Using a C-arm CT for Interventional Perfusion Imaging: A Phantom Study to Measure Linearity Between Iodine Concentration and Hounsfield Values

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Abstract

In this work we present phantom measurements to determine the relationship between iodine concentration and measured Hounsfield unit (HU) value using a clinical C-arm CT. These measurements support our current work to use a C-arm CT for brain perfusion imaging in the interventional suite which could e.g. optimize the workflow during stroke therapy. For perfusion imaging a linear relationship between iodine concentration and measured HU value is assumed. Our C-arm CT measurements show a linear relationship of these quantities ($r^2 = 0.998$, $p < 0.001$) over a broad range of iodine concentrations and HU values.

Introduction

CT or MRI perfusion imaging are the common methods for stroke diagnosis and are used to identify tissue-at-risk that may profit from stroke therapy. One option for ischemic stroke therapy is intra-arterial thrombolysis that is performed in an interventional environment [1]. With the help of a catheter a pharmaceutical is administered into a cerebral artery to dissolve the blot clot that causes the stroke. This catheter is navigated to its target location with the help of a C-arm angiography system that acquires 2-D fluoroscopic images. Since several years it is also possible to reconstruct a 3-D volume with this system from projection images that were acquired during one rotation (typically of about 200 degrees) of the C-arm [2].

This technique, also known as C-arm CT, could be used for perfusion imaging in an interventional environment. A perfusion examination immediately before the start of the intervention could be useful to assess if the state of perfusion has changed after the initial diagnosis. Furthermore, a perfusion examination during the intervention could be used to evaluate the treatment success.

To measure tissue perfusion using CT a bolus of iodinated contrast agent is injected into the antecubital vein and images are acquired at short intervals. The regional enhancement over time at different locations in the brain tissue and in a reference artery is determined from the measurements. These time curves are used to compute various perfusion parameters (e.g. cerebral blood flow) using dedicated mathematical models [1].

The peak value that is measured in the reference artery depends on the parameters of the injected contrast bolus (injection rate and duration, iodine concentration). Typical peak values can be between 200 HU and 500 HU. The enhancement in brain tissue is much lower and depends on the cerebral blood volume (CBV), i.e. the volume of blood per mass of tissue. With a CBV of 4 ml/100g the peak value can be between 8 HU and 20 HU. To compute CT perfusion parameters it is assumed that the enhancement in the tissue and the artery depend linearly on the concentration of iodine.

There have been studies to confirm this relationship using CT scanners [3]. In this work, we investigated this relationship using a clinical C-arm CT system. This investigation supports our current work on brain perfusion imaging with a C-arm CT [4,5].

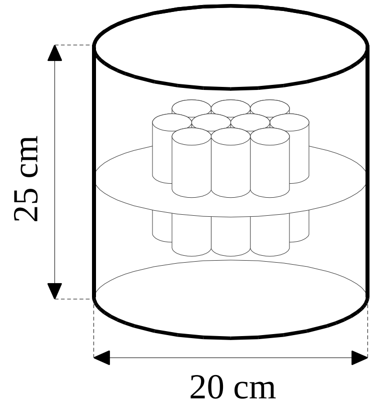

Figure 1: Drawing of the phantom used for the measurements

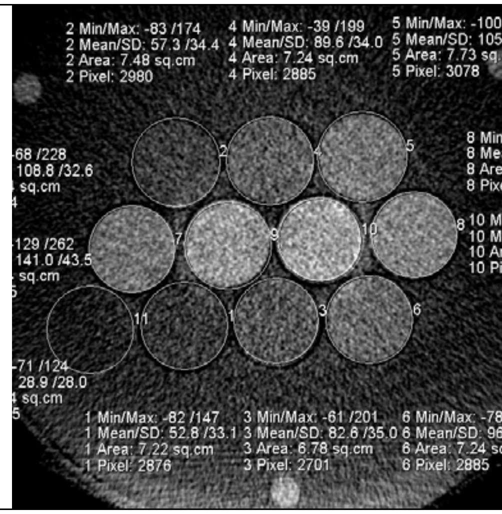

Figure 2: Axial C-arm CT scan of the phantom with circular ROIs drawn around the contrast-filled containers (the bottom left ROI is a reference ROI in water)

Material and Methods

We have built a cylindrical phantom, similar to a phantom previously described by Miles et al. [6], made of perspex that contains smaller cylindrical containers of about 3 cm diameter (Figure 1). The diameter of the phantom was about 20 cm and its height was about 25 cm. The containers were filled with different dilutions of deionized water and contrast agent (350 mg iodine per ml). Water was filled into the phantom body such that all containers were submerged.

