Choledochol Cyst – An Automated Preliminary Detection System using MRCP Images

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Abstract: - Cystic disease of the biliary duct is usually diagnosed by a specialist through examination of Magnetic Resonance Cholangiopancreatography (MRCP) images. However, due to the nature and flexible acquisition orientations of the MRCP, automated detection has thus far been unsuccessful. This paper attempts to use visually-oriented features to conduct automated preliminary diagnosis of the choledochol cyst in the central bile duct (CBD) of the liver, with the intention of highlighting the images in which the occurrence of the disease is suspected, for more detailed analysis by the specialists. The methodology and results of successful implementation of the proposed choledochol cyst detection system for MRCP is presented in this paper. The system's ability for preliminary automatic classification of MRCP images enables the further development of computer-aided diagnosis systems for MRCP.

Key-Words: - Choledochol cyst, computer-aided diagnosis (CAD), Magnetic Resonance Cholangiopancreatography (MRCP), liver, bile duct.

1 Introduction

A cyst is essentially an abnormal fluid-filled sac-like structure that may appear in various parts of the human anatomy. In the bile ducts, the usual occurrence of the cyst would be the largest part of the structure, namely the central bile duct (CBD). Such cysts are known as choledochol cysts, which cause the CBD to be distended, blocking the passageway of the bile flowing from the liver to small intestines where it is used to digest fat. Generally, in addition to digestion problems, biliary diseases also cause a buildup of toxicity in the body as fat-soluble waste matter, such as cholesterol, are unable to drain from the liver to the bowels.

The common medical imaging modality used for diagnosing biliary diseases is Magnetic Resonance Cholangiopancreatography (MRCP) [1], a sequence of MRI the pancreatobiliary region of the abdomen, which covers the bile ducts, CBD, gallbladder (used to store the bile, and responsible for releasing bile during digestion) and pancreatic duct. Often, other organs such as the bowels and pancreas are also prominent in the T2-weighted MRCP images. Although the preferred modality, MRCP images can be difficult to automatically analyze. Reasons for this include its flexibility in the orientations and parameter settings used during acquisition, which cause problems in normalizing the images. Furthermore, the 3D tree-like biliary structure can overlap in the 2D thin slice and 2D thick slab images, making them difficult to distinguish. As sampling is done as 2D images, and acquisition time is shortened for patient comfort, the resolution of the image is not as sharp as desired, and suffers from partial-volume effect due to the representation of 3D thickness of 8-50mm into a 1 pixel thick 2D image.

Under normal diagnosis, a patient examination consists of several series of acquisitions totaling to approximately 150 images, including orientation axial and coronal MRI series, T1- and T2-weighted MRI and MRCP series, thin slice series, thick slabs and projected thick slabs. A radiologist would usually go through those many images to make a diagnosis. With the increased incidence of liver diseases in the world, such thorough examinations can be tedious. Also, to facilitate the automation process and telemedicine endeavors, computer-aided diagnosis systems are the preferred choice for conducting preliminary selection and highlighting problems for further study by the specialists.

Based on the difficulties observed in MRCP images, which happens to be one of the better non-ionizing imaging modalities, thus far there has been no successful implementation of a CAD system for the detection of choledochol cyst. This paper proposes a methodology for such detection. Implementation results of the system on clinical data from a paperless hospital is presented and indicates the viability of the system for further development and use in CAD systems for MRCP.

2 Algorithm

In order to detect the choledochol cyst in MRCP images, several modules are required to pre-process the raw images, detect the biliary structures, and finally detect the potential cyst. The required modules are described below. An overview of the entire algorithm is given by the flowchart in Fig. 1.

2.1 Pre-processing

The pre-processing of the raw MRCP images may be split into two main processes. A brief description each process is given below.

2.1.1 Image Preparation

The image is normalized using dynamic histogram manipulation [2]-[3]. The soft tissues of the background are removed by truncating the histogram just after the first significant (often maximum) peak of the histogram. The very high intensities (often bright spots) are truncated about halfway after the last representative peak). The intensities representing the main section of the biliary structures (between halfway down the second significant peak until the last representative peak) is stretched such that the histogram covers the desired range of intensities. At this point, usually the 12 bpp image is scaled down to 8 bpp with 256 grey values.

The medical images stored in the DICOM standard file format [4] contain header information that specifies the pixel spacing (zooming). This information is retrieved and the image size is normalized by scaling it accordingly. Next, slight blurring using an anisotropic filter (e.g. Euclidean Shortening Flow [5]-[6]) is undertaken to remove some residual image noise.

