by FS decoction, the higher toxicity of digoxin in humans can be in part explained by the inhibited efflux of digoxin, a substrate of P-gp, into gut lumen, which then led to enhanced blood level and toxicity. Therefore, the concurrent use of FS with critical medicines which are substrates of P-gp require caution in clinical practice to ensure drug safety.

In conclusion, senna anthranoids were rapidly and extensively metabolized to mainly rhein glucuronides and aloe-emodin glucuronides in rats. FS ingestion inhibited the efflux function of P-gp in the intestine.

Materials and Methods

Chemicals and reagents
Sennoside A (purity 96%), aloe-emodin (purity 95%), DMSO, rho 123, SDS, Triton X-100, verapamil (purity 99%), β-glucuronidase (type B-1, from bovine liver), and sulfatase (type H-1 from Helix pomatia) containing 14000 units/g of sulfatase and 498 800 units/g of β-glucuronidase were purchased from Sigma Chemical Co. Rhein (purity 95%) was purchased from Aldrich Chemical Co. 1,8-Dihydroxyanthraquinone (purity 98%) and amyl paraben (purity 98%) were obtained from Tokyo Chemical Industry Co. Methanol, acetonitrile, acetic acid (glacial, 99%), and ethyl acetate were LC grade and purchased from J.T. Baker, Inc. L(+)-Ascorbic acid (purity 99.7%) was obtained from Rhd Laborchemikalien GmbH & Co. KG. Other reagents were HPLC grade or analytical grade. MTT (purity 98%) was obtained from Alpha Aesar. FBS was offered 3 h after drug administration. All animal experiments adhered to “The Guidebook for the Care and Use of Laboratory Animals” published by the Chinese Society of Animal Science, Taiwan, R.O.C. The experimental protocol had been reviewed and approved on 08/01/2013 (No. 102–144-N) by the Institutional Animal Care and Use Committee of China Medical University, Taiwan.

Preparation of Folium Sennae decoction
The crude drug of FS was purchased from an herbal drugstore in Taichung, Taiwan. The plant material was identified by Dr. Yu-Chi Hou. A voucher specimen (CMU-P-1905–11) was deposited in the Graduate Institute of Chinese Pharmaceutical Sciences, China Medical University. Water (12 L) was added to 600 g of FS and heated on a gas stove. After boiling, gentle heating was continued until the volume was reduced to less than 600 mL. The mixture was filtered while hot. The filtrate was gently boiled until the volume was reduced to below 600 mL, and sufficient water was added to make 600 mL which was immediately divided into aliquots and frozen at −20°C for later use. Each mL of decoction represents 1.0 g of FS.

Quantitation of anthraquinones in Folium Sennae decoction before and after hydrolysis
The HPLC apparatus included a pump (LC-10AT, Shimadzu), an UV spectrophotometric detector (SPD-10AvP, Shimadzu), a Chromatopac (C–R6A, Shimadzu) with an automatic injector (SIL-10A, Shimadzu), and an Alltech Apollo C18 column (5 µm, 4.6 mm × 150 mm, Alltech).

FS decoction (300 µL) was mixed with 700 µL of methanol and centrifuged to remove the precipitate. The properly diluted decoction (180 µL) was added with 20 µL of amyl paraben solution (50.0 µg/mL in methanol) as IS, and 20 µL was subject to HPLC analysis. The mobile phase consisted of methanol (A) – 0.1% acetic acid (B) and programmed in a gradient manner as follows: A/B: 45/55 (0–5 min), 52/48 (8 min), 65/35 (12 min), 80/20 (22–30 min), and 45/55 (32–35 min). The detection wavelength was set at 270 nm, and the flow rate was 1.0 mL/min.

Acid hydrolysis of 1.0 mL of FS decoction was conducted by adding 25 mg ascorbic acid and 1.0 mL of 1.2 N HCl and incubating in a water bath at 80°C for 30 min. The hydrolysate was then added with sufficient water to make 2.0 mL before HPLC analysis. The glycoside concentration of each anthraquinone was calculated by subtracting the aglycone concentrations in the original decoction from those in the hydrolysate.

