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DIETHYLENE GLYCOL POISONING AND LIVER FUNCTION FOLLOWING ACCIDENTAL DIETHYLENE GLYCOL INJECTION

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ABSTRACT

The aim of the present study was to investigate the hepatotoxic effects of accidental intravenous diethylene glycol (DEG) poisoning in patients with liver disease.

Clinical manifestations were recorded and liver function tests were carried out for 64 patients with liver disease who had been accidentally treated intravenously with DEG. Comparisons were made between the poisoned and non-poisoned groups.

Of the 64 cases with preexisting liver disease, 15 cases (23.4 %) developed toxic presentations after exposure to DEG. All cases were men. Twelve of the 15 poisoned patients (80 %) died within seven days. The intravenous administration of DEG resulted in only mild liver function impairment. Gender ($p = 0.039$) and the severity of jaundice prior to DEG administration were risk factors related to the occurrence of toxin-induced renal failure ($p < 0.006$). The results suggest that DEG may worsen liver damage in patients with preexisting liver disease. However, our study demonstrated only mild, transient alterations in patients' baseline liver functions. Severe liver damage secondary to DEG was only occasionally seen in patients with concomitant renal failure.

Keywords: diethylene glycol, hepatotoxicity, drug-induced liver disease, underlying liver diseases

Abbreviations: Diethylene glycol – DEG, Alanine transaminase – ALT, Aspartate transaminase – AST, Gamma glutamyl transpeptidase – GGT, Alkaline phosphatase – ALP, Total bilirubin – TB, Prothrombin time – PT, Prothrombin time activity – PTA, Serum cholinesterase – CHE, Serum albumin – ALB, Blood urea nitrogen – BUN, Blood creatinine – Cr, White blood cell – WBC, Standard deviation – SD

INTRODUCTION

The liver is the most important detoxifying organ in the body and plays a critical role in the metabolism of drugs and toxins. The majority of drugs and toxins can be cleared from the body following hepatic biotransformation. However, some drugs and toxins or their active metabolites can

cause liver damage resulting in drug- or toxin-induced hepatitis, or even liver failure. In patients with no preexisting liver disease, exposure to toxic substances or hepatotoxic drugs leads to the appearance of symptoms most commonly within eight weeks, and drug or toxin-induced hepatitis is not usually difficult to diagnose (Zimmerman, 2000; Sgro et al., 2002). In pa-

tients with underlying liver diseases, however, the diagnosis of drug- or toxin-induced hepatitis remains challenging as it is difficult to distinguish between the natural course of the existing liver disease and additional damage resulting from exposure to drugs or toxins. Close monitoring of liver function after toxin exposure is required in these cases.

Diethylene glycol (DEG) is an industrial product commonly used in daily life. It is used as a coolant, both lowering the freezing point of a solution and elevating its boiling point making the solution more stable in hot climates. DEG is also used as a building block in organic synthesis, e.g., in the synthesis of morpholine and 1,4-dioxane. It is a solvent for nitrocellulose, resins, dyes, oils and other organic compounds. It is a humectant (a hygroscopic substance) for tobacco, cork, printing ink and glue. It can also be found in some hydraulic fluids and brake fluids.

DEG is toxic to humans and animals, and can lead to death by renal failure. The toxicity of DEG means that its use is strictly regulated in the manufacture of food and drugs. The U.S. Code of Federal Regulations allows no more than 0.2 % of DEG in polyethylene glycol when the latter is used as a food additive. However, DEG is still illegally used as counterfeit glycerin in some nations and sold internationally as a component of cough syrup, toothpaste and mouthwash.

In April 2006, 64 patients with liver disease from The Third Affiliated Hospital (Guangzhou, China) received armillarisin A, a jaundice therapy manufactured by Qiqihar No. 2 Pharmaceutical Co. Ltd (Qiqihar, China). Fifteen of these patients developed acute renal failure following administration of armillarisin A. Testing by the Guangdong Drug Testing Center and the National Drug Testing Center of China detected high concentrations of DEG. No previous cases of DEG poisoning in patients with underlying liver disease have been reported, and the effects of DEG poi-

soning on patients with underlying liver disease are therefore unknown. The aim of this study was to investigate whether accidental intravenous DEG poisoning led to an exacerbation of liver damage in patients with underlying hepatic disease.

