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 mSv mGy^{-1} cm^{-1}) following a previously described method [26].

Quality Control – Hounsfield Unit Accuracy

Conventional CT indicates that HU variation is in the magnitude of <1HU 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.

References

1. Buck, A. Nekolla, S. Ziegler, S. Beer, A. Krause, B. Herrmann, K. Scheidhauer, K. Wester, H-J. Rummeny, E. Schwaiger, M. Drzezga, A. SPECT/CT. J Nucl Med 2008;49:1305-19.

2. O'Connor, M. Kemp, B. Single-Photon Emission Computed Tomography / Computed Tomography: Basic Instrumentation and Innovations. Semin Nucl Med 2006;36:258-66.

3. Heller, G. Links, J. Bateman, T. Ziffer, J. Ficaro, E. Cohen, M. Hendel, R. American Society of Cardiology and Society of Nuclear Medicine joint position: Attenuation correction of myocardial perfusion SPECT scintigraphy. J Nucl Cardiol 2004;11:229-30.

4. Flotats, A. Knuuti, J. Gutberlet, M. Marcassa, C. Bengel, F. Kaufmann, P. Rees, M. Hesse, B. Hybrid cardiac imaging: SPECT/CT and PET/CT. A joint position statement by the European Association of Nuclear Medicine (EANM), the European Society of Cardiac Radiology (ESCR) and the European Council of Nuclear Cardiology (ECNC) Eur J Nucl Med Mol Imaging 2011;38:201-12.

5. Goetze, S. Pannu, H. Wahl, R. Clinically Significant Abnormal Findings on the 'Nondiagnostic' CT Portion of Low-Amperage-CT Attenuation-Corrected Myocardial Perfusion SPECT/CT Studies. J Nucl Med 2006;47:1312-8.

6. Tootell, A., Vinjamuri, S., Elias, M., & Hogg, P. (2012). Clinical evaluation of the computed tomography attenuation correction map for myocardial perfusion imaging: the potential for incidental pathology detection. Nucl Med Commun, Publish Ahead of Print, 10.1097/MNM.1090b1013e3283571b3283535.

7. Chamarthy, M. Travin, M. Altered Biodistribution and Incidental Findings on Myocardial Perfusion Imaging. Semin Nucl Med 2010;40:257-70.

8. Gedik, G. Ergün, E. Aslam, M. Caner, B. Unusual Extracardiac Findings Detected on Myocardial Perfusion Single Photon Emission Computed Tomography Studies with Tc-99m Sestamibi. Clin Nucl Med 2007;32:920-6.

9. Birnbaum, B. Hindman, N. Lee, J. Babb, J. Multi-Detector Row CT Attenuation Measurments: Assessment of intra- and interscanner Variability with an Anthropomorphic Body CT Phantom. Radiol 2007;242:109-19.

10. Reza Ay, M. Zaidi, H. Computed tomography-based attenuation correction in neurological positron emission tomography: evaluation of the effect of the X-ray tube voltage on quantitative analysis. Nuc Med Commun 2006;27:339-46.

11. Kamel, E. Hany, T. Burger, C. Treyer, V. Lonn, A. von Schulthess, G. Buck, A. CT vs 68Ge attenuation correction in a combined PET/CT system: evaluation of the effect of lowering the CT tube current. Eur J Nuc Med 2002;29:346-50.

12. Preuss, R. Weiss, R. Lindner, O. Fricke, E. Fricke, H. Burchert, W. Optimisation of protocol for low dose CT-derived attenuation correction in myocardial perfusion SPECT imaging. Eur J Nucl Med Mol Imaging 2008;35:1133-41.

13. Thompson, J. Hogg, P. Szczepura, K. Manning, D. Analysis of CT acquisition parameters suitable for use in SPECT/CT: A free-response receiver operating characteristic study. Radiography 2012:doi:10.1016/j.radi.2012.05.004

14. KyotoKagaku.com Japan [updated 2011; cited 2012 Jul 04] Multipurpose Chest Phantom N1. Available from: http://www.kyotokagaku.com/products/detail03/pdf/ph-1_catalog.pdf

15. Das, M. Mühlenbruch, G. Katoh, M. Bakai, A. Salganicoff, M. Stanzel, S. Mahnken, A. Günther, R. Wildberger, J. Automated Volumetry of Solid Pulmonary Nodules in a Phantom: Accuracy Across Different CT Scanner Technologies. Invest Radiol 2007;42:297-302.

16. Ko, J. Rusinek, H. Jacobs, E. Babb, J. Betke, M. McGuinness, G. Naidich, D. Small Pulmonary Nodules: Volume Measurment at Chest CT – Phantom Study. Radiol 2003;228:864-70.