Animals
Male Sprague-Dawley rats were purchased from BioLASCO Taiwan Co., Ltd. and housed in conditioned environment with 12-h light/dark cycles. Rats were fasted overnight before drug administration, whereas water was supplied ad libitum. Food was offered 3 h after drug administration. All animal experiments adhered to “The Guidebook for the Care and Use of Laboratory Animals” published by the Chinese Society of Animal Science, Taiwan, R.O.C. The experimental protocol had been reviewed and approved on 08/01/2013 (No. 102–144-N) by the Institutional Animal Care and Use Committee of China Medical University, Taiwan.
Drug administration and blood collection

Six rats were orally given a single dose of 10.0 mL/kg of FS decoction (equivalent to 10.0 g/kg of crude drug) via gastric gavage. To another group of six rats, FS decoction was given twice daily for consecutive three days. The 7th dose of FS was given after overnight fasting, and then bioavailability and metabolic study of sen-na anthraquinones was conducted. The blood samples (0.5 mL each) were withdrawn at 10, 60, 120, 360, 720 min after dosing. The blood was collected in microtubes and centrifuged at 10,000 g for 10 min to obtain serum, which was stored at −20 °C before analysis.

Quantitation of anthraquinones and their conjugated metabolites in serum

For the assay of the parent forms of anthraquinones, 100 µL of serum was mixed with 50 µL of pH 5 acetate buffer and 50 µL of ascorbic acid (100 mg/mL), then 50 µL of 0.1 N HCl was added and partitioned with 250 µL of ethyl acetate (containing 0.2 µg/mL of 1,8-dihydroxyanthraquinone as IS). The ethyl acetate layer was evaporated under N2 gas to dryness and reconstituted with 50 µL of the mobile phase, and then 20 µL aliquot was subject to HPLC analysis.

For the quantitation of the glucuronides of rhein and aloe-emodin, 100 µL of serum was mixed with 50 µL of pH 5 acetate buffer and 50 µL of ascorbic acid (100 mg/mL). The mixture was incubated at 37 °C for 1 h under anaerobic condition and protected from light. After enzymatic hydrolysis, serum samples were subjected to the same process described above for the assay of parent forms of anthraquinones. For calibration preparation, 100 µL of serum spiked with various concentrations of rhein and aloe-emodin were added with 50 µL of pH 5 buffer and 50 µL of ascorbic acid. The later procedure followed that described above for serum samples. The calibration curve was drawn by linear regression of the peak area ratios (compounds as IS) against the known concentrations of each anthraquinone.

The HPLC apparatus included a pump (LC-10AT, Shimadzu), a fluorescence detector (RF-10AXL, Shimadzu), and an automatic injector (Series 200 Autosampler, Perkin Elmer). The Apollo C18 (4.6 × 250 mm, 5 µm) column was equipped with a guard column (4.6 × 50 mm, 5 µm) (GL Science Inc.). The isocratic mobile phase consisted of methanol and 0.1% phosphoric acid at a ratio of 80:20 (v/v). Wavelengths of excitation and emission were set at 485 nm and 528 nm. To quantify the content of protein in each well, 10 µL of cell lysate was mixed with 200 µL of diluted protein assay reagent (Bio-Rad), and the optical density was measured at 570 nm by a microplate reader (BioTex).

Effect of Folium Sennae on P-glycoprotein activity

Evaluation of the effect of FS on the transport of rho 123 followed a previous method with minor modification [20]. Verapamil was used as a positive control of P-gp inhibitor. LS-180 cells (1 × 10⁵) were cultured using a 96-well plate. After overnight incubation, medium was replaced by rho 123 in HBSS (1 µM) and incubated for 1 h. Following removal of the supernatant, cells were washed twice with ice-cold PBS, then a series of concentrations of FS and verapamil (as a positive control) were added into correspondent wells and incubated for 4 h at 37 °C.

Cell viability assay

The medium was removed, the cells were washed twice with ice-cold PBS. Then 0.1% Triton X-100 (100 µL) was added, and the fluorescence was measured with excitation at 485 nm and emission at 528 nm. To quantify the content of protein in each well, 10 µL of cell lysate was added to 200 µL of diluted protein assay reagent (Bio-Rad), and the optical density was measured at 570 nm. The relative intensity of intracellular accumulation of rho 123 was calculated by comparing with that of control after protein correction.

Data analysis

Cmax, AUC, and MRT of senna anthraquinones and their metabolites were calculated by noncompartment model of Phoenix WinNonlin® (version 6.3; Pharsight Corporation). Cmax values were obtained from experimental measurement. AUCD, was calculated using trapezoidal rule to the last point. The differences among treatments were analyzed by using one-way ANOVA and unpaired Student’s t-test for in vivo and in vitro studies, respectively, taking p < 0.05 as significance level.

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Conflict of Interest

The authors report no conflict of interest.

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