Disturbance of hepatic and intestinal microcirculation in experimental liver cirrhosis

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Abstract

AIM: To analyze hepatic, mesenteric and mucosal microcirculation and leukocyte-endothelium interaction (LEI) in a rat model with liver cirrhosis.

METHODS: Hepatic cirrhosis was induced in Wistar rats by gavage with carbon tetrachloride, and intravital videomicroscopy was performed in liver, mesentery and small intestine mucosa. Special emphasis is given on microcirculatory and morphometric changes during cirrhotic portal hypertension.

RESULTS: LEI was influenced significantly in the cirrhotic liver but not in the gut. Blood flow measurement showed significant differences among liver, main mesenteric vessels and the mucosa. The results of our study indicate that liver cirrhosis leads to alterations in hepatic and mesenteric blood flow but not in mucosal blood flow.

CONCLUSION: The enhanced inflammatory response in hepatic microvessels may be caused by a decrease of antithrombin III levels and could be responsible for disturbances of organ pathology.

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Key words: Liver cirrhosis; Microcirculation; Small intestine; Liver

Maksan SM, Ryschich E, Ülger Z, Gebhard MM, Schmidt J. Disturbance of hepatic and intestinal microcirculation in experimental liver cirrhosis. World J Gastroenterol 2005; 11 (6): 846-849
http://www.wjgnet.com/1007-9327/11/846.asp

INTRODUCTION

Liver cirrhosis is recognized as an important risk factor for the development of severe septical complications such as spontaneous bacterial peritonitis and bacteraeemia[9]. The impairment of intestinal microcirculation and mucosal barrier may contribute to an increased intestinal permeability and bacterial translocation[2-4]. Hypoperfusion of the gut mucosa has been implicated as an important mechanism contributing to gut-derived endotoxinemia and bacteraeemia in liver cirrhosis. Due to splanchnic arterial vasodilation and portal hypertension, intestinal capillary pressure is altered and effective arterial blood volume decreases[8].

It is generally recognized that there is a close relationship between the hepatic microcirculation and liver function and structure[8,7]. Recent studies established the important correlation between hepatic microcirculation and the development of liver pathology[8]. Furthermore, it has been described that leukocyte adherence in liver sinusoids is amplified after gut ischemia and reperfusion due to an up-regulation of adhesion molecules[8].

We still lack quantitative data describing hepatic and mesenteric microvascular parameters such as blood flow velocity, volumetric blood flow, leukocyte-endothelial interaction and vessel size within one experimental setting. Currently, intravital videomicroscopy is the most pretentious technique to measure variables of microvascular perfusion in vivo. In addition to the measurement of mesenteric blood flow and leukocyte kinetics, we quantified mucosal blood flow in terminal arterioles directly, since the assessment of mucosal blood flow has been simplified[10].

The present study was undertaken to quantitate basic microvascular parameters in normal rat liver and intestine and to investigate changes in these parameters associated with the development of cirrhosis.

MATERIALS AND METHODS

Male Wistar rats weighing 450±47 g at the time of surgery (initial weight 250±5 g) were used in all experiments. They were housed in a controlled environment with a 12-h light: dark cycle and were fed standard rat diet with water ad libitum.

Chronic, progressive hepatic cirrhosis was induced according to the method of Proctor and Chatamra by gavage with carbon tetrachloride (CCl4)[11]. Animals were given phenobarbital (35 mg/100 mL) in their drinking water to induce the enzyme cytochrome P450, which has been shown to increase rat liver sensitivity to CCl4[12]. Two weeks later an initial dose of 0.04 mL CCl4 was given after orogastric intubation and enhanced weekly in steps of 0.04 mL to a maximum dose of 0.4 mL CCl4. Animals were weighed weekly.
Six control animals without liver cirrhosis were observed for statistical analysis.

**Videomicroscopy**

Videomicroscopy was performed under general anesthesia. Left carotid artery was cannulated with a polypropylene catheter (B. Braun, Melsungen, FRG) to monitor arterial blood pressure, heart rate and for blood-gas analysis (ABL Radiometer). The right jugular vein was cannulated for drug administration. The abdomen was opened via a median incision. The presence of ascites and macroscopic appearance of liver cirrhosis were noted.

For intravitral microscopic investigations a Leitz microscope (Leitz GmbH, Wetzlar, Germany) was used. With different filter blocks in the epillumination technique, selective visualization of FITC-labeled erythrocytes and rhodamine 6G-stained leukocytes was possible. For contrast enhancement, FITC-labeled albumin was administered intravenously.

