Int J Clin Exp Med 2026;19(7):186-193
www.ijcem.com /ISSN:1940-5901/IJCEM0170650

Original Article

Impact of traditional Chinese medicine on liver regeneration following partial hepatectomy in cirrhotic rats

Haibin Ji[1,2*], Zhiwei Liu[2,3*], Wentao Zhu[1,2], Liang Zhao[4], Qiang Wei[1,2], Baofang Sun[1,2], Fan Zhang[1,2], Qiangpu Chen[1,2,3]

[1]Department of Hepatobiliary and Pancreatic Surgery, Clinical Nutrition Support Center, Binzhou Medical University Hospital, Binzhou, Shandong, China; [2]Clinical Nutrition and Metabolism Key Laboratory of Shandong Province, Binzhou, Shandong, China; [3]Department of Clinical Nutrition, Binzhou Medical University Hospital, Binzhou, Shandong, China; [4]Department of Hepatobiliary Surgery, Yantai Yuhuangding Hospital, Yantai, Shandong, China. [*]Equal contributors.

Received December 10, 2025; Accepted May 27, 2026; Epub July 15, 2026; Published July 30, 2026

Abstract: Objective: This study aimed to evaluate the effects of a novel traditional Chinese medicine (TCM) on liver regeneration following partial hepatectomy (PH) in cirrhotic rats. Methods: Forty-eight cirrhotic rats were randomly allocated into four groups: control, sham-operated, PH, and TCM groups. In the TCM group, rats received the novel TCM via gavage, whereas those in the other groups were administered an equivalent volume of water. Postoperative assessments included hepatocyte growth factor (HGF) levels, liver weight, hepatocyte expression of Ki-67 and cyclin D1, and intestinal mucosal expression of mucin-2 (MUC-2) and zonula occludens-1 (ZO-1). Results: On postoperative days (PODs) 3 and 7, liver regeneration rate in the TCM group was significantly higher than that in the PH group ($P < 0.05$). Similarly, on PODs 1, 3, and 7, the TCM group exhibited significantly higher HGF levels and increased hepatocyte expression of Ki-67 and cyclin D1 compared with the PH group ($P < 0.05$). Additionally, on PODs 3 and 7, the expressions of MUC-2 and ZO-1 in the intestinal mucosa were significantly higher in the TCM group than in the PH group ($P < 0.05$). Conclusions: The administration of the novel TCM during the perioperative period of PH enhanced liver regeneration in cirrhotic rats by providing hepatoprotection and preserving the intestinal mucosal barrier.

Keywords: Liver regeneration, traditional Chinese medicine, cirrhotic, intestinal mucosal barrier

Introduction

Partial hepatectomy (PH) is the standard, and most effective, surgical procedure for the treatment for hepatocellular carcinoma (HCC) [1]. However, patients with HCC often have viral hepatitis and cirrhosis, which impair the reserve function and regenerative potential of the liver [2]. Consequently, the risk of postoperative complications such as liver failure, infection, and mortality significantly increases following PH [3]. Enhancement of liver regeneration after PH has therefore attracted significant attention from clinicians in recent years.

Advancements in traditional Chinese medicine (TCM) have resulted in a steady increase in its application during the perioperative period of liver surgery. *Angelica sinensis* and *Salvia miltiorrhiza* have been shown to improve liver microcirculation by enhancing blood flow and reducing lipid peroxidation, thereby supporting hepatocyte proliferation [4, 5]. Various constituents of *A. sinensis* exert cytoprotective effects by alleviating oxidative stress and enhancing hepatocyte proliferation [6].

In addition, the gut microbiota plays a crucial role in both intestinal and extraintestinal diseases, especially liver diseases [7]. When the intestinal mucosal barrier is compromised, numerous harmful bacteria and their products enter the bloodstream through the gut-liver axis, potentially causing significant damage [8]. However, various factors such as surgical trauma, physiological stress, and intraoperative abdominal exposure can contribute to intestinal barrier dysfunction [9]. Therefore, damage

to the intestinal mucosal barrier function during the perioperative period of PH can significantly impair liver regeneration capacity.

It is noteworthy that recent research has indicated that TCM also holds significant potential in protecting the intestinal mucosal barrier and modulating the gut microbiota [10]. Rhubarb extracts have been shown to protect the intestinal barrier in rats with severe acute pancreatitis by inhibiting pyroptosis through the downregulation of the NLRP3-Caspase-1-GSDMD and TLR4-NF-κB signaling pathways [11]. *Magnolia officinalis* cortex has also been reported to increase the abundance of beneficial bacteria and reduce the abundance of pathogenic bacteria [12]. Similarly, *Astragalus membranaceus* extracts have been shown to suppress inflammation and oxidative stress in intestinal epithelial cells by inhibiting NF-κB activation and enhancing Nrf2 expression [13].

