

University of Groningen

## Evidence-Based Recommendations to Improve the Safe Use of Drugs in Patients with Liver Cirrhosis

Weersink, Rianne A; Bouma, Margriet; Burger, David M; Drenth, Joost P H; Harkes-Idzinga, S Froukje; Hunfeld, Nicole G M; Metselaar, Herold J; Monster-Simons, Margje H; Taxis, Katja; Borgsteede, Sander D

*Published in:*  
Drug Safety

*DOI:*  
[10.1007/s40264-017-0635-x](https://doi.org/10.1007/s40264-017-0635-x)

**IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.**

*Document Version*  
Publisher's PDF, also known as Version of record

*Publication date:*  
2018

[Link to publication in University of Groningen/UMCG research database](#)

### *Citation for published version (APA):*

Weersink, R. A., Bouma, M., Burger, D. M., Drenth, J. P. H., Harkes-Idzinga, S. F., Hunfeld, N. G. M., Metselaar, H. J., Monster-Simons, M. H., Taxis, K., & Borgsteede, S. D. (2018). Evidence-Based Recommendations to Improve the Safe Use of Drugs in Patients with Liver Cirrhosis. *Drug Safety*, 41(6), 603-613. <https://doi.org/10.1007/s40264-017-0635-x>

### **Copyright**

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

### **Take-down policy**

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

# Evidence-Based Recommendations to Improve the Safe Use of Drugs in Patients with Liver Cirrhosis

Rianne A. Weersink<sup>1,2</sup> · Margriet Bouma<sup>3</sup> · David M. Burger<sup>4</sup> · Joost P. H. Drenth<sup>5</sup> · S. Froukje Harkes-Idzinga<sup>6</sup> · Nicole G. M. Hunfeld<sup>7</sup> · Herold J. Metselaar<sup>8</sup> · Margje H. Monster-Simons<sup>9,10</sup> · Katja Taxis<sup>2</sup> · Sander D. Borgsteede<sup>1,11</sup>

Published online: 12 January 2018  
© The Author(s) 2018. This article is an open access publication

## Abstract

**Introduction** The presence of liver cirrhosis can have a major impact on pharmacodynamics and pharmacokinetics, but guidance for prescribing is lacking.

**Objective** The aim of this study is to provide an overview of evidence-based recommendations developed for the safe use of drugs in liver cirrhosis.

**Methods** Recommendations were based on a systematic literature search combined with expert opinion from a panel of 10 experts. The safety of each drug was classified as safe, no additional risks known, additional risks known, unsafe, unknown or the safety class was dependent on the severity of liver cirrhosis (Child–Pugh classification). If applicable, drug-specific dosing advice was provided. All recommendations were implemented in clinical decision support systems and on a website.

**Results** We formulated 218 recommendations for a total of 209 drugs. For nine drugs, two recommendations were formulated for different administration routes or indications. Drugs were classified as ‘safe’ in 29 recommendations (13.3%), ‘no additional risks known’ in 60 (27.5%), ‘additional risks known’ in 3 (1.4%), and ‘unsafe’ in 30 (13.8%). In 57 (26.1%) of the recommendations, safety depended on the severity of liver cirrhosis and was ‘unknown’ in 39 (17.9%) recommendations. Large alterations in pharmacodynamics were the main reason for classifying a drug as ‘unsafe’. For 67 drugs (31%), a dose adjustment was needed.

**Conclusions** Over 200 recommendations were developed for the safe use of drugs in patients with liver cirrhosis. Implementing these recommendations into clinical practice can possibly enhance medication safety in this vulnerable patient group.

**Electronic supplementary material** The online version of this article (<https://doi.org/10.1007/s40264-017-0635-x>) contains supplementary material, which is available to authorized users.

✉ Rianne A. Weersink  
rienne.weersink@healthbase.nl

- <sup>1</sup> Department of Clinical Decision Support, Health Base Foundation, Houten, The Netherlands
- <sup>2</sup> Department of Pharmacy, Unit of Pharmacotherapy, Epidemiology and Economics, University of Groningen, Groningen, The Netherlands
- <sup>3</sup> Department of Guideline Development, Dutch College of General Practice, Utrecht, The Netherlands
- <sup>4</sup> Department of Pharmacy, Radboud University Medical Center, Nijmegen, The Netherlands
- <sup>5</sup> Department of Gastroenterology, Radboud University Medical Center, Nijmegen, The Netherlands

- <sup>6</sup> Center for Information on Medicines, Royal Dutch Pharmacists Association (KNMP), The Hague, The Netherlands
- <sup>7</sup> Department of Pharmacy and Department of Intensive Care, Erasmus University Medical Center, Rotterdam, The Netherlands
- <sup>8</sup> Department of Gastroenterology and Hepatology, Erasmus University Medical Center, Rotterdam, The Netherlands
- <sup>9</sup> Dutch Medicines Evaluation Board, Utrecht, The Netherlands
- <sup>10</sup> Department of Clinical Pharmacy and Pharmacology, University of Groningen, Groningen, The Netherlands
- <sup>11</sup> SIR Institute for Pharmacy Practice and Policy, Leiden, The Netherlands

## Key Points

With a previously developed method, the safety and optimal dosing of more than 200 drugs in patients with liver cirrhosis were evaluated. In this study an overview of the recommendations is given.