2.1.2 Segmentation

The image is segmented using the tested watershed algorithm [7]-[8]. Through the use of filtering, over-segmentation of the image is reduced. To overcome pixel-level inconsistencies, the segment average intensity is assigned to each pixel. To reduce the number of insignificant small segments, segment merging of connected segments with similar average intensities is employed. Iterative merging from the highest to the lowest intensity is conducted in a systematic way to prevent accidental merging of the biliary structures with the background. As a safeguard to prevent over-merging, the iterations are stopped if the total number of segments reduces to less than half of that of the original image.

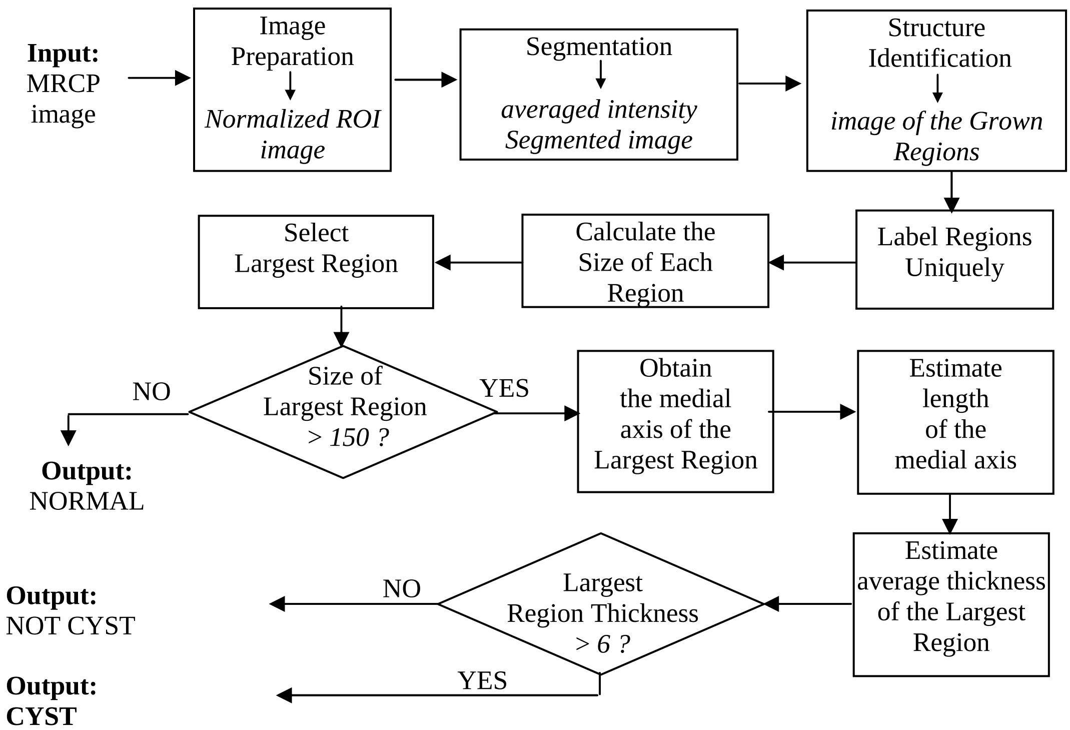


Fig. 1: Algorithm for preliminary choledochol cyst detection

2.2 Biliary Structure Detection

The biliary structures need to be detected, minimizing the presence of other organs and artifacts in the image. The main processes involved on the segmented image are given below [8].

2.2.1 Select Root (Seed) Segments

All potential root segments are identified as the segments with high average intensity in the image. Very small segments are removed from the list. The distance of each remaining root segment from the image centre is determined. All root segments are the seeds for the segment-based region growing algorithm. They are sorted from highest priority to that of the lowest priority, where the chosen root segment is the brightest unprocessed root segment located closest to the middle of the image.

2.2.2 Grow Segments

The chosen root is grown into its most eligible connected neighbours. The candidate segments are determined as unprocessed (not grown) neighbours satisfying the criteria of connectivity (shared border pixels) of more than 2 pixels, and intensity difference of within 20% of that of the chosen segment. All the candidates are grown based on priority determined by two degrees of freedom, namely, the average intensity of the candidate segment, and the intensity difference between the candidate and the chosen segment.