As mentioned above, TCM has demonstrated remarkable therapeutic effects, particularly in protecting liver function, promoting liver regeneration, and intestinal mucosal barrier preservation. To achieve the maximum therapeutic benefit, we rationally combine the drugs based on their known therapeutic effects to form a novel formula. The formula drugs mainly originate from the classic prescriptions of TCM, namely, Dachaihu decoction (Major Bupleurum decoction) and Xiaochengqi decoction (Minor Purgative decoction). This study aimed to evaluate the effect of this novel TCM formula on liver regeneration after PH in cirrhotic rats.

Methods

Rat cirrhosis model and study groups

To establish a liver cirrhosis model, forty-eight male Sprague-Dawley rats, aged six weeks and weighing 190±10 g, were housed under a specific pathogen-free (SPF) environment with a 12-hour light/dark cycle. These rats received intraperitoneal injections of 40% carbon tetrachloride (diluted in olive oil) at a dosage of 5 mL/kg, twice weekly for 8 weeks. Liver cirrhosis was confirmed by histopathological examination in three randomly selected rats. Once the model was established, rats were randomly divided into the following four groups using a random number table: control (C), sham-operated (S), PH, and TCM groups. All rats were fasted for 12 hours prior to surgery and then anesthetized with sevoflurane. The left and middle liver lobes were resected from rats in the PH and TCM groups. The abdomen was closed after confirming the absence of bleeding and bile leakage. In the S group, only the perihepatic ligaments and those surrounding the left and middle lobes were freed, without hepatectomy. Rats in the C group did not undergo any surgical procedures. Postoperatively, all animals were housed individually in the same environment. All animal experiments were approved by the Animal Ethics Committee of the Binzhou Medical University Hospital (Approval No: 20251128-12).

Interventions

The TCM formula comprised a decoction prepared from the following herbs: *Rheum officinale* (daihuang) 12 g, *Immature bitter orange* (zhishi) 24 g, *Astmgali radix* (huangqi) 20 g, *Magnoliae officmalis cortex* (houpu) 12 g, *Salvia miltiorrhiza bunge* (danshen) 10 g, *Angelicae sinensis radix* (danggui) 10 g, *Scutellariae radix* (huangqin) 10 g, *Radix bupleuri* (Chaihu) 12 g, and *Corydalis yanhusuo* (yanhusuo) 10 g. These herbs were decocted in 100 mL of water. The clinical dosage of TCM was translated to a rat dosage using the body surface area method (human:rat = 1:6.2), yielding a TCM dose of 5 ml/kg/d of crude drug [14]. This was administered 1 day before surgery and continued until postoperative day (POD) 7. The rats in the other groups were administered an equivalent volume of water under the same schedule. On PODs 1, 3, and 7, four rats from each group were anesthetized via intraperitoneal injection of sodium pentobarbital and then euthanized by cervical dislocation for subsequent analyses.

Outcomes

The METAVIR scoring system was used to assess the degree of liver cirrhosis [15]. The liver regeneration rate was calculated as follows: (remnant liver weight at a given time point - [estimated total liver weight at operation - excised liver weight]/total liver weight) × 100% [16].

The wet weights of the left and median lobes were measured after partial resection (RW). The total liver weight before resection (TW) was calculated by assuming that 70% of the liver weight was resected (TW = RW/0.7). The am-

ount of regeneration was calculated by dividing the total liver weight on the day of sacrifice (SW) by the weight before resection (SW/TW × 100%) [17].

The specimens were fixed in 4% neutral buffered paraformaldehyde for 24-48 hours, subsequently dehydrated through a graded ethanol series, cleared in xylene, infiltrated with molten paraffin, and embedded. Sections of 3 μm thickness were cut using a microtome and mounted on glass slides. Histopathological evaluation was performed via hematoxylin and eosin (H&E) staining according to standardized laboratory protocols. Collagen deposition and hepatic fibrosis were assessed quantitatively and qualitatively using Masson's trichrome staining.