For the majority of the evaluated drugs, changes in pharmacokinetics or pharmacodynamics occurred in patients with liver cirrhosis. Overall, 30% of drugs required dose adjustment and nearly 70 drugs were classified as unsafe in (a stage of) liver cirrhosis.

Healthcare professionals in The Netherlands are supported during the prescription or dispensing of drugs to patients with liver cirrhosis by alerts from their clinical decision support system and information on a free website.

## 1 Introduction

Adverse drug reactions (ADRs) are an important cause of morbidity and mortality worldwide [1, 2]. Patients with hepatic impairment have an increased risk of adverse outcomes with drug use due to the pharmacokinetic and pharmacodynamic changes occurring in liver disease [3, 4]. Most significant are the diminished first-pass effect caused by altered liver blood flow and the decreased activity of drug-metabolizing enzymes. Both result in a higher drug exposure and an increased risk of concentration-dependent ADRs. Furthermore, pathophysiological changes in patients with hepatic impairment increase the risk of specific ADRs, such as renal dysfunction or hepatic encephalopathy [5]. These alterations are considered to be clinically relevant when the liver disease has progressed to liver cirrhosis [3].

Almost 30% of patients with liver cirrhosis experience ADRs; 80% of the ADRs could probably be prevented [6]. Choosing appropriate drugs and doses for these patients is very important, especially because they often use multiple drugs [6, 7]. Practice guidelines can support healthcare professionals in safe prescribing and can reduce the number of inappropriate drug prescriptions, as seen in other patient populations such as older people [8]. For patients with liver cirrhosis, literature regarding pharmacokinetic alterations for several drugs is available [5, 9–12]; however, we were not aware of a publicly available practice guideline providing recommendations on the safe use of specific drugs in liver cirrhosis [13]. We therefore

developed a systematic method to evaluate the safety and dosing of medications to provide recommendations for safe drug use in patients with liver cirrhosis [14]. The aim of this study is to provide an overview of the recommendations for safe drug use for 208 drugs that have been evaluated.

## 2 Methods

In this study, we used our previously published method to evaluate the safety and dosing of medications to provide recommendations for safe drug use in patients with liver cirrhosis [14]. This method consists of six steps per drug, as described below. Overall, we evaluated 209 drugs, which were chosen because they were (1) often prescribed for complications of liver cirrhosis, or (2) frequently used in the general population.

### 2.1 Step 1: Collection of Evidence

Data regarding the safety and pharmacokinetics of the drug of interest in patients with liver cirrhosis were collected. This evidence was collected in the official Dutch and American product information and in the literature. The literature searches for publications were conducted in PubMed and EMBASE between January and October 2016, and no language restrictions were applied. Studies were included if they related to patients with liver cirrhosis taking the drug of interest and if they reported on outcome data on safety or pharmacokinetics. Citation tracking was used in the Web of Science database to retrieve additional relevant studies.

### 2.2 Step 2: Data Extraction and Presentation

The following data were extracted from the studies: study design, number and characteristics of included patients and controls (e.g. severity of liver cirrhosis), and information on the intervention. We extracted the following information on outcome(s):

- Pharmacokinetics: pharmacokinetic parameters (e.g. area under the curve [AUC], maximum plasma concentration [ $C_{max}$ ])
- Safety: number and type of adverse events and data on discontinuation due to these adverse events

Literature was presented in summary tables and sorted by level of evidence using the classification of the Oxford Centre for Evidence-based Medicine [15]. All evidence was included in an assessment report.

### 2.3 Step 3: Initial Safety Classification and Dosing Advice

The collected data were used to propose an initial safety classification and dosing advice if applicable. The safety classification (Table 1) was designed to help healthcare professionals efficiently judge the safety of a drug in liver cirrhosis. We added the classification ‘safety class is dependent on severity of cirrhosis’ to the earlier developed classifications (see Table 1) [14]. Pharmacokinetic data were used for the dosing advice. In general, this was advised if the AUC was more than doubled. If the pharmacokinetic alterations were so large that dose reductions were unlikely to allow safe drug use, drugs were classified as ‘unsafe’. The dosing advice could also depend on the severity of liver cirrhosis, expressed as Child–Pugh class (i.e. Child–Pugh A, B or C) [16].