2.3 Cyst Detection

Choledochol cyst resembles a dilated CBD. The detected regions are processed with a dilation detection algorithm to identify if dilated biliary structures are present in the image. The algorithm is described by the following steps.

2.3.1 Label the regions

Each detected biliary region is labelled individually.

2.3.2 Calculate regions sizes

The size, in terms of the total number of pixels present in a region, is calculated for each region.

2.3.3 Identify largest region

It is assumed that if there are sections of the biliary structure that are dilated, the largest region would typically be significantly dilated and be suitably analysed in the consequent steps.

2.3.4 Identify medial axis

Normal biliary structures are fine, with the largest part, the CBD, being less than 6 mm in diameter. As the biliary ducts form a tree-like structure in the 3D volume, the branches may appear as small disconnected regions in a 2D image. The medial axis of the largest region is determined, by eroding the region to 1 pixel thickness, to estimate its thickness.

2.3.5 Estimate length of the region

The length of the region is estimated as the length of its medial axis, i.e. the total number of pixels that make up the medial axis.

2.3.6 Estimate thickness of the region

The region's thickness is approximated by dividing its size (in pixels) with its length.

2.3.7 Identify Potential Choledochol Cyst

Ideally, the acquisition orientation and focus has to be optimal in order to locate the CBD when employing the algorithm. This is to be able to clearly differentiate a dilated duct from a dilated CBD, which in turn differs from a choledochol cyst. As this is beyond the scope of this work due to the use of actual clinical images, the region size and thickness are used as the main detection parameters.

The dilation due to cysts are expected to be larger, thus, the size thresholds are set higher. The detection criteria would be for the region (structure) thickness to be greater than the 6 mm of the normal CBD (specifically, the thickness threshold is 6 pixels multiplied by the zooming ratio) AND the region size to be greater than 150 pixels (chosen empirically) multiplied by the zooming ratio. Images without tagged regions are considered as those with normal healthy biliary structure.

3 Performance Evaluation

Although a recognised and documented disease, choledochol cysts are less common and the number of study cases available were very limited. As such, the test set is relatively small. All images used in evaluating the performance of the proposed scheme are actual clinical MRCP images used in the examination and diagnosis of various liver, and specifically, liver conditions. The test set encompasses normal, choledochol cyst, and a number of other diseases (tumor, stones, Klatskin's disease, Caroli's disease), in order to provide a more robust testing of the algorithm. The goal of the testing was not just to be able to differentiate choledochol cysts from normal healthy livers, but also to differentiate them from other more common liver illnesses, mimicking actual situations faced in a medical institution.

3.1 Algorithm Validation

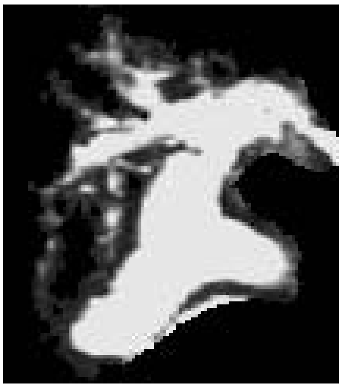
A subset of the images is tested to validate the sensitivity of the detection scheme. The results achieved are given in Table 1. The results are given in terms of the popular performance statistics [9], namely, *true positives* (*TP*, cysts detected correctly), *true negatives* (*TN*, non-cyst images identified correctly), *sensitivity* (probability of cyst being correctly detected), *specificity* (probability of non-cyst being correctly identified), *false positives* (*FP*, non-cyst detected wrongly as cyst), *false negatives* (*FN*, cyst wrongly identified as non-cyst) and *overall* performance for correct detection and identification of the images in the test set.

Table 1: Validation results of classifying MRCP images as 'normal' or 'cyst'

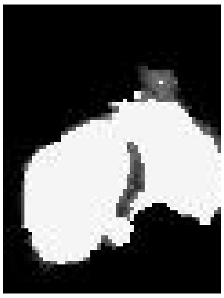
	Normal Images	Images with Cyst
Medically Diagnosed	20	10
Detected	19 *(TN)*	7 *(TP)*
Accuracy %	95% *(Specificity)*	70% *(Sensitivity)*
Error	1 *(FP)*	3 *(FN)*
Description of Error	Large biliary structures	Small cyst; small ducts; CBD not identified
Performance	86.67% *(Overall)*	

The resulting detection for the choledochol cyst is not as high as would be hoped for to be able to conduct 'perfect' classification. But this is expected as most of the images containing choledochol cyst in the hospital archive were not optimally focused (see Fig. 2(a), where the CBD is overlapped).

