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Accurate localization of incidental findings on the CT attenuation correction image:

The influence of tube current variation

Introduction

Computed tomography (CT) has improved the sensitivity and specificity of many nuclear medicine techniques through the provision of additional anatomic information or by providing a high quality attenuation correction (AC) map [1,2]. The use of AC is strongly recommended in some patients undergoing certain procedures, most notably for those undergoing myocardial perfusion imaging (MPI) [3,4]. Within this patient group there is also potential for the discovery of extra-cardiac pathology by examining the co-incidentally produced CTAC image [4,5]. The ethical and legal considerations of reviewing the CTAC image have been discussed previously [6] and it is known that some nuclear medicine centres routinely review these images to determine whether incidental chest pathology is present. To a similar end, it has also been suggested that the raw projection data from the SPECT acquisition should be assessed for incidental cardiac and extra-cardiac findings as part of the clinical routine [7,8].

Variation of tube current has no impact on tissue attenuation values and Hounsfield Units (HU) – the resultant attenuation maps are therefore largely independent of mA [9,10,11,12]. However, the impact of varying mA on lesion detection is less clear and this deserves investigation because of the potential dose saving at lower mA values.

A suitable approach to investigating this would be through visual performance assessment; previous visual performance phantom simulations have shown that lesion detection rates can be maintained at reduced tube currents [13]. This paper describes a free-response receiver operating characteristic (FROC) investigation of the full clinical mA range available on the GE Infinia Hawkeye 4 SPECT/CT (GEH4; General Electric Medical Systems, WI, USA) to establish the impact on lesion detection performance within an anthropomorphic chest phantom.

Method

CTAC Acquisitions / Anthropomorphic Phantom

The four mA values available for clinical use (1.0, 1.5, 2.0 and 2.5) on the GEH4 were used to image a static anthropomorphic chest phantom which contained simulated pulmonary lesions [14] (Figure 1). All other CT acquisition parameters remained constant (Table 1). The lesions simulated intra-pulmonary pathology with diameters of 3, 5, 8, 10 and 12mm at 630, -800 and +100 Hounsfield Unit (HU) values. This gave good representation of described density ranges for solid lesions (20-60HU) [15-18] and ground glass opacity (GGO) lesions (-850 to -450HU) [19,20]. The phantom and simulated lesion positions remained constant for the four mA image acquisitions, ensuring the production of a case-matched series of images suitable for FROC analysis. A pre- and post-study diagnostic quality CT scan was acquired to ensure that no movement of simulated lesions had occurred. These diagnostic quality images also acted as the FROC truth (gold standard/true lesion positions) to aid accurate localisation on the CTAC images. Observers were blinded to this data.

Free-Response Receiver Operating Characteristic Analysis (FROC)

FROC methodology is a significant enhancement on conventional ROC techniques. ROC investigations simply demand an observer to determine whether an image contains lesions and assign a confidence (rating) score to the image. FROC methods allow observers to accurately localise multiple lesions within a single image, with all localizations individually scored. A proximity criterion, surrounding a lesion, is applied to resolve ambiguities in lesion detection (lesion or lesion mimic). This prevents non-lesion localisations (NL) being classified as successful lesion localisations (LL) [21] and the methodology also allows multiple NL marks to be made on an image. Image display and response capture (IDRC) software, ROCView [22], was applied in this observer performance study, to collect localisation and confidence score (mark-rating pairs) data. Data were analysed using jackknife alternative free-response receiver operating characteristic (JAFROC) analysis [23] using the JAFROC figure of merit (FOM) for optimal statistical power. A difference in lesion detection performance would be considered significant at $p < 0.05$.

Twenty observers, of varying CT experience (0-24 years, mean 4.25 ± 6.78 years), performed the ROCview lesion detection study. They assessed case-matched images (15 normal and 12 abnormal cases for each mA value (FROC modality), 108 images in total) showing 17 simulated pulmonary lesions. Observers were aware of the case mix and the range of simulated pulmonary lesions per image (0-4). Observers were able to make up to 6 localisations per image, allowing opportunity for both lesion localisations (LL) and non-lesion localisations (NL) in all images. Observers were

instructed to locate only the simulated pulmonary lesions and to ignore all other coincidental mimics of pathology that the phantom may produce.

Viewing Conditions and Study Controls

The TG-18 test card [24,25] was used to ensure the quality of the reporting standard monitor used for displaying the images on ROCView. The monitor was calibrated according to local clinical specification with ambient lighting dimmed and constant for all observers. The influence of observer familiarity with CT image adjustment (zooming/windowing) was negated, as image adjustment was not permitted in this FROC study. Consequently, the only variable was the mA value used. ROCview automatically randomised and displayed images on a CT lung window (width 1500, level -500).