These first three steps were performed by a pharmacist with expertise in drug safety and clinical decision support systems (CDSSs) (RW). Critical steps were verified by a second pharmacist/epidemiologist (SB) and discussed with the expert panel in cases of disagreement.

### 2.4 Step 4: Consensus of Recommendations by an Expert Panel

An expert panel was composed consisting of 10 members with expertise in the treatment of patients with liver cirrhosis, clinical pharmacology and/or evidence-based medicine. The expert panel evaluated the validity and clinical relevance of the proposed safety classification and dosing advice. The panel concluded by consensus. The final assessment report consisted of the recommendations, supporting evidence and considerations of the expert panel.

### 2.5 Step 5: Implementation

The recommendations were implemented in all relevant CDSSs in The Netherlands (G-standard and Pharmabase), automatically reaching all pharmacists and numerous general practitioners. If an evaluated medicine was prescribed or dispensed to a patient marked with contraindication ‘liver cirrhosis’, an alert was generated with a short recommendation. Healthcare professionals were referred to a website for more information (<http://www.geneesmiddelenbijlevercirrose.nl>). This free website also contained a part aimed at patients.

**Table 1** Safety classification with recommended actions [14] Adapted from Weersink et al. [14]

Safety class	Description	Action
Safe	The drug has been evaluated in patients with liver cirrhosis, and no increase in harm was found compared with persons without liver cirrhosis. The safety of the drug is supported by pharmacokinetic studies and/or safety studies over a long period. It might be necessary to use an adjusted dose	This drug can be used in patients with liver cirrhosis
No additional risks known	The limited data suggest that this drug does not increase harm in patients with liver cirrhosis in comparison with persons without liver cirrhosis. It might be necessary to use an adjusted dose	The drug can be used in patients with liver cirrhosis Adverse drug reactions need to be monitored
Additional risks known	The limited data suggest an increase in patient harm in patients with liver cirrhosis compared with persons without liver cirrhosis. However, the number of studies is limited and/or the studies show contradicting results regarding the safety in patients with liver cirrhosis	This drug should preferably not be used in patients with liver cirrhosis if there is a safer alternative available Adverse drug reactions need to be monitored
Unsafe	Data indicate this drug is not safe in patients with liver cirrhosis	This drug should be avoided in patients with liver cirrhosis
Unknown	For this drug, insufficient data are available to evaluate the safety in patients with liver cirrhosis	This drug should preferably not be used in patients with liver cirrhosis if there is a safer alternative available Individual judgement of therapeutic need versus additional risks in patients with liver cirrhosis Adverse drug reactions need to be monitored
Safety class is dependent on the severity of cirrhosis	The safety class and/or the dose adjustment of this drug depends on the severity of liver cirrhosis of the patient, expressed by Child–Pugh class	Retrieve severity of liver cirrhosis (Child–Pugh class)

## 2.6 Step 6: Continuity

To ensure that recommendations remain up-to-date, the expert panel will meet yearly to discuss new literature and comments from healthcare professionals and patients. If necessary, recommendations will be updated.

## 2.7 Analyses

We determined the total number of recommendations for the 209 drugs evaluated. We also determined the number of drugs per safety class and the number of drugs with dosing advice. It is outside the scope of this paper to show the complete evidence-base we gathered during evaluation of the 209 drugs. To give insight into the type and extent of evidence available, we selected two drugs from every safety class. For these drugs, we described the evidence supporting the classification. This consisted of the number of pharmacokinetic and safety studies and the number of included patients with liver cirrhosis. We also included information on whether the Summary of Product Characteristics (SmPC) contained information on use of the drug in patients with liver cirrhosis.

## 3 Results

The safety of 209 drugs in patients with liver cirrhosis was evaluated. A total of 218 recommendations were formulated as nine drugs had a different recommendation per route of administration or per indication. Figure 1 represents an overview of the recommendations. Twenty-nine drugs were classified as ‘safe’ (13.3%), 60 as ‘no additional risks known’ (27.5%), 3 as ‘additional risks known’ (1.4%), and 30 as ‘unsafe’ (13.8%). In 57 (26.1%) of the recommendations, safety depended on the severity of liver cirrhosis, and was ‘unknown’ in 39 (17.9%) recommendations. In Table 2, all recommendations are presented. Table 3 shows examples of the evidence supporting the classification of two drugs per safety class. Besides evidence from literature, the last column displays information from the SmPC, which was often lacking or not specifically aimed at patients with liver cirrhosis. The recommendations were successfully implemented in the relevant CDSSs in The Netherlands and on a website.

