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Research article

Multi-detector CT: Liver protocol and recent developments

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ABSTRACT

Multi-detector computed tomography is today the workhorse in the evaluation of the vast majority of patients with known or suspected liver disease. Reasons for that include widespread availability, robustness and repeatability of the technique, time-efficient image acquisitions of large body volumes, high temporal and spatial resolution as well as multiple post-processing capabilities. However, as the technique employs ionizing radiation and intravenous iodine-based contrast media, the associated potential risks have to be taken into account.

In this review article, liver protocols in clinical practice are discussed with emphasis on optimisation strategies. Furthermore, recent developments such as perfusion CT and dual-energy CT and their applications are presented.

1. Introduction

In general terms, imaging plays a crucial role in diagnosis, staging, treatment planning and evaluation as well as follow-up of patients with suspected or known liver diseases. Multi-detector computed tomography (MDCT) is today the workhorse in the evaluation of these patients. Reasons for that include widespread availability, robustness and repeatability of the technique, time-efficient image acquisitions of large body volumes, high temporal and spatial resolution as well as multiple post-processing capabilities. However, as the technique employs ionizing radiation and intravenous (IV) iodine-based contrast medium (CM), the associated potential risks have to be taken into account.

In this review article, liver protocols in clinical practice will be discussed with emphasis on optimisation strategies. Furthermore, recent developments such as perfusion CT (PCT) and dual-energy CT (DECT) and their applications will be presented.

2. Liver protocols in clinical practice

2.1. Choice of appropriate protocol

In order to provide helpful clinical information, it is of critical importance to choose the appropriate imaging protocol taking into consideration the given clinical context for the particular patient and the associated potential risks. Images may be acquired before (unenhanced) and at various time-points after the IV administration of CM. Imaging at these time-points comprise the various so-called “contrast-enhancement phases”, such as: early arterial (EAP), late arterial (LAP) (or, portal venous inflow), hepatic parenchymal (HPP) (or, portal venous dominant/portal venous phase), equilibrium (3 min) and delayed venous (5–10 min) phases. The clinical scenario and the specific type of lesion one is searching for determine the appropriate combination of the above contrast phases [1]. For hypovascular lesions, such as colorectal cancer (CRC) liver metastases (LM), acquisition solely of HPP phase is suggested [1]; however, the addition of LAP may improve the detectability particularly of small LM [2]. For hypervascular tumours, acquisition of both LAP and HPP is recommended and in case of hepatocellular carcinoma (HCC) the addition of equilibrium phase is suggested [1,3]. EAP does not contribute in HCC diagnosis and should not be obtained routinely [4]. Unenhanced scans should be reserved for post treatment evaluation (e.g. post chemoembolization) or for detection of calcified lesions [1].

2.2. Optimisation strategies

The aim is to achieve optimal visual contrast between liver

Abbreviations: ALP, arterial liver perfusion; BV, blood volume; BW, body weight; CLD, chronic liver disease; CM, contrast medium; CNR, contrast-to-noise ratio; CRC, colorectal cancer; DECT, Dual-energy CT; EAP, early arterial phase; HCC, hepatocellular carcinoma; HPI, hepatic perfusion index; HPP, hepatic parenchymal phase; HU, hounsfield units; LAP, late arterial phase; LIC, liver iron content; LM, liver metastasis; LNR, lesion-to-normal parenchyma iodine concentration ratio; MDCT, multidetector CT; MTT, mean transit time; MVD, microvessel density; NIC, normalised iodine concentration; PCT, , perfusion CT; PLP, portal venous perfusion; PS, permeability surface-area product; SECT, single-energy CT; TAC, time-attenuation-curve; TACE, transarterial chemoembolization; TLC, tumour-to-liver contrast; TNC, true non-contrast; TLP, total liver perfusion; VIC, Virtual iron content; VNC, virtual non-contrast

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parenchyma and the lesion of interest in each of the acquired contrast phases. In case of hypervascular lesions, the specific aim is to obtain maximal lesion enhancement simultaneously with minimal enhancement of the adjacent parenchyma during the early phases. On the contrary, the aim for hypovascular lesions is to achieve minimal lesion enhancement while the parenchymal enhancement is maximal. In quantitative terms, this is most often represented by tumour-to-liver contrast (TLC) and tumour-to-liver contrast-to-noise ratio (CNR). Various parameters need to be considered in order to optimise image acquisition. For the sake of simplicity, these are divided into two major categories: 1. IV CM-related and 2. Scanner-related.

2.2.1. Intravenous contrast medium-related

Included parameters in this category are the total amount of iodine (iodine-load), iodine administration (by means of injection rate and duration) and timing of the image acquisition [5].