Immunohistochemical staining was performed on formalin-fixed, paraffin-embedded (FFPE) tissue sections using the EnVision™ dual-link polymer detection system. Standardized procedures included deparaffinization in xylene, rehydration through graded ethanol series, heat-induced epitope retrieval (HIER) in citrate buffer (pH 6.0), quenching of endogenous peroxidase activity with 3% hydrogen peroxide, blocking of nonspecific binding sites with 5% normal goat serum. Sections were incubated overnight at 4°C with primary antibodies diluted in antibody diluent: rabbit monoclonal anti-α-smooth muscle actin (α-SMA; 1:200, HY-P83739, MCE, USA), rabbit monoclonal anti-Ki-67 (1:200; IHC0246R, Bioss, China), rabbit monoclonal anti-cyclin D1 (1:200, IHC0325R, Bioss, China), rabbit monoclonal anti-mucin-2 (MUC-2; 1:200, NBP3-16481, Novus Biologicals, USA), and rabbit monoclonal anti-zonula occludens-1 (ZO-1; 1:200, 66452-1-Ig, Proteintech, China). Following three 5-minute washes in phosphate-buffered saline (PBS), sections were incubated for 1 hour at room temperature with horseradish peroxidase (HRP)-conjugated goat anti-rabbit IgG secondary antibody (1:500; GB23303, Servicebio, China). Immunoreactive signals were visualized using a commercial 3,3'-diaminobenzidine (DAB) substrate kit (ZLI-9018, ZSGB-BIO, China), and nuclei were counterstained with hematoxylin solution.

For quantitative image analysis, positive immunoreactivity was defined as distinct brown-yellow staining localized to the cytoplasm or plasma membrane. Five non-overlapping high-power fields (HPFs) were systematically selected per tissue section-either at ×200 or ×400 magnification, depending on the target antigen's subcellular distribution. The number of positively stained cells and the percentage of positively stained areas were quantified semi-quantitatively using ImageJ software (v1.54f, National Institutes of Health), with threshold-based segmentation applied consistently across all images.

Liver tissue lysates were normalized to total protein concentration using the bicinchoninic acid (BCA) assay, and hepatocyte growth factor (HGF) levels were quantified by enzyme-linked immunosorbent assay (ELISA) on postoperative days 1, 3, and 7.

Statistical analysis

Data were expressed as the mean ± standard deviation. Normality was tested using the Shapiro-Wilk test. For comparisons among multiple groups, one-way analysis of variance was used, followed by Tukey's honestly significant difference post-hoc test for normally distributed data with homogeneous variance. For data that did not meet the assumptions of normality or equal variance, the non-parametric Kruskal-Wallis test followed by Dunn's post-hoc test was applied. Data were analyzed using SPSS (version 25.0; IBM) and GraphPad Prism (version 9.5.1; GraphPad Software). Statistical significance was set at $P < 0.05$.

Results

Liver histopathological examination

The livers of the cirrhotic rats exhibited atrophy, appearing deep red in color with a firm texture and rough nodular surface. HE and Masson's trichrome staining revealed a disorganized hepatocyte arrangement and fibrotic septa encircling hepatocytes to form pseudolobules. According to the METAVIR scoring system, the degree of liver cirrhosis has reached stage F4. Hepatocyte necrosis and apoptosis occurred alongside the formation of regenerative hepatocyte clusters (**Figure 1**).

Hepatocyte proliferation

Ki-67 expression in hepatocytes: On PODs 1 and 3, the number of Ki-67-positive cells in hepatocytes was significantly higher in the TCM group than that in the PH group ($P < 0.05$).