For 57 drugs, the recommendation depended on the severity of liver cirrhosis, and dosing advice was given for 67 drugs (Fig. 1). The drug simvastatin illustrates the recommendations that were given in such cases. Simvastatin was classified as ‘safe’ for patients with liver cirrhosis Child–Pugh class A or B, under the condition that the patient is started on a low dose (20 mg) and the dose is slowly increased until in the therapeutic range or until

ADRs develop. Because of a lack of studies in patients with Child–Pugh class C, the safety of simvastatin was classified as unknown for patients with Child–Pugh class C and no dosing advice was given. All recommendations that depended on the severity of liver cirrhosis, and those with dosing advice, can be found in electronic supplementary Tables 1 and 2, respectively.

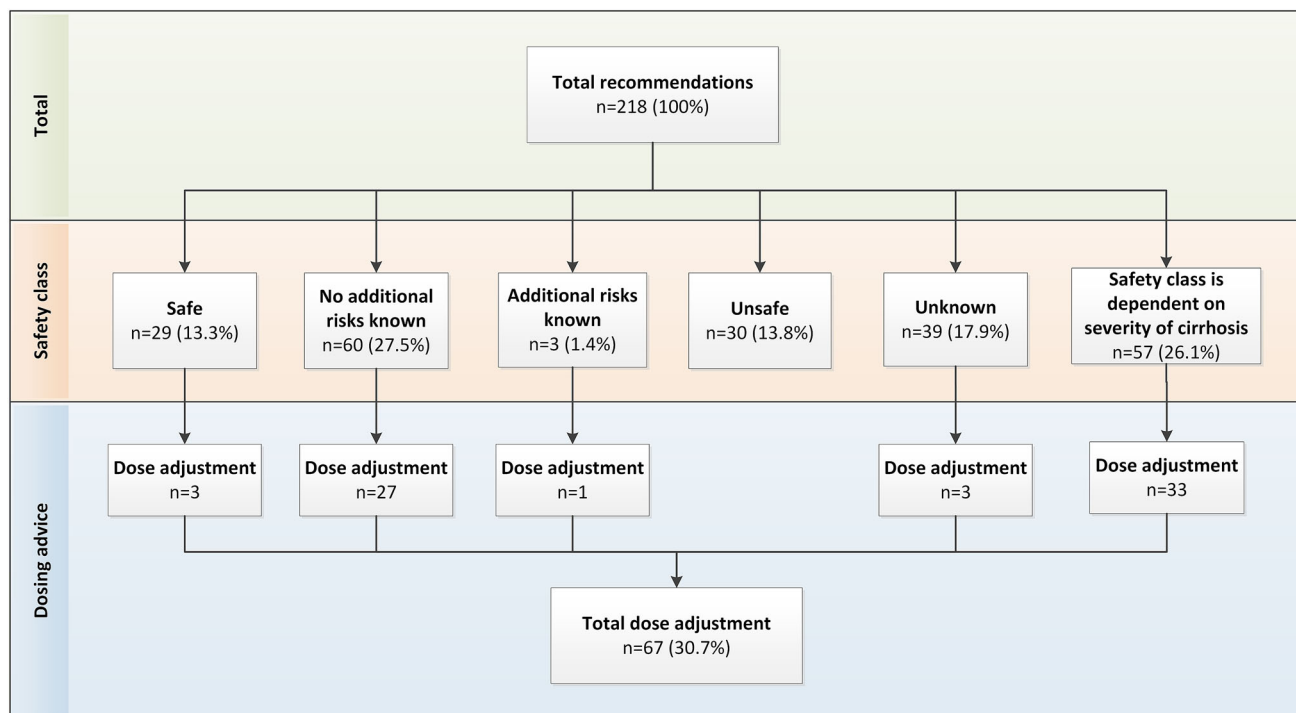
We recommended avoiding the use of 30 drugs (classification ‘unsafe’) in all patients with liver cirrhosis. Another 38 drugs were considered unsafe as related to certain Child–Pugh classes ( $n = 9$  Child–Pugh B + C, and  $n = 29$  Child–Pugh C) because of altered pharmacodynamics ( $n = 41$ ), altered pharmacokinetics ( $n = 24$ ), or a combination of both ( $n = 3$ ). Examples of drugs contraindicated because of altered pharmacodynamics were all nonsteroidal anti-inflammatory drugs (NSAIDs). Literature showed that patients with cirrhosis have an increased risk of renal insufficiency with NSAID use compared with healthy controls with more severe consequences. Even so, cirrhotic patients are at risk for gastrointestinal bleeding. Examples of drugs contraindicated due to altered pharmacokinetics were several calcium antagonists (i.e. barnidipine, isradipine). Most calcium antagonists are highly cleared by the liver, resulting in largely increased exposure in patients with cirrhosis compared with healthy controls.