MATERIALS AND METHODS

Study subjects

The study population consisted of 64 patients with liver disease who were administered 10–20 ml of intravenous armillarisin A (Qiqihar No. 2 Pharmaceutical Co. Ltd., Qiqihar, China), to treat jaundice. The armillarisin A was later found to contain 30 % DEG. All patients were treated at the Third Affiliated Hospital of Sun Yat-Sen (Guangzhou, China) between April 19, 2006 and May 1, 2006. Patients were treated with armillarisin A once daily for 1–11 days during this time (see Suppl. Table 1).

Diagnostic criteria

Based on previous research, a 3–point criteria for the clinical diagnosis of DEG poisoning was followed. The criteria specified: (1) an obvious history of DEG exposure (intravenous or oral), (2) the appearance of oliguria or anuria that are characteristic of acute renal impairment or renal failure following DEG exposure (i.e., typically within two weeks of the final dose), and (3) the exclusion of other factors that cause acute renal impairment or renal failure. Other clinical manifestations and laboratory tests including the presence of metabolic acidosis, neurological impairment symptoms (predominantly a multifocal peripheral neuropathy) and histopathological characteristics of renal damage, such as acute tubular necrosis and tubulointerstitial nephritis, were carried out in some cases to assist in the diagnosis of DEG poisoning. Fifteen cases of DEG poisoning were identified by a group of experts in the field according to the criteria specified above.

Method of detection

Liver function and serum biochemical assays including: alanine transaminase [ALT], aspartate transaminase [AST], gamma glutamyl transpeptidase [GGT] or alkaline phosphatase [ALP], total bilirubin [TB], prothrombin time [PT], prothrombin time activity [PTA], serum cholinesterase [CHE] serum albumin [ALB], blood urea nitrogen [BUN] and blood creatinine [Cr], were performed using BS-200 (Mindray Company, Shenzhen, Guangdong Province, China), a fully automated biochemistry analyzer. The DEG content of armillarisin A solutions was determined using spectrophotometry by the Food and Drug Administration in Guangdong Province (GDFDA; China) (Maurer et al., 2001).

Study method

Clinical manifestations were recorded and blood samples were collected before, and 1–8 weeks after, the intravenous administration of the DEG-contaminated armillarisin a solution (see Suppl. Table 2). Based on these results, the 64 patients involved were divided into two groups: poisoning or non-poisoning depending on whether DEG poisoning was evident. A case-control method was subsequently employed to examine whether DEG exacerbated the preexisting liver damage in this patient population.

The relationship between DEG poisoning and alterations in liver function were analyzed based on the standard diagnostic criteria for drug-induced liver damage and toxin-induced hepatitis (Bissell et al., 2001; Schencker et al., 1999; Tegeder et al., 1999). Diagnostic standards of acute exacerbation of liver function specify that one or more of the following clinical signs occur within 1–8 weeks following DEG exposure: liver function abnormalities (including a five-fold elevation of any of the following: ALT, AST, GGT or ALP); an ALT/ALP ratio >5; elevation of preexisting jaundice, increased PT; development of new complications, and improvement or

recovery following the removal of the toxin.

In this study, the following data were recorded for all members of the study population: gender, age, whether poisoning had occurred, total dose of DEG inadvertently administered, dose concentration each time and pre-treatment liver function indicators. These data were used for multivariable regression analysis to detect the risk factors of poisoning.

Statistical analysis

Statistical analysis was carried out using the SPSS 13.0 software (2006, Guangzhou, China). Measurement data were presented as means \pm standard deviation (SD), and comparisons between pre- and post-poisoning data were performed using non-parametric multiple correlation sample analysis (Friedman test). Wilcoxon rank sum test of two independent samples was used to compare the accumulated dosage of armillarisin A between the poisoned group and non-poisoned group. Statistical significance was defined as $p < 0.05$. Unifactorial chi-squared analysis was used to analyze dynamic changes in liver function indicators between the poisoning and non-poisoning group. Enumeration data were examined using four-fold table chi-squared analysis. Logistic multivariable regression analysis was used to analyze factors correlated with the occurrence of poisoning.

