Automatic Tube Voltage Selection and Dose Reduction in Computed Tomography

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INTRODUCTION

The use of computed tomography (CT) has greatly increased in recent years, with the latest survey showing 68% of all medical radiation exposures result from CT scans in the United Kingdom (Public Health England, 2010). Despite CT being an invaluable diagnostic tool, exposure to ionising radiation can lead to adverse health effects (World Health Organisation, 2016). To minimise this exposure the 'as low as reasonably practicable' principle is used in radiology (ICRP, 2006) and in response manufacturers have introduced multiple dose-reduction strategies. Many of these are automated, such as automatic tube current modulation (ATCM), iterative reconstruction (IR) and the recent software development of automatic tube voltage selection (ATVS) (Barker et al., 2015).

The aim of this poster is to describe the technology of ATVS, explore its use in dose reduction, discuss its clinical benefits and explain its limitations.

TECHNOLOGY

ATVS is an algorithm software that enables CT scanners to automatically select the kilovoltage (kV) that achieves a desired image quality at the lowest appropriate dose for the patient's size, system capabilities and examination (Kalra, Sodickson and Mayo-Smith, 2015). Image quality is defined by a user-specified constant contrast-to-noise ratio (CNR). Dose is considered in terms of the CT volume dose index ($CTDI_{vol}$) (Higaki et al., 2019).

To use the ATVS a topogram is performed using a protocol specific reference kV and the corresponding attenuation information of the patient obtained. The algorithm then calculates the required tube current (mAs) for each kV setting (typically 80, 100, 120 or 140) to achieve the user-specified image quality and calculates their respective $CTDI_{vol}$. Ideally this step is performed with ATCM for further dose reduction. Finally, the optimal kV and ATCM combination is selected that delivers the lowest $CTDI_{vol}$ whilst achieving constant CNR for that specific patient's scan (Chae et al., 2014).

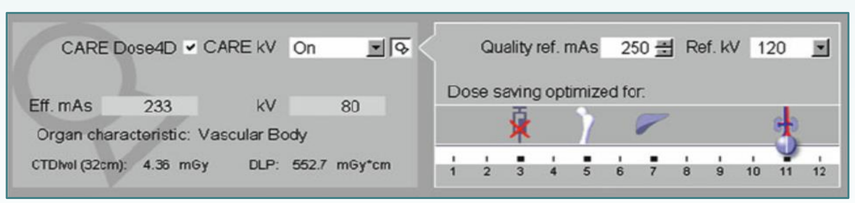

Figure 1. Shows CARE kV turned 'On', with the dose saving optimizer bar set to 11. (Yu, Fletcher and McCollough, 2010).

Figure 1 is an example of ATVS, named CARE kV, on a Siemens Healthcare CT scanner. The reference kV and quality reference mAs were set as 120 and 250 respectively, with the optimal kV calculated to be 80. This is with the dose saving optimizer bar position set at 11, which corresponds to the CNR for vascular examinations. Near position 1 the algorithm strength is weaker and the chance of selecting a lower kV is unlikely with less or no dose reduction. Towards 12 the strength is stronger and the chance of selecting a lower kV is higher with more potential for dose reduction (Yu, Fletcher and McCollough, 2010).

ATVS AND DOSE

Numerous studies have shown ATVS can reduce dose significantly for a variety of examinations, including non-contrast chest (Chae et al., 2014), contrast-enhanced chest-abdomen-pelvis (CAP) (Beeres et al., 2014) and paediatric scans (Shimonobo et al., 2016). Another recent retrospective study by O'Hora and Foley (2018) examined the effect of ATVS on radiation doses in four common CT examinations; brain, pulmonary angiogram (PA), abdomen and CAP scans. ATVS demonstrated a potential 4-42% dose reduction whilst maintaining image quality. However ATVS was not used alone, but alongside IR and ATCM. This potential dose reduction was then compared to ATCM alone and ATCM with IR. The table in Figure 2 shows the frequency that ATVS altered the reference kV for the four scans and therefore lowered the patients $CTDI_{vol}$. For 100% of the brain scans ATVS used the reference kV, this is likely due to skull sizes seldom differing substantially between adults. Conversely ATVS selected a lower kV for 100% of the abdomen and CAP scans. The study suggests that depending on the scan type, ATVS can reduce dose by adjusting the kV from the typical protocol kV. However this study is limited as the abdomen and CAP results suggest the study cohort contains a homogenous group of patient sizes.

		Frequency of automatic tube voltage selection changing the kV(%)		
CT scan type	Number of scans	Reference tube voltage used	Lower tube voltage used	Higher tube voltage used
Brain	348	100	0	0
CTPA	286	40	48	12
Abdomen	320	0	100	0
CAP	337	0	100	0

Figure 2. Percentage frequency of ATVS altering the kV from the reference kV set per scan type. The reference kV used for the brain, abdomen and CAP scans was 120kV. The reference kV for the CTPA scans was 100kV (O'Hora and Foley, 2018).