## 4 Discussion

In this study, we provide an overview of 218 evidence-based recommendations developed to improve safe drug use in patients with liver cirrhosis. Overall, 30% of drugs required dose adjustment and nearly 70 drugs were classified as unsafe in (a stage of) liver cirrhosis. The main reason for unsafe classification were pharmacodynamic changes. The recommendations were implemented in all relevant CDSSs in The Netherlands. In addition, all recommendations are available on a free website (<http://www.geneesmiddelenbijlevercirrose.nl>).

In this study, we tried to tackle the problem of insufficient information on safe prescribing in patients with liver cirrhosis. A number of comparable studies are available [5, 9–12]. Most focus on altered pharmacokinetics, while we show that pharmacodynamic changes are also relevant in the decision process. This study is therefore unique in using both pharmacokinetic and pharmacodynamic (safety) literature to develop recommendations.

An important source of prescribing information is the product information (SmPC). We noted a lack of information on liver cirrhosis in the product information, which was also recognized in a study from 2001 that classified the SmPC information on liver disease as “often inconsistent, unclear and unhelpful” [17]. Since 2003 and 2005, the



**Fig. 1** Overview of evidence-based recommendations. Results are expressed as a percentage of the total number of recommendations

FDA and EMA, respectively, published guidelines for pharmacokinetic research in patients with hepatic impairment and how to present this data in the product information [18, 19]. For further research it would be interesting to study the quality of the information in these new SmPCs. In addition, many agents were licensed before 2003–2005 and these product labels require updating based on these new guidelines [18, 19].

We developed and published the safety classification we used to support healthcare professionals to efficiently judge the safety of a drug in liver cirrhosis [14]. In our original safety classification, there was also an option for classifying drugs cleared for <20% by the liver as ‘no additional risks known’, although no data were available. Based on the important influence of pharmacodynamics, the expert panel specified this to locally-acting drugs with no systemic uptake (bioavailability [ $F$ ] <1%, not based on an extensive first-pass effect). The classification of drugs was not always easy as the following two examples show. Codeine is a prodrug that requires liver metabolism for conversion to the active drug and it can be expected that efficacy will decrease with the increasing severity of liver cirrhosis. Azathioprine was associated with increased adverse events in patients with liver cirrhosis, but is also one of the only effective treatments for autoimmune hepatitis. Our recommendation therefore includes explanations in which we try to deal with such issues by comprehensively discussing the details of the classification of a drug.

The recommendations were implemented on a website and in all relevant CDSSs in The Netherlands. The implementation revealed issues that need attention. First, patients with liver cirrhosis need to be correctly marked in the CDSSs. In The Netherlands, the contraindication ‘hepatic impairment’ was always used for this purpose; however, we noted that most of the patients marked with this contraindication did not have liver cirrhosis, causing an incorrect signal in the CDSSs. Another difficulty is that in a substantial part of the recommendations, the severity of liver cirrhosis needs to be known (i.e. Child–Pugh class). Before these recommendations can be used, gastroenterologists need to determine the Child–Pugh class of their patients and communicate this to the general practitioner and pharmacist. These difficulties are also recognized in literature about implementing contraindications into a CDSS [20] and are important to consider when setting up medication monitoring via a CDSS for these patients.

This study has its limitations. Although we evaluated 209 drugs, this is only a proportion of all drugs available. The choice for these drugs was based on an estimation of the most frequently used drugs in patients with liver cirrhosis and is in good agreement with the literature [21, 22]. We aim to eventually evaluate all drugs. Another limitation is the amount of literature available. As stated in Table 3, for some drugs there were several studies performed in patients with liver cirrhosis, while for others, there were only a few or no studies. Because of the limited literature,

**Table 2** Overview of the 218 recommendations. Details on the supporting evidence for the recommendations and expert considerations can be found at <http://www.geneesmiddelenbijlevercircrose.nl>

Drug class		Safety class				Dependent on the severity of cirrhosis	
		Safe	Unsafe	Unknown			
		No additional risks known	Additional risks known	Unsafe	Unknown	Dependent on the severity of cirrhosis	
Analgesics, mild	Paracetamol	Tramadol <sup>a</sup>		All COX-2-inhibitors <sup>b</sup> All NSAIDs <sup>b</sup>		Codeine <sup>c</sup>	
Analgesics, strong		Buprenorphine <sup>a</sup> Morphine (PO + IV) <sup>a</sup> Oxycodone <sup>a</sup> Remifentanyl Sufentanyl Moxifloxacin	Methodone		Hydromorphone (PO) <sup>a</sup> Hydromorphone (IV) Nalbuphine Nicomorphine Pitramide <sup>a</sup> Levofloxacin Pipemidic acid	Alfentanil Fentanyl <sup>a</sup> Pethidine Tapentadol <sup>a,d</sup>	
Antibiotics, chinolones	Ciprofloxacin Norfloxacin Ofloxacin						
Antibiotics, penicillins	Amoxicillin Amoxicillin/clavulanic acid	Piperacillin/tazobactam			Benzylpenicillin Flucloxacillin Phenethicillin Phenoxyethylpenicillin Doxycycline Minocycline Tetracycline Sulfadiazine Sulfametrole/trimethoprim	Tigecycline <sup>a</sup>	
Antibiotics, tetracyclines							
Antibiotics, sulfonamides and trimethoprim		Sulfamethoxazole/trimethoprim Trimethoprim Azithromycin Clarithromycin Erythromycin Roxithromycin <sup>a</sup> Clindamycin <sup>a</sup> Fosfomycin (PO)					
Antibiotics, macrolides							
Antibiotics, other	Rifaximin				Fosfomycin (IV) Nitrofurantoin		