RESULTS

Baseline characteristics

Of the 64 patients included in this study, 15 were female (23.4 %) and 49 were male (76.6 %). The oldest patient was 76 years old and the youngest patient was five years old (mean: 45.7 ± 1.91). All patients were diagnosed with chronic liver disease, including 14 cases of severe hepatitis (21.9 %), 14 cases of cirrhosis resulting from hepatitis B (21.9 %), 20 cases of severe chronic hepatitis (31.3 %), six cases of hepatocellular carcinoma (9.4 %), two cases of post-transplantation liver disease

(3.1 %), and one case each of Wilson's disease, primary biliary cirrhosis, lymphoma-induced liver damage and cholangiocarcinoma (1.6 % each). Prior to the initiation of intravenous injections of DEG-contaminated armillarasin A, chronic hepatobiliary tract infections and variable degrees of jaundice were present in all cases.

Characteristics of DEG poisoning

DEG poisoning occurred in 15 of the 64 patients (23.4 %) and they were all male. All DEG poisoned patients developed oliguric acute renal failure after a latency period of 2–12 days (mean = 5 days) after DEG administration. There was no significant difference in the accumulated dosage of armillarasin A between the poisoned group and non-poisoned group (see Table 1). Renal failure in patients poisoned with DEG can display a wide spectrum of liver disease severity, from mild to more advanced stages, compared with hepatic renal failure patients, who usually display severe hepatic disease with higher levels of TB, much lower PTA, more frequent ascites and a higher white blood cell (WBC) count. In this study, the onset of renal failure in DEG poisoned patients was more acute than in hepatic renal failure. Urinary output decreased rapidly and the mean progression time from oliguria to anuria was only one day. In DEG poisoned patients, Cr increased rapidly and reached a higher level than that in patients with hepato-renal failure. Renal damage was observed by routine urinalysis and ultrasonic exams (see Table 2). Percutaneous renal biopsies were obtained in two cases and each demonstrated acute tubular necrosis.

In the early periods of poisoning, most patients had nonspecific symptoms such as abdominal distension, abdominal pain and loin pain. Seven of the 15 patients also developed a low-grade fever. Nine cases had nausea and vomiting which were initially assumed to be due to worsening of the underlying liver disease. Ten of the 15 pa-

tients developed symptoms of neurological system damage, which manifested mainly as cranial nerve damage or paralysis. Peripheral nerves were affected in four cases which resulted in limb paralysis and even respiratory muscle paralysis. Metabolic acidosis developed in the majority of patients (13/15, 86.7 %). In total, 12 of the 15 poisoned patients (80 %), equivalent to 18.7 % of exposed patients, died within seven days of exposure to DEG. Of these, seven patients died from multiple organ dysfunction syndromes, four patients died from severe infection and one patient died from gastrointestinal hemorrhage. Concerning the three surviving patients inadvertently poisoned with DEG, one patient received a liver transplant (which presumably played an integral role in patient survival) and two patients totally recovered.

Liver function dynamic changes

Liver function indicators were recorded from 64 patients for eight weeks following the administration of DEG-contaminated armillarasin A. Comparisons between pre-injection and post-injection, and between the poisoned and non-poisoned group of patients were made. The results revealed that the intravenous administration of DEG resulted in mild liver function impairment. ALT levels were slightly increased at week 6, TB transiently increased at week 3 (which lasted less than one week), CHE transiently decreased slightly at week 3 and small fluctuations in ALP occurred throughout the period (see Table 3). No additional abnormalities were noted. As some patients died, some patients improved and were discharged, we can only collect liver functions of different weeks in remain patients. Comparisons between pre-injection and post-injection for the patients observed a complete set of data were made. The results suggested that there was no significant difference in ALT ($P=0.248$) and ALP ($P=0.107$) after the intravenous administration of DEG. TB transiently increased at week 3 (see Table 4).

Table 1: Comparing the accumulated dosage of amillarisin A between the poisoned group and non-poisoned group

Groups	n	Accumulated dosage (ml) (Median)	Inter-quartile range (ml) (P ₂₅ -P ₇₅)
Poisoned group	15	50.0*	40.0-80.0
Non-poisoned group	49	70.0	30.0-110.0

* P=0.768

Table 2: Comparing the basic information and main changes after onset of renal failure between DEG poisoning and hepatic renal failure