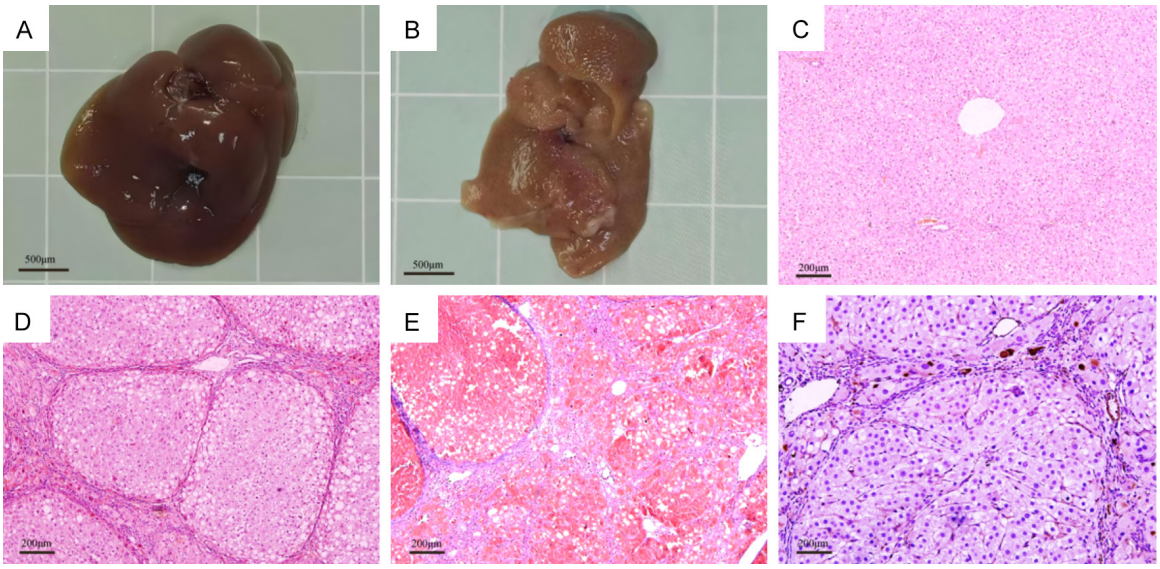

Figure 1. Liver histopathological examination. A. Normal liver. B. Cirrhotic liver. C. Normal hepatic lobular architecture (Hematoxylin and Eosin staining). D. Cirrhosis model induced by carbon tetrachloride, demonstrating regenerative nodules (Hematoxylin and Eosin staining). E. Masson's trichrome staining showing extensive collagen deposition in cirrhotic liver tissue. F. Immunohistochemical staining showing increased α-smooth muscle actin (α-SMA) expression in cirrhotic liver tissue.

Moreover, the number of Ki-67-positive cells in hepatocytes was significantly higher in the PH and TCM groups compared with in the C and S groups ($P < 0.05$) (**Figure 2A**, **2B** and **2E**).

Cyclin D1 expression in hepatocytes: On PODs 1 and 3, the number of Cyclin D1-positive cells in hepatocytes was significantly higher in the TCM group than that in the PH group ($P < 0.05$). Moreover, the number of Cyclin D1-positive cells in hepatocytes was significantly higher in the PH and TCM groups compared with in the C and S groups ($P < 0.05$) (**Figure 2C**, **2D** and **2F**).

HGF levels: On PODs 1, 3 and 7, although the overall HGF level gradually decreased in all groups, HGF levels were significantly higher in the TCM group than that in the PH group ($P < 0.05$). In addition, HGF levels were significantly higher in the PH and TCM groups compared with in the C and S groups ($P < 0.05$). These results indicate that PH promoted an increase in HGF levels and subsequently enhanced hepatocyte proliferation, with an even more pronounced effect observed in the TCM group (**Figure 2G**).

Liver regeneration rate

Compared with the PH group, the TCM group showed a significantly higher liver regeneration rate on POD 3 (0.409 ± 0.008 vs. 0.382 ± 0.017, $P = 0.003$). Similarly, on POD 7, the liver regeneration rate remained significantly higher in the TCM group compared with the PH group (0.552 ± 0.022 vs. 0.515 ± 0.011, $P = 0.004$) (**Figure 2H**).

Intestinal mucosal barrier function

MUC-2 expression in the intestinal mucosa: On PODs 3 and 7, MUC-2 expression in the intestinal mucosa was significantly reduced in the PH and TCM groups compared with in the C and S groups ($P < 0.05$). However, it was significantly higher in the TCM group than that in the PH group on POD 3 ($P < 0.05$) (**Figure 3A**, **3B** and **3E**).

ZO-1 expression in the intestinal mucosa: On PODs 3 and 7, ZO-1 expression in the intestinal mucosa was significantly lower in the PH and TCM groups than in the C and S groups ($P < 0.05$). However, ZO-1 expression in the TCM group was significantly higher compared with that in the PH group on POD 3 ($P < 0.05$) (**Figure 3C**, **3D** and **3F**).

Discussion

Our findings demonstrate that the novel TCM enhanced liver regeneration after PH, as evi-

