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Evaluation of bile reflux in HIDA images based on fluid mechanics

Rong-Chin Lo [a], Wen-Lin Huang [a,*], Yu-Ming Fan [b]

[a] National Taipei University of Technology, Dept. of Electronic Engineering & Graduate Institute of Computer and Communication Engineering, Taipei, Taiwan
[b] Catholic Cardinal Tien Hospital, Taipei, Taiwan

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ABSTRACT

We propose a new method to help physicians assess, using a hepatobiliary iminodiacetic acid scan image, whether or not there is bile reflux into the stomach. The degree of bile reflux is an important index for clinical diagnosis of stomach diseases. The proposed method applies image-processing technology combined with a hydrodynamic model to determine the extent of bile reflux or whether the duodenum is also folded above the stomach. This condition in 2D dynamic images suggests that bile refluxes into the stomach, when endoscopy shows no bile reflux. In this study, we used optical flow to analyze images from Tc99m-diisopropyl iminodiacetic acid cholescintigraphy (Tc99m-DISIDA) to ascertain the direction and velocity of bile passing through the pylorus. In clinical diagnoses, single photon emission computed tomography (SPECT) is the main clinical tool for evaluating functional images of hepatobiliary metabolism. Computed tomography (CT) shows anatomical images of the external contours of the stomach, liver, and biliary extent. By exploiting the functional fusion of the two kinds of medical image, physicians can obtain a more accurate diagnosis. We accordingly reconstructed 3D images from SPECT and CT to help physicians choose which cross sections to fuse with software and to help them more accurately diagnose the extent and quantity of bile reflux.

1. Introduction

The cause of bile reflux gastritis is uncontrolled bile reflux into the stomach. When alkaline bile moves through the pylorus into the stomach, it can destroy the stomach mucosa solidity, posing the risk of gastritis that may eventually turn into cancer. Bile reflux may lead to mucosal injury and may appear with surgical excision of part of the stomach and the failure of the pylorus [1]. For this reason, physicians want to detect bile reflux as early as possible. From the fluid mechanics point of view, normal bile can be considered as a Newtonian fluid, and an increase in bile viscosity is an important factor in bile stone pathology [2,3]. Ooi et al. presented 2D and 3D computational models for bile flow in different geometrical cases of the cystic duct as a channel with baffles [4]. Li et al. simulated Newtonian and non-Newtonian bile flow in the cystic duct. They presented a model for analyzing bile flow at a *T* junction with rigid and flexible walls [5]. Agarwal et al. developed a mathematical model of bile flow, considering bile as a Herschel–Bulkley fluid in a constricted channel [6]. Maiti and Misra [7] presented a peristaltic flow motion model to evaluate the influence of critical pressure, porosity parameter, and bile velocity on reflux. Physicians are used to judging bile flow motion from diisopropyl iminodiacetic acid (DISIDA) images. If bile reflux is not serious, physicians cannot easily judge whether or not the bile flow is passing through the pylorus without analysis of SPECT DISIDA images. Physicians can easily judge the position of the stomach from CT images but cannot determine the bile flow to the stomach from SPECT images alone. The present study aimed to integrate CT and SPECT images to accurately find the position of the stomach and to determine whether or not there is reflux of bile into the stomach. Although instruments able to merge SPECT and CT, the procedure is very expensive, reflecting the high cost of the instruments to hospitals. For this reason, an interface is used to help physicians fuse DISIDA and SPECT images. Digital medical images are becoming increasingly more important to physicians, who use them to assess the severity of many diseases.

Fig. 1 shows a flow chart of the analysis system proposed in this study. The system was built with MATLAB 7. In the system, we processed the dynamic DISIDA images using the proposed methods. This system can help doctors to estimate duodenogastric reflux and quantify the duodenogastric reflux easily.

2. Methodology

Fig. 2 shows the human biliary system, which consists of the gallbladder, cystic duct, common hepatic duct, and common bile duct. The gallbladder, which is approximately 7–10 cm in length and 1–3 cm in width, stores 20–30 ml of bile. The cystic duct is approximately 3.5 cm in length and 3 mm in width, and merges with the common bile duct. There are 3–7 crescentic folds known as the spiral valves of Heister, as shown in Figs. 3 and 4. The hepatic common duct and common bile duct are approximately 4 cm

* Corresponding author.
E-mail addresses: rclo@ntut.edu.tw (R.-C. Lo), t6418523@ntut.org.tw (W.-L. Huang), simhuang@gm.nkhs.tp.edu.tw (Y.-M. Fan).

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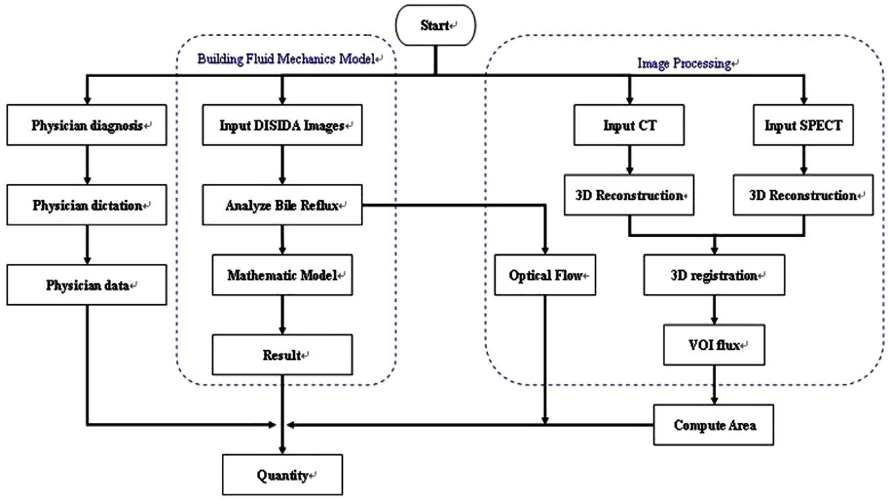

Fig. 1. Flow chart of the analysis.