17. Marten, K. Grabbe, E. The challenge of the solitary pulmonary nodule: Diagnostic assessment with multislice spiral CT. Clin Imaging 2003:27;156-61.

18. Wormanns, D. Kohl, G. Klotz, E. Marheine, A. Beyer, F. Heindel, W. Diederich, S. Volumetric measurements of pulmonary nodules at multi-row detector CT: in vivo reproducibility. Eur Radiol 2004:14;86-92.

19. Oda, S. Awai, K. Murao, K. Ozawa, A. Yanaga, Y. Kawanaka, K. Yamashita, Y. Computer-Aided Volumetry of Pulmonary Nodules Exhibiting Ground-Glass Opacity at MDCT. Am J Roentgenol 2010:194;398-406.

20. Funama, Y. Awai, K. Liu, D. Oda, S. Yanaga, Y. Nakaura, T. Shimamura, M. Yamashita, Y. Detection of nodules showing ground-glass opacity in the lungs at low-dose multidetector computed tomography: phantom and clinical study. J Comput Assist Tomogr 2009:33;49-53. Abstract Only accessed via www.ncbi.nlm.nih.gov/pubmed

23. devchakraborty.com Philadelphia [updated 2011; cited 2012 Jul 04]. Available from: http://www.devchakraborty.com/Historical%20Background.html

22. Thompson, J. Hogg, P. Thompson, S. Manning, D. Szczepura, K. ROCView: Prototype software for data collection in jackknife alternative free-response receiver operating characteristic analysis.
Br J Radiol 2012: doi:10.1259/bjr/99497945

23. devechakraborty.com Philadelphia [updated 2011; cited 2012 Jul 04]. JAFROC 4.0.1 Available from: http://www.devchakraborty.com/downloads

24. Samei, E. Badano, A. Chakraborty, D. Compton, K. Cornelius, C. Corrigan, K. Flynn, MJ. Hemminger, B. Hangiandreou, N. Johnson, J. Moxley, M. Pavlicek, W Roehrig, H. Rutz, L. Shepherd, J. Uzenoff, R. Wanj, J. Willis, C. Assessment of Display Performance for Medical Imaging Systems: Report of the American Association of Physicists in Medicine (AAPM) Task Group 18; Medical Physics Publishing, Madison, WI, AAPM On-Line Report No. 3, April 2005.

25. deckard.mc.duke.edu Assessment of Display Performance for Medical Imaging Systems (American Association of Physicists in Medicine (AAPM) Task Group 18) [updated 2006 Jan 10; cited 2012 Jan 31] Available from: deckard.mc.duke.edu/~samei/tg18

26. Jessen, K. Shrimpton, P. Geleijns, J. Panzer, W. Tosi, G. Dosimetry for optimisation of patient protection in computed tomography. Appl Radiat Isot 1999;50:165-72.

27. gammex.com Wisconsin [updated 2011; cited 2012 Jul 11]. CT Accreditation Phantom Instructions. Available from: http://www.gammex.com/acefiles/manuals/ACR_CT_Phantom.pdf (American College of Radiologists)

28. Rosset A, Spadola L, Ratib O. OsiriX: an open-source software for navigating in multidimensional DICOM images. J Digit Imaging. 2004 Sep;17(3):205–16.

29. Hamann, M. Aldridge, M. Dickson, J. Endozo, R. Lozhkin, K. Hutton, B. Evaluation of a low-dose/slow-rotating SPECT-CT system. Phys Med Biol 2008;53:2495-508.

30. Liu, C. Pierce, LA. Alessio, AM. Kinahan, PE. The impact of respiratory motion on tumor quantification and delineation in static PET/CT imaging. Phys Med Biol 2009;54:7345-7362.

31. Dey, J. Segars, WP. Pretorius, H. Walvick, RP. Bruyant, PP. Dahlberg, S. King, MA. Estimation and correction of cardiac respiratory motion in SPECT in the presence of limited-angle effects due to irregular respiration. Med Phys 2010;37;6453-6465.

32. Koshino, K. Fukushima, K. Fukumoto, M. Sasaki, K. Moriguchi, T. Hori, Y. Zeniya, T. Nishimura, Y. Kiso, K. Iida, H. Breath-hold CT attenuation correction for quantitative cardiac SPECT. Eur J Nuc Med Mol Imaging Res 2012;2;2 doi: 10.1186/2191-219X-2-33 Accessed via PubMed: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3444955/pdf/2191-219X-2-33.pdf