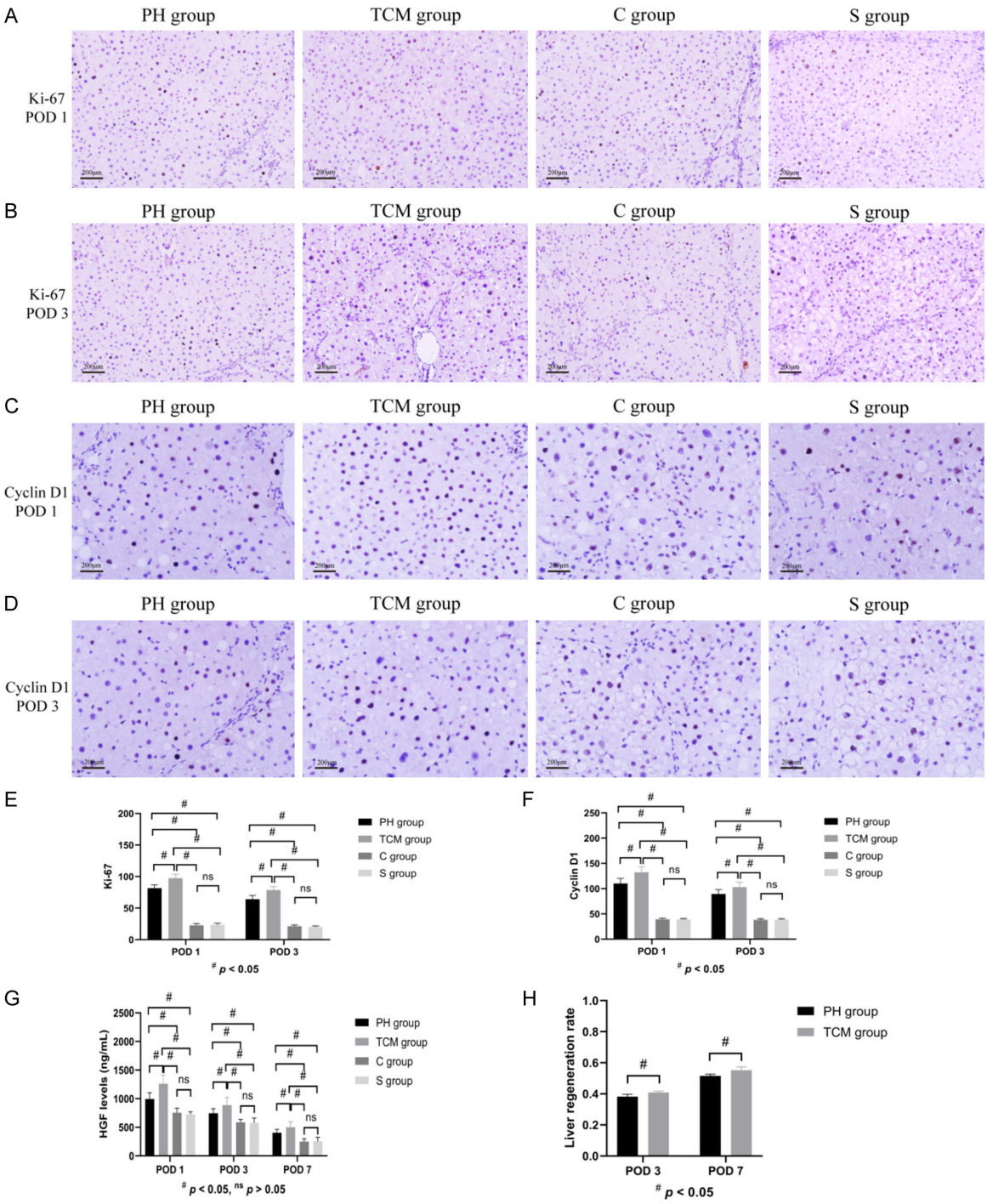

Figure 2. Liver regenerative capacity. A, B. Immunohistochemical staining showing Ki-67 expression levels in hepatocytes on PODs 1 and 3. C, D. Immunohistochemical staining showing Cyclin D1 expression level in hepatocytes on PODs 1 and 3. E. Comparison of Ki-67 expression levels among groups after PH. F. Comparison of cyclin D1 expression levels among groups after PH. G. Comparison of hepatocyte growth factor levels among groups after PH. H. Liver regeneration rates on PODs 3 and 7. PH, partial hepatectomy; TCM, traditional Chinese medicine; C group, control group; S group, sham-operated group; POD, postoperative day; HGF, hepatocyte growth factor; $^{\#}P < 0.05$, $^{ns}P > 0.05$.

denced by increased liver weight and HGF levels, and the upregulation of the key proliferative markers, Ki-67 and cyclin D1. Furthermore, this TCM protected intestinal mucosal barrier func-