In order to study the relationship of HU values and iodine concentrations in the low concentration range we filled 10 containers with dilutions containing 0.1% to 1.0% (in steps of 0.1%) of contrast agent using milliliter syringes. The phantom was scanned in four different orientations, obtained by rotation of the phantom by 90° around its longitudinal axis, using a C-arm CT system (Artis *d*TA with syngo DynaCT; Siemens AG, Healthcare Sector, Forchheim, Germany). This system had undergone routine calibration. We chose a protocol with a fast C-arm rotation speed (4.3 s per 190°) that is usually used for cardiac imaging and which we also used for our experimental perfusion studies [4,5]. This protocol acquired 191 projection images using a X-ray tube voltage of 83 kV.

Mean HU values were determined inside circular region of interests (ROI) that were drawn around the containers in a central slice of the reconstructed volume (Figure 2). Finally, the mean HU values were averaged over the measurements from the four different orientations. We compared the C-arm CT phantom measurement with measurements using a clinical CT scanner (Somatom Definition; Siemens AG, Healthcare Sector, Forchheim, Germany).

To study the relationship of HU values and iodine concentrations in the high concentration range we replaced the ten original containers with six containers that were filled with dilutions containing 1.0% to 6.0% (in steps of 1.0%) of contrast agent. We repeated the measurements with the six containers as described above.

Results

The results from the C-arm CT and CT measurements of the low concentration range are shown in Figure 3. There is a very high linear correlation (C-arm CT: $r^2 = 0.986$, $p < 0.001$; CT: $r^2 = 0.992$, $p < 0.001$) between the contrast concentration and the measured attenuation values. The slopes of the regression lines are very similar (121 HU/% in C-arm CT and 120 HU/% in CT). The regression line of the C-arm CT data has an initial offset of 39 HU with respect to the regression line of the CT data.

Figure 4 shows the measurements of the low and high concentration range using C-arm CT. The linear correlation between the contrast agent concentration and the measured attenuation value is again very high ($r^2 = 0.998$, $p < 0.001$)

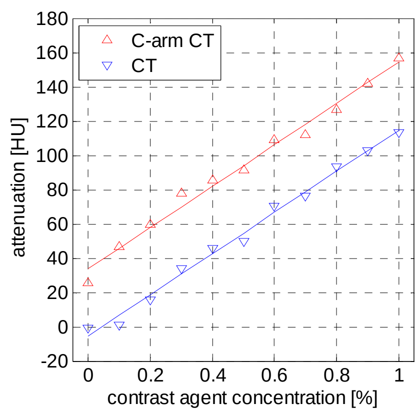

Figure 3: Plot of contrast agent concentration and measured attenuation using CT and C-arm CT in the low concentration range

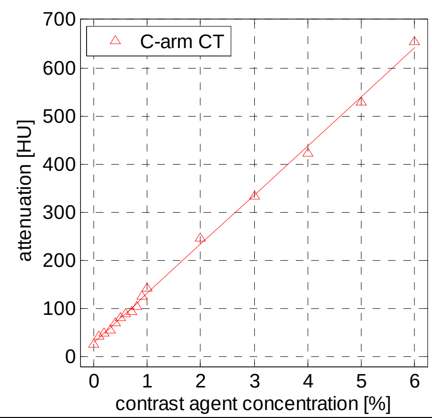

Figure 4: Plot of contrast agent concentration and measured attenuation using C-arm CT in the low and high concentration range

Discussion

The measured data showed significant linear correlation. For comparison, Du et at. [7] did similar measurements using a micro-CT system and obtained a correlation value of r^2=0.9996. From the results we conclude that, using the given clinical C-arm CT, the measured attenuation is a linear function of the concentration of iodine. This linear relation is a pre-requisite when using the standard mathematical models to compute perfusion parameters like cerebral blood flow (CBF). The actual slope and the offset of the concentration-attenuation curve do not influence the computed CBF values due to the normalization of the tissue time curves with the arterial time curve [1].

Generally, the results from this work may also be of interest for other potential applications of contrast-enhanced imaging with a C-arm CT system. For example, various CT applications in tumor diagnosis based on measurement of iodine concentrations are described in Miles et al. [6]. An application of a C-arm CT to measure iodine concentration in the liver was suggested by Taguchi et al. [8].

Acknowlegments

The authors gratefully acknowledge funding of the Erlangen Graduate School in Advanced Optical Technologies (SAOT) by the German Research Foundation (DFG) in the framework of the German excellence initiative.

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