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Frequency-selective non-linear blending for the computed tomography diagnosis of acute gangrenous cholecystitis: Pilot retrospective evaluation

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ABSTRACT

Purpose: To compare the diagnostic performance of frequency-selective non-linear blending and conventional linear blending contrast-enhanced CT for the diagnosis of acute (AC) and gangrenous (GC) cholecystitis.
Materials and methods: Following local ethics committee approval for retrospective data analysis, a database search derived 39 patients (26 men, mean age 67.8 ± 14.6 years) with clinical signs of acute cholecystitis, contrast enhanced CT (CECT) evaluation, cholecystectomy, and pathological examination of the resected specimen. The interval between CECT and surgery was 4.7 ± 4.1 days. Pathological gross examination was used to categorize the cases into AC and GC. Subsequently, two radiologists categorized the CECT studies in a blinded and independent fashion into AC and GC, during two different reading sessions using linear blending and frequency-selective non-linear blending CECT.
Results: Histologic analysis diagnosed 31/39 (79.4%) cases of GC and 8/39 (20.6%) cases of AC. Image interpretation of linear blending CECT resulted in classification of 7/39 (17.9%) patients as GC and 32/39 (82.1%) as AC, whereas image interpretation of frequency-selective non-linear blending CECT resulted in classification of 29/39 (74.3%) patients as GC and 10/39 (25.7%) as AC. Sensitivity/specificity/PPV/NPV for detection of GC were 22.6%/100%/100%/25% with linear blending CECT and 80.6%/50%/86.2%/40% with frequency-selective non-linear blending CECT, respectively. Based on the histopathologic diagnosis frequency-selective non-linear blending had a significant improvement ($p > 0.0001$) in the diagnostic accuracy of gangrenous cholecystitis compared with linear blending.
Conclusion: Frequency-selective non-linear blending post-processing increases the diagnostic accuracy of gangrenous cholecystitis owing to improved visualization of absence of focal enhancement and mural ulcerations.

1. Introduction

Acute cholecystitis (AC) is a frequent cause of severe abdominal pain that often requires surgical treatment [1–4]. While AC can be diagnosed based on typical symptoms and several inflammatory markers, cross-sectional imaging is often used to confirm the diagnosis and diagnose potential mimics. Ultrasound and computed tomography (CT) have been used most frequently, whereas magnetic resonance imaging has not shown relevant advantages in diagnosis [1,4,5].

Different imaging findings for the diagnosis of acute gangrenous cholecystitis, including decreased or absent mural enhancement, intramural or intraluminal gas, irregular wall thickening, perforation, pericholecystic abscess and pericholecystic stranding have been described [1,6–10] whereas for acute non-gangrenous cholecystitis gallbladder wall thickening with edema pattern and layering, sloughing of the inner layer of the gallbladder wall, hyperattenuation of the gallbladder fossa, pericholecystic fluid, gall bladder distension and gallstones are usually expected [6,9,11,12]. The findings mural striation

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and intraluminal membranes, were discussed controversially [1,2]. Using histology as a standard of reference, findings such as thinning and erosive irregularities of the gallbladder wall have been found to be more often present in gangrenous cholecystitis [1,6,7,13]; however, great overlap exists between both entities and absent wall enhancement, ulcerations, and perforation are the most reliable findings of transmural necrosis [1,8,13].

An accurate imaging diagnosis is important for treatment decisions such as surgical versus systemic antibiotic treatment, and for the surgical approach, such as laparoscopic versus open cholecystectomy. Systemic antibiotic therapy and in select cases percutaneous cholecystostomy may be suitable alternatives to cholecystectomy in patients with high perioperative risk factors, but require the exclusion of gangrenous cholecystitis [3,7,11,14].

Improved tissue contrast can improve the detectability of gangrenous and non-gangrenous acute cholecystitis through improved visibility of signs of transmural necrosis of the gall bladder wall. Increasing the tube current, as well as volume and concentration of iodine-based contrast agents may be beneficial but come with concerns of increasing radiation dose and potential for impairment of renal function. The possibility of low-kilovolt acquisition to increase iodine attenuation closer to the k-edge is not available on all CT-scanners, whereas the use of low-keV monoenergetic extrapolation is limited to dual-energy CT acquisitions. Contrary to linear blending, which affects the entire dynamic contrast range, frequency-selective non-linear blending can be applied to a select range of Hounsfield units, e.g. in the low-keV range to improve the visibility of possibly undetectable small differences in tissue contrast [15–18]. Frequency-selective non-linear blending is independent of the acquisition technique and can be applied to single and dual energy CT data.

Therefore, the purpose of our study was to compare the diagnostic performance of the novel technique called frequency-selective non-linear blending with that of conventional linear blending applied on contrast-enhanced CECT image data for differentiation between acute non-gangrenous vs. gangrenous cholecystitis.