Dose Recordings

The GEH4 provides the computed tomography dose index ($CTDI_{vol}$) as an indication of dose received. The effective mAs was calculated and effective dose (E) estimated using a chest specific conversion factor ($0.014 \text{ mSv mGy}^{-1} \text{ cm}^{-1}$) following a previously described method [26].

Quality Control – Hounsfield Unit Accuracy

Conventional CT indicates that HU variation is in the magnitude of $<1\text{HU}$ for a variation in mA [9]. This was assessed on the GEH4 using the American College of Radiologists (ACR) CT Accreditation Phantom [27]. The average pixel value of a 200mm^2 region of interest (ROI) was recorded for five modules of known density. HU

value accuracy is required for AC as they are converted to attenuation coefficients at the energy of the SPECT radionuclide [2].

Results

The JAFROC FOM revealed no significant difference in lesion detection performance for all mA values used ($p=0.826$). Observer averaged JAFROC FOM values can be found in Table 2 alongside the dose recordings and calculated E for each mA value. Individual observer performance was consistent between variations of mA with an intra-observer standard deviation (SD) range of 0.01-0.11. Inter-observer variation was also low for each mA setting (1mA SD = 0.08; 1.5mA SD = 0.09; 2.0mA SD = 0.10; 2.5mA SD = 0.13). E was calculated for full FOV (40cm) CTAC acquisitions at each mA setting, estimating a dose saving of 60% if using 1mA instead of 2.5mA. CT HU values measured in a DICOM viewer [28] showed negligible variation as a result of changing mA (Table 3). The greatest deviation was observed within the low-density regions of the phantom (Poly and Air); although this was still small in magnitude (change of 3HU). The variation in image quality at the four mA values can be seen in Figure 2.

Discussion

For the static anthropomorphic chest phantom representative of a 70Kg male there was no statistically significant difference in lesion detection for the four mA values. Although our experiment did not simulate respiratory motion there is evidence to suggest that incidental extra-cardiac lesions could be detected equally well on images acquired at 1mA as those acquired at 2.5mA. This finding concurs with a previous patient based study, where a 1mA attenuation map was acquired at rest

and a 2.5mA attenuation map at stress; both image sets revealed abnormal findings at a rate of 9.7% [12]. The patient based study and our work both describe potential dose saving in the region of 60%.

We have shown, via the acquisition of QC data, that HU accuracy is unaffected by mA in this SPECT/CT system (Table 3); therefore the linear attenuation coefficients that make up the attenuation map must also be unaffected. This is suggestive of the quality of AC being maintained despite a reduced mA. Combining this information with the results of our JAFROC analysis suggests a potential for dose saving without any detrimental effect on the primary outcome (good quality AC) in regard of the CTAC acquisitions for this system or secondary outcome (detection of incidental chest pathology). The GEH4 offers image reconstruction filters that are optimized for low-dose operation and this system can outperform diagnostic systems in terms of contrast-to-noise ratio (CNR), in the low-dose range, due to the filters in operation [29]. Consequently, it is possible that not all systems will respond to using a very low dose regime.

Our data provide insight into the potential for dose saving in patients undergoing myocardial perfusion SPECT/CT. However, some caution must be applied to the results because our work only considers a phantom representing 'Standard Man'; there is an acknowledged gap between phantom studies and clinical work. In our (static) phantom study we did not set out to determine the effect of respiratory motion on lesion detection. Variation in respiratory motion can be great, both within subjects and between them [30,31] but previous work comparing 2.5mA attenuation

maps at stress and 1mA attenuation maps at rest saw equal detection rates (9.7%) of abnormal findings [12]. In this work the authors do comment that the attenuation map, with a rotation time of 14 seconds was sampled over approximately 3 respiratory cycles.

Respiratory motion has been a persistent problem in hybrid imaging, affecting both emission and transmission acquisitions with errors of mis-registration known to contribute to errors in AC [30,31]. Methods of correction, including respiratory gating, deep-inspiration-breath-hold (DIBH), motion correction and post processing methods, have been discussed to correct for these errors [30]. Furthermore the phase of breathing (inspiration, mid-breath, expirations) also has been found to have a significant bearing on AC [30,32].

Further phantom work should attempt to simulate motion over a range of respiratory amplitudes, with a previous patient study has suggested that lesion position and size can contribute to errors caused by respiratory motion [30].

Investigating the effect of patient size might prove beneficial too

Conclusion

Using a static anthropomorphic chest phantom with simulated lesions, the GEH4 can be used with equal confidence at each of its 4 mA settings for accurate lesion localisation on the CTAC image. Prior to conducting a human study further phantom work should be conducted to consider the effect of respiratory motion and patient size on lesion detection.

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