Table 2 continued

Drug class	Safety class	No additional risks known	Additional risks known	Unsafe	Unknown	Dependent on the severity of cirrhosis
Antidiabetic drugs	Safe					
	Acarbose	Dapagliflozin <sup>a</sup>				Alogliptin
	Insulin	Empagliflozin				Canagliflozin
	Metformin	Glibenclamide <sup>a</sup>				Repaglinide <sup>a</sup>
	Tolbutamide <sup>a</sup>	Gliclazide <sup>a</sup>				Sitagliptin
		Glimepiride <sup>a</sup>				
Anti-hepatitis B	Adefovir	Linagliptin				Interferon- $\alpha$ -2a <sup>c</sup>
	Entecavir	Pioglitazone <sup>a</sup>				Interferon- $\alpha$ -2b <sup>c</sup>
	Lamivudine	Saxagliptin				Peginterferon- $\alpha$ -2a <sup>c</sup>
	Telbivudine	Vildagliptin				Peginterferon- $\alpha$ -2b <sup>c</sup>
	Tenofovir					Dasabuvir <sup>d</sup>
Anti-hepatitis C		Daclatasvir				Elbasvir/grazoprevir <sup>c</sup>
		Ledipasvir				Ombitasvir/paritaprevir/ritonavir <sup>d</sup>
		Sofosbuvir				Ribavirin
		Velpatasvir				Simeprevir <sup>c</sup>
						Metoprolol <sup>a,d</sup>
$\beta$ -Blockers	Atenolol	Acebutolol		Nebivolol	Celiprolol	
	Carvedilol <sup>a</sup>	Bisoprolol <sup>a</sup>			Pindolol	
	Propranolol <sup>a</sup>	Esmolol				
		Labetalol (PO) <sup>a</sup>				
		Labetalol (IV)				
Calcium channel blockers		Sotalol				
		Amlodipine <sup>a</sup>		Barnidipine	Lacidipine <sup>a</sup>	Felodipine <sup>a,d</sup>
		Nifedipine <sup>a</sup>		Isradipine	Nicardipine (IV)	Lercanidipine <sup>d</sup>
		Nimodipine (PO) <sup>a</sup>		Nicardipine (PO)	Nimodipine (IV)	
				Nitrendipine		
Calcium channel blockers, other		Diltiazem <sup>a</sup>				Verapamil (PO) <sup>a,d</sup>
						Verapamil (IV) <sup>a,d</sup>



Table 2 continued

Drug class	Safety class		Additional risks known	Unsafe	Unknown	Dependent on the severity of cirrhosis
	Safe	No additional risks known				
Coumarins		Acenocoumarol <sup>a</sup> Phenprocoumon <sup>a</sup>				
Diuretics	Furosemide Spironolactone	Amiloride Bumetanide Eplerenone Hydrochlorothiazide	Triamterene		Chlorthalidone Epitizide Indapamide	
Drugs for acid-related disorders		Esomeprazole <sup>c</sup> Famotidine Ranitidine	Cimetidine Lansoprazole Pantoprazole		Algedrate/magnesium oxide Algedrate/magnesium oxide/ dimethicone Aluminium hydroxide/magnesium carbonate Calcium carbonate/magnesium carbonate Nizatidine	Omeprazole <sup>a,d</sup> Rabeprazole <sup>a,d</sup>
Drugs used in hepatorenal syndrome	Albumin					
Drugs used in PBC or AIH	Terlipressin Prednisolone Prednisone Ursodeoxycholic acid			Budesonide		Mycophenolate mofetil
Heparins		Dalteparin <sup>a</sup> Enoxaparin <sup>a</sup> Nadroparin <sup>a</sup>			Tinzaparin	
Laxant drugs	Lactitol Lactulose	Bisacodyl Macrogol Macrogol/electrolytes Psyllium Sterculia			Magnesium (hydr)oxide Senna Sennosides A + B Sodium picosulfate	