2. Material and methods

2.1. Patient selection

This retrospective data evaluation was approved by the local institutional ethics committee of the Eberhard-Karls-University Tuebingen, Germany and registered under the number 791/2017BO2. The Declaration of Helsinki protocols were followed. The informed consent requirement was waived. A database research between January 2010 and October 2017 derived 350 pathological examinations of gall bladder specimens. Of them, 311 were excluded due to diagnoses of chronic cholecystitis and neoplastic disease, small gallbladder specimens in the database that was insufficient for reexaminations, lack of CECT during presurgical work-up.

The remaining 39 patients were included in the final evaluation (mean age 67.8 ± 14.6 years; range 33–92 years; 33% women). The length of time between CECT and surgery was 4.7 ± 4.1 days. All included patients presented with clinical signs of acute cholecystitis and underwent single energy CECT evaluation, were treated with cholecystectomy, and had a pathological examination of the resected specimen.

2.2. Histologic diagnosis

Following cholecystectomy and formalin fixation, representative cross sections of the most abnormal area of the gall bladder and the resection margin of the cystic duct were taken from each specimen. The histologic slides were retrieved from the appropriate paraffin embedded material and stained with hematoxylin and eosin. Necrosis was defined as transmural wall devitalization, whereas wall defects of the inner layer were diagnosed as ulcers. Gangrenous cholecystitis was diagnosed if at least one of following three criteria were met: Transmural necrosis, laminar ulcers, and gallbladder wall perforation. Acute cholecystitis was diagnosed in the presence of wall thickening secondary to edema, infiltration with inflammatory cells and granulation tissue, and lack of tissue necrosis [19,20]. One pathologist (H.B.) with 20 years of experience re-evaluated every case included in our study.

2.3. Computed tomography technique

CT studies were performed with patients in the supine position using 128-256-slice MDCT scanners (SOMATOM Definition AS+, Flash or Force, Siemens Healthcare, Forchheim, Germany). All patients received 100 ml iodinated contrast agent Imeron 400 (Bracco, Imaging Deutschland GmbH), which was given intravenously at a rate of 2 mL/s followed by a 30 ml saline chaser. Contrast medium was administered by using a dual-head pump injector (Stellant, Medtron, Saarbruecken, Germany). Post-contrast images were obtained in the portal-venous phase following a delay time of 70–80 seconds in all patients using 100 kV and tube current dose modulation. Images were reconstructed at 1 mm and 3 mm using a soft tissue kernel and a matrix of 512 × 512. For interpretation of linear blending and frequency-selective non-linear blending CECT images, axial reformations of 3 mm slice thickness were used, which parallels our clinical practice. The length of time of image data pre- and post-processing was approximately 3.5 min, including 120 s for image data transfer to the workstation where the prototype software was installed; 60 s for loading of images with the prototype software, and 30 s for adjusting the viewing parameters (see below).

2.4. Conventional CECT evaluation

Two radiologists (M.H. and R.S.) with 27 and 2 years of experience in abdominal imaging interpreted the conventional linear blending CECT images with use of a questionnaire for the presence or absence of ulcers (focal missing enhancement of the inner layer), focal/patchy pattern of necrosis (patchy/focal enhancement of all layers), diffuse necrosis of all layers (visually below the liver parenchyma), perforation (discontinuous gall bladder wall with fluid in the gall bladder fossa), striation, pericholecystic abscess, enhancement of the adjacent liver parenchyma, sludge/sedimentation, cholecystolithiasis, pericholecystic lymphadenopathy, inflammatory reaction of the duodenum or the right colic flexure. Intramural gas was not included in the questionnaire, but not present in our cohort. The definition of these criteria was in line with that of previous reports dealing with this issue [1,6,9,10,13]. Prior to image interpretations, the two radiologists were provided with the definitions and image examples of the imaging signs of the questionnaire and underwent basic training using 10 patients with acute, chronic and gangrenous cholecystitis that were not included in this study. The interpretation of the study cases was performed following separation and randomization of corresponding linear blending and frequency-selective non-linear blending CECT datasets. The two radiologists performed the imaging analysis using the same criteria and questionnaires following a three weeks interval to limit recall bias and the intraobserver agreement was calculated. For statistical evaluation the first interpretation of the more experienced radiologist was used.

2.5. Image analysis using frequency-selective non-linear blending

For the frequency-selective non-linear blending reading session, all CT images – performed in daily routine with a soft tissue kernel B30 and filtered back projection reconstruction with conventional linear weighting of frequencies – were transferred to an external offline workstation with a frequency-selective non-linear blending prototype software (Siemens Healthineers) [15–18]. The algorithm enabling non-linear blending of CT images first divided image information into low and high frequencies, whereas high frequencies represented the main