For hypervascular lesions, all the above parameters contribute to a variable degree to the optimisation process. Regarding iodine-load, most of the available data are from studies performed on patients with chronic liver disease (CLD) and HCCs. Results from a prospective multicentre study in Japan with 348 included patients indicate that 567–647 mg iodine (I)/kg body-weight (BW) is to be preferred [6] while in another report the proposed dose was at least 525 or, preferably, 600 mgI/kg BW [7]. Regarding iodine administration, injection rates of 4–6 ml/sec result in stronger arterial enhancement and distinct separation of the LAP and HPP compared to 2–3 ml/sec and, thus, contribute in the detection of hypervascular lesions. Lower injection rates of high-concentration CM lead to similar results. However, due to the risk of inconsistent results in case patient size is not taken into account, adopting a fixed injection duration while adjusting the injection rate and amount of iodine to patient weight is to be preferred [5]. Regarding timing of the image acquisition, the adoption of a technique that accounts for inter-patient variations in circulation, such as test-bolus or bolus-tracking, is suggested, particularly concerning the LAP [5]. Considering the optimal scan delay in case of using a bolus-tracking technique, a prospective study from 2010 showed that 10–19 s diagnostic delay from an abdominal aortic threshold of 100 HU is to be preferred (in case the iodine load of 700 mgI/kg BW is injected at a fixed rate of 4 ml/sec) [8]. In this study, it was also demonstrated that the depiction of vascular structures is acceptable at the LAP and there are no additional advantages from the acquisition of EAP. In a very recent study, it was shown that triggering image acquisition based on spleen enhancement results in slightly higher tumour CNR compared to aortic-triggering (for a flat dose of 150 ml of CM with concentration of 300 mgI/ml) [9]. However, in the qualitative analysis there were no significant differences in the diagnostic confidence for lesion detection, lesion conspicuity or diagnostic accuracy [9]. In Fig. 1, two different protocols at different occasions within the same patient with cirrhosis and HCC are demonstrated.

For hypovascular lesions (as well as for the assessment of washout appearance of HCC) the evaluation/survey is performed during the HPP (or/and the equilibrium phase in case of HCC) and, thus, in order to obtain the optimal visual contrast/CNR, a sufficient parenchymal enhancement is necessary. The magnitude of parenchymal enhancement is almost linearly proportional to the administered iodine-load [5]. It is widely considered that a parenchymal enhancement of 50 HU is diagnostically sufficient and the iodine-load required to reach this level of enhancement has been shown to correspond to slightly higher than 500 mgI/kg BW [10]. In Fig. 2, a liver metastasis from pancreatic cancer is clearly delineated on the HPP acquired with 750 mgI/kg BW while not visible at 450 mgI/kg BW. In the prospective multicentre study on patients with CLD and HCC [6], it was shown that 572 mgI/kg BW were needed in order to reach 50 HU enhancement during hepatic parenchymal phase. In the study of Yanaga et al. from 2008 [7], the mean attenuation difference (ΔHU) between HCC and liver parenchyma in the HPP was less than 5 HU irrespectively of the dose within the spectrum of 450–600 mgI/kg BW. In an older study from 2000, it was shown that 750 mgI/kg BW resulted in significantly higher quantitative liver parenchyma enhancement, higher percentage of patients showing parenchymal enhancement of 50 HU or more, and subjective assessment of parenchymal and portal vein enhancement compared to 600 and 450 mgI/kg BW (Fig. 1) [11]. The use of lean body weight or body surface area may estimate the required iodine load with higher precision [5]. Iodine administration and timing of image acquisitions are less critical compared to when hypervascular lesions are of interest.

For a more detailed illustration of the role of all the above-mentioned parameters, the reader is referred to the comprehensive work of Bae [5].

2.2.2. Scanner-related

Included parameters in this category are tube potential (kV), tube current (mA) and reconstruction/post-processing algorithms. In general, all of the above parameters are taken into consideration and modified simultaneously with the aim to increase CNR and/or to lower radiation dose without loss of valuable diagnostic information. Regarding changes in the kV-settings and the potential benefits for liver diagnostics, the reader is referred to the section of DECT. Automatic tube current modulation is a technique that aims to individualise radiation dose depending on the attenuation of the various anatomic regions of a particular patient. The tube current varies during the scan in order to keep noise index constantly to a predefined level [12]. Iterative reconstructions are increasingly used for noise reduction purposes, particularly when lower kV- and/or mA-settings are used [13]. Furthermore, algorithms such as an iodine contrast enhancement tool might be helpful in order to increase the tumour-to-liver CNR of HCC during the LAP and improve subjective assessment [14].

3. Perfusion CT

3.1. General principles

Perfusion is defined as the transport of blood to a unit volume of tissue per unit of time. Liver perfusion can be assessed with CT technique when the organ is scanned multiple times within short intervals (usually 1.5–4 s) prior, during and after CM injection. Changes of tissue HU over time are directly proportional to changes in iodine concentration within the tissue's microvasculature and interstitial space. Thus, P-CT may provide information about the microcirculation of both the liver and focal lesions [15–19]. Two phases of CM pharmacokinetics are critical for perfusion imaging: the first-pass (or, perfusion) phase and the delayed (or, interstitial) phase. In the first-pass phase, which lasts for approximately 40–60 s, iodine is largely contained in the intravascular compartment. In the delayed phase, iodine passes to a certain extent from the intravascular space across the capillary basement membrane into the extravascular extracellular space. The delayed phase ranges from 2 to 10 min after CM injection [16,18,19].

Several analytical models are used for the quantification of tissue perfusion and/or permeability from the acquired CT raw data set. The dual maximum slope model is most commonly used in liver P-CT. It is simpler and permits the calculation of parameters from the first-pass phase [arterial liver perfusion (ALP), portal venous liver perfusion (PLP), total liver perfusion (TLP), hepatic perfusion index (HPI) and time to peak enhancement (TTP)] [20,21]. Other common models are the Patlak and the Johnson-Wilson [22,23]. These may calculate parameters such as blood volume (BV), mean transit time (MTT) and permeability surface-area product (PS). The use of two input functions, e.g. one in the aorta and one in the portal vein, and of an appropriate dual-input kinetic model enables the separate calculation of ALP and PLP and, thus, the estimation of HPI, i.e. the arterial proportion of the total liver perfusion [15,21]. The most commonly used perfusion parameters are described in Table 1.