Table 2 continued

Drug class	Safety class					Dependent on the severity of cirrhosis
	Safe	No additional risks known	Additional risks known	Unsafe	Unknown	
Lipid-lowering agents	Colestyramine	Colesevelam		Atorvastatin	Ciprofibrate Fenofibrate Acipimox	Bezafibrate Ezetimibe <sup>c</sup> Fluvastatin <sup>a</sup> Gemfibrozil Lomitapide <sup>a,c</sup> Pravastatin <sup>a</sup> Rosuvastatin <sup>a</sup> Simvastatin <sup>a</sup> Clopidogrel <sup>d</sup> Dipyridamole Prasugrel Ticagrelor Domperidone <sup>a,d</sup> All ACE inhibitors <sup>b,d</sup> All AT-II antagonists <sup>b,d</sup>
Platelet aggregation inhibitors		Acetylsalicylic acid <sup>a</sup> Carbasalate calcium <sup>a</sup>				
Prokinetics		Metoclopramide <sup>a</sup>				
RAS inhibitors						

ACE angiotensin-converting enzyme, *AIH* autoimmune hepatitis, *AT* angiotensin, *COX* cyclooxygenase, *IV* intravenous, *NSAIDs* nonsteroidal antiinflammatory drugs, *PBC* primary biliary cholangitis, *PO* oral, *RAS* renin-angiotensin system

<sup>a</sup>Dose adjustment also necessary

<sup>b</sup>The advice is applicable to all drugs from the class

<sup>c</sup>Unsafe in Child–Pugh B and C

<sup>d</sup>Unsafe in Child–Pugh C

**Table 3** Collected evidence for classifying the safety of drugs in patients with liver cirrhosis

Drug	Safety class	Pharmacokinetic literature			Safety literature			SmPC
		Studies	Level of evidence	Cirrhotic participants	Studies	Level of evidence	Cirrhotic participants	Recommendation for cirrhosis given?
Furosemide	Safe	6	3, 4	52	16	2	374	Yes
Lactulose	Safe	1	3	26	8	1	>750	No
Macrogole	No additional risks known	1	3	53	3	2, 3	89	No
Bumetanide	No additional risks known	1	3	8	5	2, 3	81	Yes
Azathioprine	Additional risks known	0	NA	NA	7	3, 5	80	Yes
Methadone	Additional risks known	2	3	21	4	4	13	Yes
Triamterene	Unsafe	2	3, 4	11	2	4	3	Yes
Nebivolol	Unsafe	1	4	0	1	2	10	No
Acipimox	Unknown	0	NA	NA	0	NA	NA	No
Nitrofurantoin	Unknown	0	NA	NA	1	3	4	No

Two examples of drugs per safety class are shown

NA not applicable, *SmPC* Summary of Product Characteristics

39 drugs were classified as ‘unknown’, including frequently used drugs such as nitrofurantoin. As the recommendations are evidence-based, more research will improve the quality of the recommendations and can better support healthcare professionals. For now, the literature review per drug identifies knowledge gaps and is a good starting point for further research. A third limitation is that the complete recommendations with detailed explanations are currently only available in the Dutch language. Nevertheless, in this study, we provided an overview in English and plan to translate the recommendations in the future.

## 5 Conclusions

In this study, we provided evidence-based recommendations to aid in prescribing for patients with liver cirrhosis. This is the first study that applies a practical approach providing recommendations that have been implemented in all relevant CDSSs in The Netherlands and on a website. Our advice aids healthcare professionals in tailoring pharmacotherapy for the individual patient with liver cirrhosis, which can possibly prevent ADRs and subsequent morbidity and mortality in vulnerable cirrhotic patients.

**Acknowledgements** The authors would like to thank Minke Kranenborg, Ton Lisman, Eline Okel, Sandra van Putten and Elise Smolders for their contributions.

## Compliance with Ethical Standards

**Funding** This work was supported by ZonMw GGG-STIP Grant number 836044009. ZonMw is the Dutch national organisation for health research and healthcare innovation.

**Conflict of interest** Rianne A. Weersink, Margriet Bouma, David M. Burger, Joost P.H. Drenth, S. Froukje Harkes-Idzinga, Nicole G.M. Hunfeld, Herold J. Metselaar, Margje H. Monster-Simons, Katja Taxis and Sander D. Borgsteede have no conflicts of interest directly relevant to the content of this article.

**Open Access** This article is distributed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (<http://creativecommons.org/licenses/by-nc/4.0/>), which permits any noncommercial use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

## References

1. Thomsen LA, Winterstein AG, Søndergaard B, Haugbølle LS, Melander A. Systematic review of the incidence and characteristics of preventable adverse drug events in ambulatory care. *Ann Pharmacother*. 2007;41(9):1411–26.
2. Pirmohamed M, James S, Meakin S, Green C, Scott AK, Walley TJ, et al. Adverse drug reactions as cause of admission to hospital: prospective analysis of 18,820 patients. *BMJ*. 2004;329(7456):15–9.