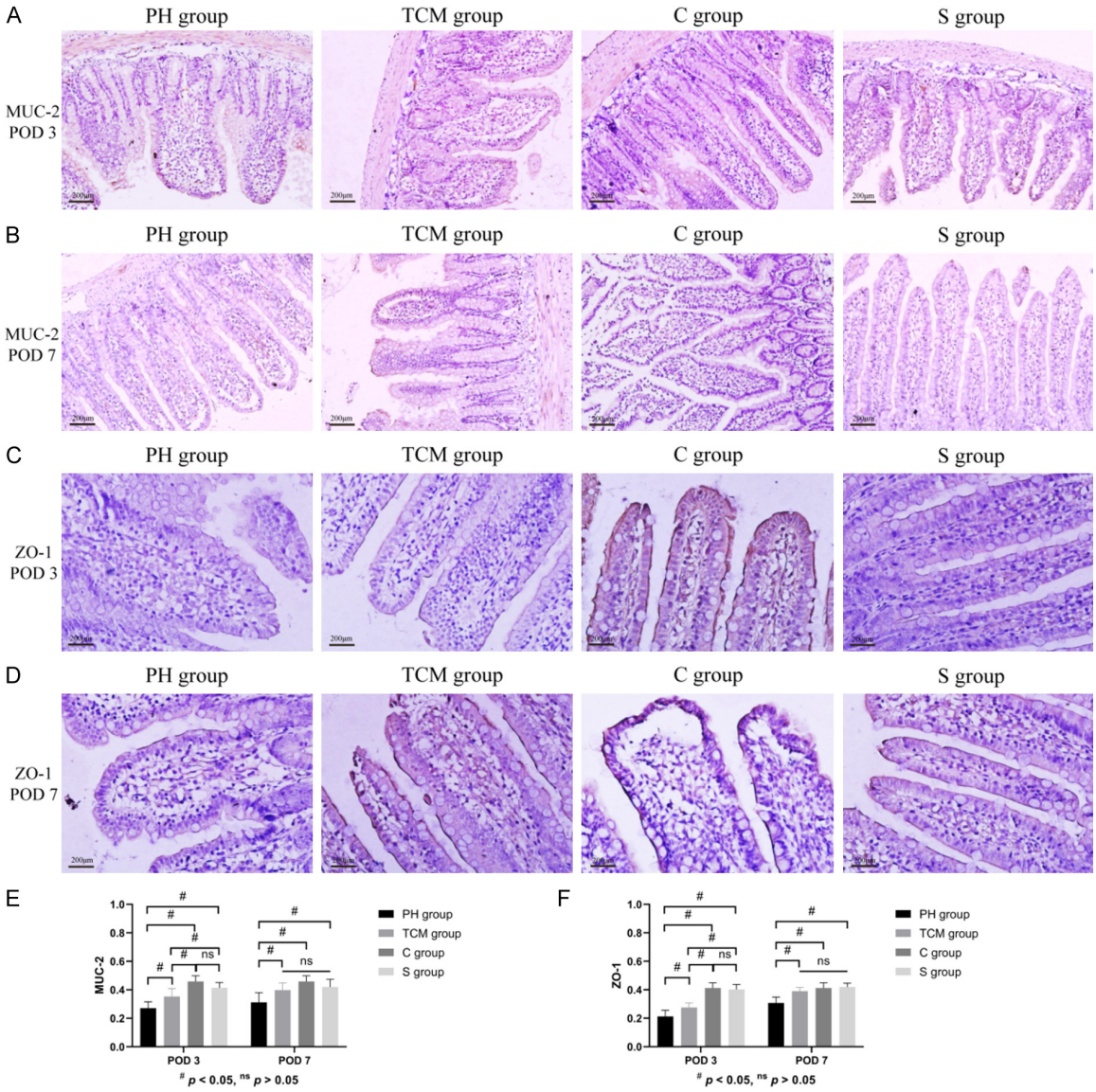

Figure 3. Intestinal mucosal barrier function. A, B. Immunohistochemical staining showing MUC-2 expression level in hepatocytes on PODs 3 and 7. C, D. Immunohistochemical staining showing ZO-1 expression level in hepatocytes on PODs 3 and 7. E. Expression of MUC-2 in the intestinal mucosa. F. Expression of ZO-1 in the intestinal mucosa. PH, partial hepatectomy; TCM, traditional Chinese medicine; C group, control group; S group, sham-operated group; POD, postoperative day; MUC-2, mucin-2; ZO-1, zonula occludens-1; $^{\#}P < 0.05$, $^{ns}P > 0.05$.

tion, as indicated by an increased expression of MUC-2 and ZO-1.

The liver plays a crucial role in metabolizing substances such as carbohydrates, fats, and proteins, and possesses remarkable regenerative capabilities [18]. Insufficient hepatic regeneration capacity following PH may lead to hepatic dysfunction, small-for-size syndrome, or even liver failure, which can be life-threatening in severe cases [19]. During the perioperative period of PH, impairment of the intestinal mucosal barrier function occurs, allowing gut microbiota and their metabolites to exacerbate liver injury via the gut-liver axis [20].