Characteristics	Poisoning group (n=15)	Hepatic renal failure (n=45)	P
Gender male	15 (100 %)	41 (91.1 %)	0.55
Age			
Median	49.23 ± 13.73	49.31 ± 11.85	0.982
Range	33-76	13-70	
Diagnosis			
Liver failure	7 (46.7 %)	41 (91.1 %)	0.001
Liver disease without liver failure	8/15 (53.3 %)	4 (8.9 %)	0.001
Complications			
Ascites	10 (66.7 %)	42/45 (93.3 %)	0.028
Renal diseases	5 (33.3 %)	6 (13.3 %)	0.178
After renal failure:			
TB (µmol/L)	375.59 ± 260.70	617.07 ± 210.37	0.001
PTA (%)	55.0 ± 25.48	22.18 ± 10.46	0.000
BUN (mmol/L)	15.41 ± 7.40	25.10 ± 26.07	0.026
Cr (µmol/L)	340.55 ± 151.91	229.60 ± 129.28	0.009
WBC (10 ⁹ /L)	7.63 ± 2.99	13.47 ± 5.50	0.000
Platelet count (10 ⁹ /L)	106.9 ± 50.6	101.32 ± 90.95	0.983
Urine routine abnormal*	10 (66.7 %)	2 (4.65 %)	0.000
Ultrasound exam abnormal*	14 (93.3 %)	3 (6.7 %)	0.000

Urine routine abnormal*: white blood cell elevation, urine protein positive or cylindruria

Ultrasound exam abnormal*: signal enhancement of renal parenchyma

Table 3: Changes in liver function after administration of DEG

Time*	N	Alt (Mean ± SD)	N	TB (Mean ± SD)	N	ALP (Mean ± SD)
0	61	178.98 ± 264.70	61	253.8661 ± 217.89	59	194.53 ± 232.35
1	58	79.31 ± 61.36	58	247.99 ± 220.79	57	156.44 ± 155.65
2	40	131.70 ± 428.80	40	270.6663 ± 247.85	40	150.38 ± 127.65
3	26	60.58 ± 48.18	25	299.61 ± 251.62	25	137.00 ± 136.72
4	20	70.65 ± 55.33	20	307.06 ± 251.77	20	145.30 ± 133.11
5	17	80.35 ± 79.69	17	226.59 ± 221.11	17	181.19 ± 167.95
6	15	69.69 ± 49.45	14	185.75 ± 202.87	14	205.00 ± 206.11
7	13	64.00 ± 40.65	13	191.42 ± 225.39	12	188.00 ± 117.19
8	7	63.43 ± 35.06	6	200.97 ± 314.00	7	277.43 ± 206.11

*weeks after DEG administration

Table 4: Changes in liver function after administration of diethylene glycol (for the patients observed a complete set of data)

Time*	Alt (Mean ± SD) (n=7)	TB (Mean ± SD) (n=6)	ALP (Mean ± SD) (n=7)
0	130.86 ± 89.77	293.87 ± 177.73	289.57 ± 253.84
1	76.29 ± 35.16	268.00 ± 180.64	216.57 ± 106.03
2	70.57 ± 37.34	332.83 ± 272.69	192.00 ± 98.67
3	67.71 ± 33.47	257.90 ± 239.77	250.29 ± 224.7
4	86.57 ± 67.91	222.92 ± 213.68	240.14 ± 196.13
5	110.86 ± 107.96	188.31 ± 186.83	295.29 ± 207.08
6	73.57 ± 43.35	188.07 ± 231.15	300.71 ± 264.64
7	78.29 ± 46.40	199.93 ± 182.95	244.24 ± 124.87
8	63.43 ± 35.06	200.97 ± 314.00	277.43 ± 188.26

*weeks after DEG administration

Compared with pre-injection levels, ALT increased five-fold in two of the 15 patients in the poisoned group at week 5 post-injection. AST increased to more than five-fold in four patients in the poisoned group. Of these, AST levels increased during week 1 in three of the four patients whereas AST did not increase until week 3 in the final patient. GGT increased to more than five-fold in four patients, but only one of these patients was in the poisoned group. ALP increased by more than five-fold in one patient in the non-poisoned group (see Table 5).