3. Verbeeck RK. Pharmacokinetics and dosage adjustment in patients with hepatic dysfunction. *Eur J Clin Pharmacol.* 2008;64(12):1147–61.
4. Delco F, Tchambaz L, Schlienger R, Drewe J, Krahenbuhl S. Dose adjustment in patients with liver disease. *Drug Saf.* 2005;28(6):529–45.
5. Westphal J, Brogard J. Drug administration in chronic liver disease. *Drug Saf.* 1997;17(1):47–73.
6. Franz CC, Hildbrand C, Born C, Egger S, Bravo AER, Krähenbühl S. Dose adjustment in patients with liver cirrhosis: impact on adverse drug reactions and hospitalizations. *Eur J Clin Pharmacol.* 2013;69(8):1565–73.
7. Lucena IM, Andrade RJ, Tognoni G, Hidalgo R, de la Cuesta F. Multicenter hospital study on prescribing patterns for prophylaxis and treatment of complications of cirrhosis. *Eur J Clin Pharmacol.* 2002;58(6):435–40.
8. Zhang YJ, Liu WW, Wang JB, Guo JJ. Potentially inappropriate medication use among older adults in the USA in 2007. *Age Ageing.* 2011;40(3):398–401.
9. Schlatter C, Egger SS, Tchambaz L, Krähenbühl S. Pharmacokinetic changes of psychotropic drugs in patients with liver disease. *Drug Saf.* 2009;32(7):561–78.
10. Lewis JH, Stine JG. Review article: prescribing medications in patients with cirrhosis - a practical guide. *Aliment Pharmacol Ther.* 2013;37(12):1132–56.
11. Steelandt J, Jean-Bart E, Goutelle S, Tod M. A Prediction Model of Drug Exposure in Cirrhotic Patients According to Child-Pugh Classification. *Clin Pharmacokinet.* 2015;54(12):1245–58.
12. Rodighiero V. Effects of liver disease on pharmacokinetics. *Clin Pharmacokinet.* 1999;37(5):399–431.
13. Hilscher M, Odell L, Myhre L, Prokop L, Talwalkar J. The pharmacotherapy of cirrhosis: concerns and proposed investigations and solutions. *J Clin Pharm Ther.* 2016;41(6):587–91.
14. Weersink RA, Bouma M, Burger DM, Drenth JP, Hunfeld NG, Kranenborg M, et al. Evaluating the safety and dosing of drugs in patients with liver cirrhosis by literature review and expert opinion. *BMJ Open.* 2016;6(10):e012991.
15. OCEBM Levels of Evidence Working Group. The Oxford Levels of Evidence 2. Oxford Centre for Evidence-Based Medicine. Available at: <http://www.cebm.net/index.aspx?0=5653>. Accessed 2 Mar 2017.
16. Pugh RN, Murray-Lyon IM, Dawson JL, Pietroni MC, Williams R. Transection of the oesophagus for bleeding oesophageal varices. *Br J Surg.* 1973;60(8):646–9.
17. Failings in treatment advice. SPCs and black triangles. *Drug Ther Bull.* 2001;39(4):25–7.
18. Food and Drug Administration. Guidance for Industry. Pharmacokinetics in Patients with Impaired Hepatic Function: Study Design, Data Analysis, and Impact on Dosing and Labeling. 2008. Available at: <https://www.fda.gov/downloads/Drugs/GuidanceComplianceRegulatoryInformation/Guidances/ucm072123.pdf>. Accessed 17 Jan 2017.
19. European Medicines Agency. Guideline on the evaluation of the pharmacokinetics of medicinal products in patients with impaired hepatic function. 2005. Available at: [http://www.ema.europa.eu/docs/en\\_GB/document\\_library/Scientific\\_guideline/2009/09/WC500003122.pdf](http://www.ema.europa.eu/docs/en_GB/document_library/Scientific_guideline/2009/09/WC500003122.pdf). Accessed 17 Jan 2017.
20. Kuperman GJ, Bobb A, Payne TH, Avery AJ, Gandhi TK, Burns G, et al. Medication-related clinical decision support in computerized provider order entry systems: a review. *J Am Med Inform Assoc.* 2007;14(1):29–40.
21. Lucena MI, Andrade RJ, Tognoni G, Hidalgo R, de La Cuesta FS. Drug use for non-hepatic associated conditions in patients with liver cirrhosis. *Eur J Clin Pharmacol.* 2003;59(1):71–6.
22. Franz CC, Egger S, Born C, Ratz Bravo AE, Krahenbuhl S. Potential drug-drug interactions and adverse drug reactions in patients with liver cirrhosis. *Eur J Clin Pharmacol.* 2012;68(2):179–88.