HGF is a hepatocyte mitogen that binds to HGFR/c-MET expressed in hepatocyte. Following PH, the plasma level of HGF rises rapidly and is related to the liver regenerative rates [21]. In addition, recombinant human HGF-activator was administered via the portal vein and

proliferating cell nuclear antigen labelling indices, and the liver regeneration rates were significantly higher in the rhHGF-activator group compared to control animals [22]. Consistent with our findings, on PODs 1, 3 and 7, the HGF levels were significantly higher in the TCM group than in the PH group. Additionally, other markers of hepatocyte proliferation, including liver weight and the expression of Ki-67 and cyclin D1, were markedly increased. Thus, our novel TCM formula demonstrated promising efficacy in enhancing liver regeneration following PH.

Moreover, MUC-2, secreted by goblet cells, is a key component of the intestinal mucosal barrier that plays a crucial role in preventing harmful bacteria and their products from invading the intestinal lumen [23, 24]. ZO-1 is a tight junction protein that plays a critical role in maintaining intestinal barrier integrity and permeability [25]. In our study, the expressions of MUC-2 and ZO-1 were higher in the TCM group than in the PH group, suggesting that the novel TCM formula exerted a protective effect on the intestinal mucosal barrier. Therefore, maintaining the intestinal mucosal barrier helps reduce bacterial translocation from the gut, thereby creating a more favorable microenvironment for hepatocyte regeneration.

This study presents our preliminary experience with the application of this novel formulation, and several limitations of the current work warrant careful consideration. Firstly, although the current research results have provided experimental evidence for liver regeneration in the context of liver cirrhosis, the mechanism remains unclear, which is also the focus of our next research plan. Secondly, the traditional Chinese medicine formula used in this study is composed of multiple herbal components. Although this reflects its holistic treatment concept, it also poses challenges for standardization. In the future, we will focus on the research of individual bioactive components and mechanism verification, which may help to further clarify its pharmacokinetic and pharmacodynamic effects.

Conclusion

Administration of a novel TCM formula during the perioperative period of PH enhanced liver regeneration in cirrhotic rats by providing hepatoprotection and preserving the intestinal mucosal barrier. This finding provides an innovative therapeutic strategy for improving postoperative recovery in cirrhosis patients. Future research should focus on identifying key active components and validating their efficacy and safety to advance clinical application.

Acknowledgements

This study was supported by the Shandong Provincial Clinical Key Specialty Construction Fund (No. SLCZDZK-0701) and Shandong Provincial Clinical Key Specialty Construction Project (No. SLCZDZK-2401).

Disclosure of conflict of interest

None.

Address correspondence to: Qiangpu Chen, Department of Hepatobiliary and Pancreatic Surgery, Clinical Nutrition Support Center, Binzhou Medical University Hospital, No. 661 Huanghe 2nd Road, Binzhou 256603, Shandong, China. Tel: +86-0543-3257387; E-mail: drchenqiangpu@163.com

References

[1] Allaire M, Goumard C, Lim C, Le Cleach A, Wagner M and Scatton O. New frontiers in liver resection for hepatocellular carcinoma. JHEP Rep 2020; 2: 100134.

[2] Liang BY, Gu J, Xiong M, Zhang EL, Zhang ZY, Lau WY, Wang SF, Guan Y, Chen XP and Huang ZY. Histological severity of cirrhosis influences surgical outcomes of hepatocellular carcinoma after curative hepatectomy. J Hepatocell Carcinoma 2022; 9: 633-47.

[3] Merath K, Tiwari A, Court C, Parikh A, Dillhoff M, Cloyd J, Ejaz A and Pawlik TM. Postoperative liver failure: definitions, risk factors, prediction models and prevention strategies. J Gastrointest Surg 2023; 27: 2640-2649.

[4] Shen J, Qin H, Li K, Ding H, Chen X, Peng M, Jiang X and Han Y. The angelica polysaccharide: a review of phytochemistry, pharmacology and beneficial effects on systemic diseases. Int Immunopharmacol 2024; 133: 112025.

[5] Guo R, Li L, Su J, Li S, Duncan SE, Liu Z and Fan G. Pharmacological activity and mechanism of Tanshinone IIA in related diseases. Drug Des Devel Ther 2020; 14: 4735-4748.

[6] Kil YS, Park J, Jafari M, Woo HA and Seo EK. Minor phenolics from *Angelica keiskei* and their proliferative effects on Hep3B cells. Bioorg Med Chem Lett 2017; 27: 3065-3070.