Jaundice increased in 24 of the 64 patients, including seven patients from the poisoning group, which was not statistically significant. PTA decreased in 23 patients, including nine patients from the poisoned group ($p < 0.05$). Albumin decreased in 35 patients, 12 of whom were from the poisoned group ($p < 0.05$). Overall, a greater than five-fold increase in a single serum biochemistry parameter was noted

in 11 of the 64 patients, but no patient displayed a simultaneous increase of two enzymes. Only one patient from the non-poisoned group experienced a simultaneous increase of jaundice, GGT and ALP. Decreased PTA and elevation of jaundice was observed simultaneously in 14 patients (five patients were from the poisoning group, $p > 0.05$).

Risk factors of poisoning

The risk factors of the occurrence of DEG-induced renal failure were assessed by multivariable regression analysis. The results showed gender ($p = 0.039$) and the severity of jaundice prior to DEG administration were related to the occurrence of DEG-induced renal failure ($p < 0.006$). Total dose was not related to the occurrence of DEG-induced renal failure ($p = 0.821$). No significant correlations between age, dose concentration and pre-injection ALT, AST, GGT, ALP, PTA and CHE levels, were identified.

Table 5: Cases that met the severe liver damage criteria

Index	Poisoning group	No poisoning group	Statistically significant
ALT (increase > 5-fold)	2	0	neg
AST (increase > 5-fold)	4	0	neg
GGT (increase > 5-fold)	1	3	neg
ALP (increase > 5-fold)	0	1	neg
TB (elevation)	7	17	neg
PTA (decrease)	9	14	$p = 0.04$
ALB (decrease)	12	23	neg

DISCUSSION

Diethylene glycol (DEG) is an organic compound with a wide range of applications. During the past century there have been a few incidents of acute DEG poisoning. In 1937, ethanol and sugar were replaced by DEG in the manufacture of Elixir Sulfanilamide in the United States which resulted in 358 cases of poisoning, including 107 deaths. In this incident, individuals were exposed to DEG via the oral route and poisoning was mostly detected in retrospective analysis of renal failure and epidemiological investigations (O'Brien et al., 1998; Karlson-Stiber and Persson, 1992; Hanif et al., 1995). In this report, we describe patients with preexisting liver disease who were exposed to a high concentration of DEG after accidental intravenous injection.

DEG itself is nontoxic. Poisoning by this compound is a result of the toxicity of its metabolites following hepatic and renal metabolism. It is currently thought that the occurrence of poisoning after DEG exposure depends on endogenous alcohol dehydrogenase (ADH) activity. ADH is present in the liver, kidneys and gastrointestinal tract. If the level of ADH activity is high, more active products of DEG metabolism are produced, and there is a higher likelihood of developing DEG poisoning. Following the development of renal failure, the pharmacodynamics of DEG is correspondingly altered (Heilmair et al., 1993). DEG remains detectable in the organs and blood in poisoned patients for up to 2–3 days following the onset of renal failure. Therefore, patients with renal failure may develop liver function impairment more easily, this is confirmed by the results of this study. In patients poisoned with DEG, two patients developed worsening gastrointestinal symptoms, abdominal distension and hepatic encephalopathy. Eight weeks following the inadvertent intravenous administration of DEG, analysis of liver dynamic function showed that PTA and ALB

were decreased in nine and 12 patients, respectively.

Jaundice was a common observation in DEG-poisoned patients reported during the 1937 incident in the United States. In a separate group of patients, hepatomegaly was more commonly noted in DEG-related renal failure than non-DEG-related renal failure (53 % and 33 %, respectively) (Okuonghae et al., 1992). This finding suggests that DEG poisoning may result in liver damage in patients without underlying liver disease, and possible manifestations include hepatomegaly, jaundice, increased GGT and increased ALP (Kawamoto et al., 1990). Under normal circumstances, the presence of intrinsic liver disease is often an independent risk factor in the development of drug- or toxin-induced hepatitis. The results of this study suggest that liver disease may have an effect on the occurrence of renal failure following DEG poisoning as the rate of renal failure was related to the severity of jaundice prior to administration of DEG.

In patients with severe liver disease or deep jaundice, the ability of hepatocytes to synthesize ADH or the liver's ability to excrete DEG was impaired, thereby resulting in decreased formation of hepatotoxic active metabolites. In turn, a greater proportion of unmetabolized DEG existed, which resulted in a higher incidence of renal toxicity. A significant worsening of liver disease, however, was not observed in patients with underlying liver disease administered intravenous DEG. Indeed, liver function indicators showed only transient, slight or insignificant changes in hepatic function, indicating that DEG-induced liver damage is less severe in these patients.