The images are correctly detected as being dilated, however, the inaccuracies are caused by small choledochol cyst (not distinguishable from the dilated biliary structure, as shown in Fig. 2(b)-(c)), dilated gallbladder (Fig. 3(a)) and over distended biliary ducts (Fig. 3(b)). High intensity background that gets detected as a large biliary region could also be wrongly detected as a cyst. In general, the validation testing shows good sensitivity, specificity and overall performance of the proposed algorithm.



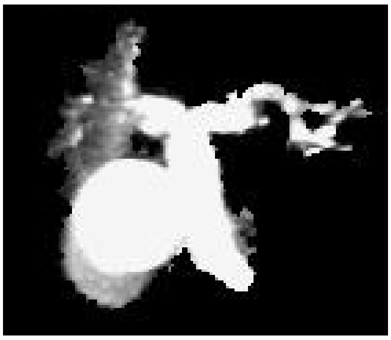
(a) overlapped CBD



(b) small CBD, large gallbladder

(c) small CBD, stone

Fig. 2: MRCP images containing choledochol cyst



(a) dilated gallbladder & CBD

(b) large dilated biliary tract

Fig. 3: Problems faced in structures wrongly diagnosed as choledochol cyst

3.2 Algorithm Refinement

In most focused MRCP images, the ROI is central in the image. As such, assuming good acquisition (or pre-processing through interactive ROI selection) where the biliary structure is parallel to the slice plane, the CBD location may be approximated to being in the middle lower half of the image. The detection could then be focused to that area, avoiding the potential difficulties in the presence of over-dilated structures or organs. Care should be taken though as the gallbladder also appears as a distended biliary duct, just off the lower middle half of the image.

The orientation of the image is critical to be able to detect the difference, where post-processing erosion operators can be used to disconnect both structures at the narrow branching between them. Once disconnected, assuming good orientation, the gallbladder and CBD can be differentiated by the orientation of the structures, where the gallbladder is usually more horizontal and slightly towards the left of the image, while the CBD is more vertical and at the lower middle of the image. It is then also possible to further differentiate a dilated CBD (dilation due to blockage, possibly caused by a tumour at the hepatic hilium) from an actual choledochol cyst through shape analysis (e.g. using an approximation to the circular Hough transform), as the CBD should appear more circular in the presence of a choledochol cyst.

3.3 Overall Performance

With the success of the validation testing, the algorithm was tested on a more complete clinical test set with 593 2D T2-weighted MRCP images. The performance is calculated as the correct detection of images with choledochol cyst, correct detection of images with biliary diseases (dilation due to the various liver diseases) and correct identification of normal healthy liver images. All experiments were conducted by evaluating the system performance for the individual 2D slice image (thin or thick), testing the capability of the proposed system beyond that expected by a human who would have series of images available for comparisons. The results of the performance evaluation is given in Table 2.

From the results in Table 2, it is seen that the performance of the proposed system is satisfactorily high (almost 90%) in successfully detecting choledochol cysts and differentiating that pathology from other liver diseases and that of normal healthy liver, in MRCP images. The added novelty in this implementation is the ability to achieve such high success rates via examination of single 2D images (as opposed to the conventional attempt to analyze series of images and/or the reconstructed 3D volume [10], and that too from non-optimal acquisitions from a patient records archive at the collaborating medical institution. The proposed implementation is more efficient in terms of required resources and as an end result, is able to conduct preliminary selection of images (cf. series) for further diagnosis by the medical specialist.

Table 2: Performance evaluation of the preliminary diagnosis algorithms

	Dilation	Cyst
TP (true positives)	327 (dilated)	8 (cyst)
TN (true negatives)	129 (normal)	523 (non-cyst)
Accuracy	94.78 % *(Sensitivity)*	93.23 % *(Specificity)*
Overall performance of algorithm for choledochol cyst detection		89.55 %

4 Conclusion

This paper proposes a novel scheme for an automated preliminary diagnosis of choledochol cyst affecting the central bile duct (CBD) in the abdominal region, via examination of individual 2D thick slab or thin slice images. The system employs non-intensive visual-based features for detection, allowing for more efficient handling of the medical images during processing, without taxing the computational power and storage resources during processing. The successful results achieved by the proposed scheme is encouraging and is hoped to pave the way for more attempts in developing computer-aided diagnosis systems for choledochol cysts and for the handling of MRCP images.

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