[7] Lynch SV and Pedersen O. The human intestinal microbiome in health and disease. N Engl J Med 2016; 375: 2369-2379.
[8] Milosevic I, Vujovic A, Barac A, Djelic M, Korac M, Radovanovic Spurnic A, Gmizic I, Stevanovic O, Djordjevic V, Lekic N, Russo E and Amedei A. Gut-liver axis, gut microbiota, and its modulation in the management of liver diseases: a review of the literature. Int J Mol Sci 2019; 20: 395.
[9] Marwaha K, Cain R, Asmis K, Czaplinski K, Holland N, Mayer DCG and Chacon J. Exploring the complex relationship between psychosocial stress and the gut microbiome: implications for inflammation and immune modulation. J Appl Physiol (1985) 2025; 138: 518-535.
[10] Zhou Y, Zhang D, Cheng H, Wu J, Liu J, Feng W and Peng C. Repairing gut barrier by traditional Chinese medicine: roles of gut microbiota. Front Cell Infect Microbiol 2024; 14: 1389925.
[11] Zeng Y, Liu X, Yi Q, Qiao G, Wang L, Chen L, Fan L, Li Y, Duan L, Huang L, Zhuang Q, Zhou Y and Xiong Y. Free total rhubarb anthraquinones protect intestinal mucosal barrier of SAP rats via inhibiting the NLRP3/caspase-1/GSDMD pyroptotic pathway. J Ethnopharmacol 2024; 326: 117873.
[12] Wang Y, Zhang Y, Wang Q, Fan Y, Li W, Liu M, Zhang X, Zhou W, Wang M, Jiang S, Shang E and Duan J. Multi-omics combined to explore the purging mechanism of Rhei Radix et Rhizoma and Magnoliae Officinalis Cortex. J Chromatogr B Analyt Technol Biomed Life Sci 2024; 1243: 124218.
[13] Cui L, Guan X, Ding W, Luo Y, Wang W, Bu W, Song J, Tan X, Sun E, Ning Q, Liu G, Jia X and Feng L. Scutellaria baicalensis Georgi polysaccharide ameliorates DSS-induced ulcerative colitis by improving intestinal barrier function and modulating gut microbiota. Int J Biol Macromol 2021; 166: 1035-1045.
[14] Nair AB and Jacob S. A simple practice guide for dose conversion between animals and human. J Basic Clin Pharm 2016; 7: 27-31.
[15] Chowdhury AB and Mehta KJ. Liver biopsy for assessment of chronic liver diseases: a synopsis. Clin Exp Med 2023; 23: 273-285.
[16] Holländer S, von Heesen M, Gäbelein G, Mercier J, Laschke MW, Menger MD, Glanemann M and Spiliotis AE. Perioperative treatment with cilostazol reverses steatosis and improves liver regeneration after major hepatectomy in a steatotic rat model. Sci Rep 2025; 15: 2753.
[17] Sumer F, Colakoglu MK, Ozdemir Y, Ozsay O, İlter O, Bostanci EB and Akoglu M. Effect of nebivolol on liver regeneration in an experimental 70% partial hepatectomy model. Asian J Surg 2017; 40: 375-379.
[18] Solhi R, Lotfinia M, Gramignoli R, Najimi M and Vosough M. Metabolic hallmarks of liver regeneration. Trends Endocrinol Metab 2021; 32: 731-745.
[19] Riddiough GE, Christophi C, Jones RM, Muralidharan V and Perini MV. A systematic review of small for size syndrome after major hepatectomy and liver transplantation. HPB (Oxford) 2020; 22: 487-496.
[20] Zhang Y, Xu L and Xu M. The significance of severe postoperative complications on liver regeneration. Hepatobiliary Surg Nutr 2023; 12: 978-980.
[21] Zhao Y, Ye W, Wang YD and Chen WD. HGF/c-Met: a key promoter in liver regeneration. Front Pharmacol 2022; 13: 808855.
[22] Hoffmann K, Nagel AJ, Tanabe K, Fuchs J, Dehlke K, Ghamarnejad O, Lemekhova A and Mehrabi A. Markers of liver regeneration-the role of growth factors and cytokines: a systematic review. BMC Surg 2020; 20: 31.
[23] Gustafsson JK and Johansson MEV. The role of goblet cells and mucus in intestinal homeostasis. Nat Rev Gastroenterol Hepatol 2022; 19: 785-803.
[24] Paone P and Cani PD. Mucus barrier, mucins and gut microbiota: the expected slimy partners? Gut 2020; 69: 2232-2243.
[25] Kuo WT, Zuo L, Odenwald MA, Madha S, Singh G, Gurniak CB, Abraham C and Turner JR. The tight junction protein ZO-1 is dispensable for barrier function but critical for effective mucosal repair. Gastroenterology 2021; 161: 1924-1939.