Toxin-induced liver damage can be divided into three categories: hepatocellular, cholestatic and mixed types. Hepatocellular damage is characterized mainly by increased ALT, AST, GGT and ALP levels. ALT and AST are often significantly elevated in hepatocellular toxin-induced liver damage, often by more than 100 times the

normal level. AST levels greater than 3000 IU/L have been reported in patients with 90 % hepatocellular toxin-induced liver damage. In contrast, jaundice is normally less severe in hepatocellular damage compared with cholestatic and mixed types of liver damage (Gunawan and Kaplowitz, 2004; Dufour et al., 2000). Cholestatic liver disease is characterized by elevation of jaundice accompanied by increased GGT and ALP levels. Moreover, if liver disease progresses to liver failure, the clinical presentation may manifest as elevated jaundice and prolonged PTA.

In this study, a five-fold increase in a single enzyme was observed in 11 patients, but a simultaneous increase in two enzymes was not noted in any of the 64 patients. This finding suggests that the risk of developing acute cellular toxicity is low in patients with liver disease following intravenous DEG administration. The absence of increased ALT, AST and ALP levels was consistent with the results obtained from animal studies. In our study, only one patient simultaneously developed worsening jaundice, increased GGT and increased ALP. Interestingly, this patient was from the non-poisoned group and these findings might simply be due to a worsening of the patient's condition. Therefore, most patients did not match the diagnostic criteria for hepatocellular or cholestatic toxin-induced liver damage.

Changes in liver function indicators within the first eight weeks post-DEG injection were observed in patients with underlying liver disease. These results showed that a worsening in liver function was not observed in the majority of patients, and obvious acute increases in ALT, AST, GGT and ALP did not occur; the proportion of patients who developed concurrent worsening jaundice and decreased PTA levels did not increase. Liver function prior to and post-DEG administration, and the differences in most liver function indicators between the poisoned and non-poisoned groups were not significant. Only

a small number of patients developed slight increases in ALT, early increases in TB and decreases in CHE. Most values returned to normal levels rapidly and the alterations lasted less than one week. Liver function changes may relate to underlying liver disease as well as DEG poisoning. Whether these changes were secondary to progression of underlying liver disease or exacerbated by acute DEG poisoning is still unclear. Further research is needed to establish a standard for the diagnosis of toxic liver damage in cases of underlying liver disease. We combined dynamic monitoring of liver function with identification of cases with liver enzymes elevated more than five times the normal levels after DEG exposure, to detect the hepatic toxic effect of DEG on patients with underlying liver disease.

The exacerbation of liver function was rare in this study. This finding is inconsistent with previous reports in which liver damage was observed in patients without liver disease following DEG or other toxin poisoning. Normally, the incidence of drug and toxin poisoning is higher in patients with intrinsic liver disease, and the risk of developing toxic liver damage relates to the severity of liver disease. Also, liver damage is often further accelerated following drug or toxin poisoning. A number of possible reasons for this disparity exists. First, exposure via the intravenous route may result in different degrees of toxicity or poisoning compared with exposure via the oral route. For example, DEG may be more deleterious to the liver following oral administration. Second, in liver disease, especially severe liver disease associated with decreased liver enzyme activity, the liver's ability to produce hepatotoxic active metabolites is reduced. However, the correlation between jaundice severity before DEG injection and the rate of poisoning noted in this study does not support this view. Instead, the underlying liver damage might increase the excretion of the unaltered form of DEG, resulting in an in-

crease in the occurrence of renal failure. Next, the onset of poisoning in patients was acute, and disease progression and death due to renal failure was rapid. In the early stages of poisoning, immediate initiation of dialysis and other hepatoprotective treatments may reduce the risk of developing additional liver function impairment. Finally, individual variation in response to the administration of DEG may also explain the differences in poisoning rates.

Many developing countries lack the ability or resources to monitor and prevent the occurrence of this type of poisoning and underlying liver diseases such as hepatitis and alcoholic liver diseases are epidemic in many countries. The early detection of poisoning would allow for treatment by hemodialysis and liver protected therapy, possibly increasing the survival rate. Therefore further animal experiments, especially those including subjects with liver disease, are needed to establish the metabolism of DEG, the risk of worsening liver damage and the type of liver impairment that occurs following DEG exposure.

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