**Hepatic microcirculation**

The hepatic microvascular parameters were measured in vivo using the epillumination microscopic setup described in detail elsewhere. In brief, the left liver lobe was exteriorized onto a specially designed stage and prepared for intravitral videomicroscopy. Continuous superfusion with buffered 37 °C Ringer’s solution was provided. At the beginning of videomicroscopy, FITC-labeled erythrocytes (1 mL/kg BW) and rhodamine 6G-labeled leukocytes (0.05 nmol/kg BW) were injected intravenously. Using a FITC selective filter block, 5 fields of normal liver tissue during a period of 30 s were analyzed. Observations of leukocytes were done using a rhodamine-selective filter block. Vessels with a length of at least 100 µm were registered for a period of 60 s each.

**Intestinal microcirculation**

In a second step, terminal ileum was exteriorized and placed on a glass slide. Videomicroscopy of mean mesenteric vessels was performed. Subsequently the bowel was opened along the antimesenteric border and fixed at the incision margins. The prepared bowel was bathed and superfused with buffered Ringer’s solution. Mesenteric microcirculation was investigated in 10 fields of ileal arteries and corresponding veins following the scheme of hepatic videomicroscopy. Mucosal microcirculation was measured in the main arteriole of 5 single villus. Each vessel was observed for 30 s.

**Data interpretation**

Measurements were videotaped and off-line analysis was performed by means of an image-processing system (Capimage®, Zeintl GmbH, Heidelberg, Germany). The red cell blood velocity and vessel diameter were measured using the frame-to-frame method. Leukocyte contact to endothelium was analyzed and described as leukocyte-endothelium interaction (LEI). The definition of the duration of this interaction results in leukocyte rolling and leukocyte sticking. Leukocyte rolling was based on the movement along the endothelial lining that was less than 66% of the red cell blood velocity. Temporary interactions with the endothelium of not more than 30 s duration were also considered as rollers. Leukocyte sticking was defined as the attachment to the vessel endothelium for at least 30 s.

Microvascular blood flow ($V_b$ in nL/min) was calculated using the following equation:

$$V_b = \pi \times r_e \times (D/2)^2.$$  

Determinants were erythrocyte velocity ($r_e$) and vessel diameter ($D$).

**Histology and blood tests**

At the end of experiments, liver and small intestine specimens were taken and the sections were stained with hematoxylin and eosin. Blood samples were taken for measurement of serum concentration of GOT, GPT, γ-GT and AP. Prothrombin time and the antithrombin III level were taken for hemostatic analysis.

**Statistical analysis**

Results were expressed as mean±SD. Statistical analysis was performed using Mann-Whitney U test. Results are considered significant at $P<0.05$.

**RESULTS**

Cardiorespiratory parameters did not differ between groups throughout the observation period (Table 1).

**Histological findings**

Ascitic rats had microscopic evidence of cirrhosis in all cases. Liver histology revealed extensive deposits of fibrous tissue with regenerative nodules in at least some areas. Foci of necrotic cells were also observed. Sections of ileum showed a higher number of lymph vessels in cirrhotic rats than that in controls.

**Intravitral observations**

The quantitative measurements of microvascular parameters are summarized in Table 2. Blood flow in terminal arterioles of the villus was similar between both the groups (5.3±0.3 vs 5.4±0.2 nL/min in control animals, NS). Marked differences were observed in main mesenteric blood flow (135.1±3.5 vs 156.5±4.3 nL/min in controls, $P<0.01$). Liver blood flow remained comparable (32.1±0.4 vs 31.2±0.6 nL/min in controls, NS), although red blood cell velocity in cirrhosis was reduced significantly (0.93±0.09 vs 1.22±0.18 mm/s in controls, $P<0.05$).

Hepatic LEI was enhanced in cirrhosis. The number of rolling leukocytes and high-affinity leukocytes raised significantly (4.80±0.90 vs 2.33±0.75 roller/100 µm and 1.91±0.28 vs 0.5±0.5 sticker/100 µm in controls, $P<0.01$). Analysis of LEI in main mesenteric arterioles showed no differences between the groups (Table 3).