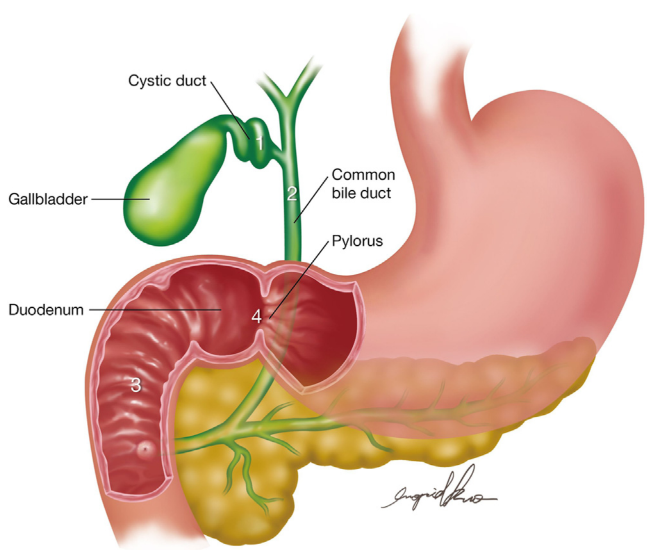

Fig. 2. The biliary system and stomach.

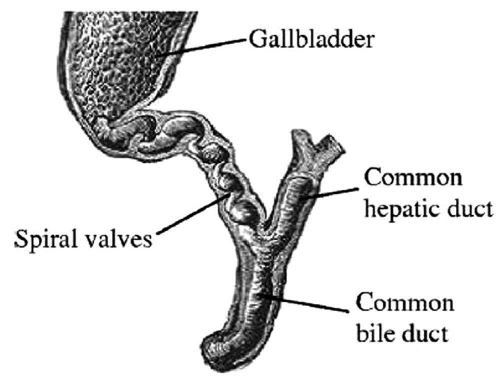

Fig. 3. The physiological structure of the biliary system [10].

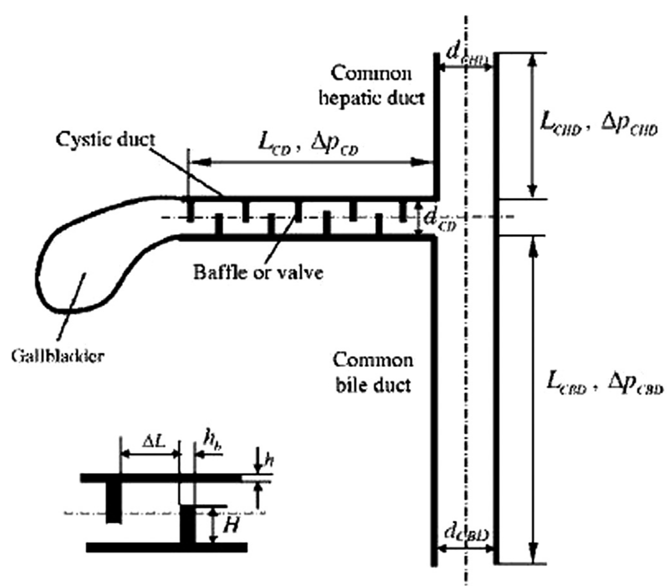

Fig. 4. Model of the cystic duct [9].

and 6–11 cm long, respectively. Earlier experimental work by Rodkiewicz and Otto [8] showed that bile behavior is like a Newtonian fluid. According to their study in which the biliary system is divided into three parts, three hydromechanical models, as shown in Fig. 4, can be used to describe flow.

2.1. Model of the cystic duct

Fig. 3 shows that the cystic duct is not a straight tube but instead, is rotated and distorted. Thus, we cannot directly use the steady flow of fluid in the tube model. To improve the model of the cystic duct by referring to literature [9], we see the cystic duct rotation as a tube filled with the same half-size of the valve shown in Fig. 4. The curved pipe length is included in the calculation to analyze the model. After stretching the cystic duct to an equalization tube, we get into the steady flow tube model of fluid mechanics in application. Using this model, we combined the bile flow and optical flow to predict and evaluate the bile flow status. The following derivation describes the hydrodynamic modeling procedure and its results.

The equivalent diameter d_{CD} of the cystic duct is dependent on the baffle number and baffle height H. Fig. 5 shows that the bile flow traveled twice the distance from points 1 to 2 between any two baffles in the duct, and A_1 and A_2 are the corresponding cross-sectional areas at points 1 and 2. The sector area A_1 can be easily calculated from formula (1) [9]:

$$A_1 = (d_{CD}^2\theta)/4 - \sqrt{d_{CD}^2/4 - (H-(d_{CD})/2)^2}\,(H-(d_{CD}/2)) \tag{1}$$