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**Table 1 Cardiorespiratory parameters**

|                  | Cirrhosis | Controls | $P$  |
|------------------|-----------|----------|------|
| Mean arterial blood pressure (mmHg) | 107±8.4 | 112±7.3 | NS   |
| Heart rate (bpm) | 310±9.2  | 304±8.4 | NS   |
| $paO_2$ (mmHg)   | 89.1±5.3 | 92.3±4.8 | NS   |

**Table 2 Microvascular parameters**

| Parameter                        | Cirrhosis | Controls | $P$  |
|----------------------------------|-----------|----------|------|
| Microvascular blood flow (nL/min)|           |          |      |
| Main mesenteric arterioles       | 5.3±0.3   | 5.4±0.2  | NS   |
| Terminal ileal arterioles        | 135.1±3.5 | 156.5±4.3| $P<0.01$|
| Liver blood flow (nL/min)        | 32.1±0.4  | 31.2±0.6 | NS   |
| Red blood cell velocity (mm/s)   | 0.93±0.09 | 1.22±0.18| $P<0.05$|
Antithrombin III (IU) 108.50±14.59         125.0±8.96             <0.05

Blood tests
Serum enzyme tests revealed significant disturbances of hepatocellular integrity and reduction of blood clotting capacity. Further antithrombin III levels were significantly reduced in cirrhotic animals (108.5±14.59 vs 125.0±8.96 IU in controls, P<0.05) (Table 4).

DISCUSSION
Liver cirrhosis has been detected to be an important risk factor for mortality in critically ill patients. Its incidence in western countries is rising and represents the most common cause of mortality among the non-malignant digestive diseases. The mechanisms for the increased morbidity and mortality may be immunological, mechanical or pharmacological. Special emphasize is given to hepatic and intestinal microcirculatory disorders. However, it is still not clear how alterations in hepatic microcirculation contribute to the progression of the disease and its sequelae.

In the present study, we have applied the technique of intravital videomicroscopy to quantitate intestinal and hepatic microcirculation and LEI in cirrhotic rats. We used a model of CCl4-induced cirrhosis. Liver damage is mainly caused by hepatotoxic CCl4 metabolites produced within the liver. The intensity of the hepatic damage is exaggerated when the microsomal enzyme oxidizing system is previously induced, for instance by the administration of phenobarbital.

Induced cirrhosis is associated with marked hemodynamic disturbances. These include changes in both the intrahepatic and splanchic circulation resulting in portal hypertension. Our quantitative studies of hepatic and mesenteric microvascular parameters indicate that cirrhosis leads to a marked arterial vasodilatation. This observation is in accordance with other experimental studies. The pathogenesis of vascular tone is explained by biochemical investigations and disorders of vascular heme oxygenase-1 expression and nitric oxide synthase expression in experimental cirrhosis.

In this study, presence of liver cirrhosis had no effect on villus blood flow measured in the terminal, central villus arteriole. To our knowledge, there is no other study where the effects of cirrhosis and portal hypertension on villus blood flow were derived directly from data obtained on the level of single villus arterioles. The disturbance of mucosal blood flow may contribute to an impairment of the intestinal barrier function. It has been described that alterations of the mucosal permeability in cirrhosis are related to the degree of liver failure and to the progression of the liver disease.

However, the impact of liver cirrhosis on hepatic microcirculation is more evident. LEI is enhanced significantly and may explain organ disturbances. LEI itself is modulated by a variety of adhesion molecules expressed on the surface of leukocytes and endothelial cells. These adhesion molecules mediate the decrease in leukocyte rolling and the increase in leukocyte adherence and migration.

In summary, this study demonstrates that in the gut mucosa, cirrhosis may not induce disturbances in the villus microcirculation, despite altered levels of mesenteric blood flow.

Experimental liver cirrhosis is associated with a marked increase of liver enzymes and a decrease of antithrombin III levels and prothrombin time. Antithrombin III is one of the most important physiological inhibitors of coagulation. It is synthesized in liver parenchymal cells. Moreover, it has been described that AT III has anti-inflammatory actions in experimental sepsis and hepatic ischemia-reperfusion. It could be presumed that in cirrhosis a drop of the antithrombin III level leads to hemostatic disorders similar to disseminated intravasal coagulation (DIC) and inflammatory response in the microcirculatory units, even if clinical observations did not emphasize those findings.

In our study, hemostatic dysfunction could be measured and LEI in liver parenchyma and mesenteric vessels was enhanced significantly.

We conclude that experimental liver cirrhosis leads to disturbances in hepatic and mesenteric but not in mucosal microcirculation. Although not proven by our experiments, lower antithrombin III levels as found in our study could potentially maintain or aggravate hemostatic disorders and alterations in hepatic inflammatory response to portal hypertension associated with a deterioration of liver function.

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Assistant Editor Li WZ Edited by Gabbe M