ATVS is examination specific and multiple studies have found that when used alongside intravenous contrast medium (CM), radiation dose can be further reduced whilst maintaining CNR (Choi, Lee and Jung, 2020) (Lü et al., 2015). The administration of CM is typically used to improve image contrast, which is best when a low kV is used, since the relative attenuation of CM is increased (Aschoff et al., 2017).

Figure 3 (a-d) shows a comparison of the CNR in the aorta at different radiation exposures, illustrating how lower kV can lower dose whilst maintaining a similar CNR with CM (Higaki et al., 2019). Image Contrast appears the same after adjustment of the window level (WL) and window width (WW), however the study is limited as only one size phantom was used. Complementary to this a retrospective study by Mangold et al. (2016) on CT coronary angiograms, found ATVS provided 98.9% diagnostic images, whilst providing dose reductions up to 81% and in addition a CM reduction up to 37.5 %. This reduction was calculated in comparison to using the standard 120kV. The study used an arbitrarily chosen fixed amount of CM volume at each kV level and therefore cannot represent the true potential CM reduction capabilities of ATVS.

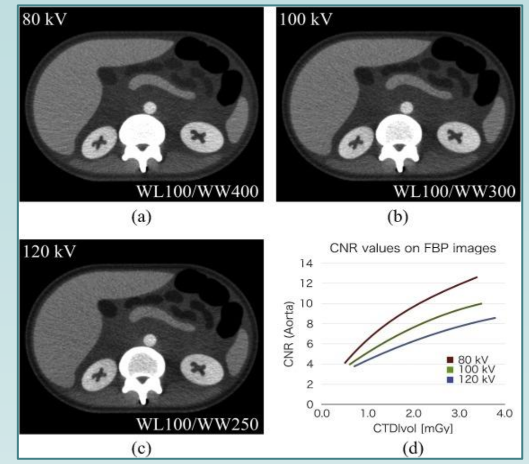

Figure 3. A single phantom study by Higaki et al. (2019), demonstrating contrast-enhanced abdominal phantom images and aortic CNR at different X-ray tube voltages.
(a) 80 kV, 0.9 mGy
(b) 100 kV, 1.3 mGy
(c) 120 kV, 2.0 mGy
(d) Graph showing CNR values on filtered back projection images. CNR of the aorta is plotted against the $CTDI_{vol}$ of the phantom at the three different kV voltages.

LIMITATIONS

A study by Yu, Fletcher and McCollough (2010) compared the $CTDI_{vol}$ at four different kV levels when the CNR is constant for three different sized phantoms. As demonstrated in Figure 4, the $CTDI_{vol}$ required to match CNR is lower for kV levels below 120 for the two smallest phantoms. However the larger 45cm phantom shows minimal to no dose saving at alternative kV levels. Higher doses were actually required to match CNR at 80kV and 140kV. Patient size is therefore a limiting factor for ATVS to reduce dose. A study by Chae et al. (2014) also found that only patients with a body mass index (BMI) less than 30 showed statistically significant radiation dose reductions.

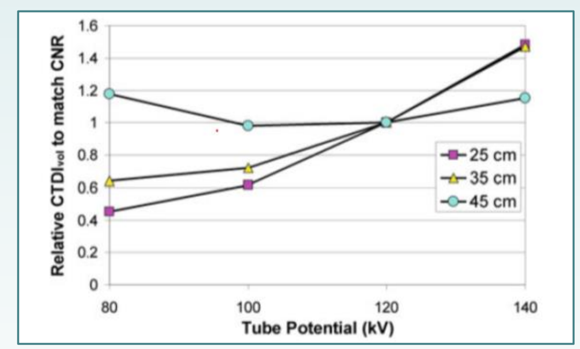

Figure 4. The relative $CTDI_{vol}$ required to match CNR for each kV used compared to $CTDI_{vol}$ for 120kV to provide desired CNR. Therefore 120kV is fixed at 1 on this graph for all kV levels. Plotted are the results for three different sized phantoms; 25cm, 35cm and 45cm in lateral width (Yu et al., 2010).

Another limiting factor is patient positioning within the iso-centre of the gantry. A single phantom study by Kaasalainen, Mäkeläa, and Kortesniemia (2019) demonstrated that incorrect positioning can cause a $CTDI_{vol}$ increase of up to 91%. This was due to the topogram appearing magnified and therefore ATVS estimated higher patient attenuation and selected a higher kV than appropriate. This also causes higher ATCM and is an attributing factor. Therefore correct patient centring is essential for ATVS to select the appropriate kV.

CONCLUSION

This poster has explained the technology of ATVS, discussed its clinical benefits and explored the software's limitations. In conclusion ATVS can significantly reduce dose and in some cases the amount of CM used, depending on patient size and diagnostic task. It has particular benefits for low BMI adults, paediatric patients and contrast-enhanced scans. However correct patient positioning is essential and it should be used in conjunction with ATCM and IR for optimal dose reduction and image quality.

REFERENCES

Student number:110006423

Aschoff, A. J., Catalano, C., Kirchin, M. A., Krix, M. and Albrecht, T. (2017) ‘Low radiation dose in computed tomography: the role of iodine’, *The British Journal of Radiology*, 90(1076). doi:10.1259/bjr.20170079

Barker, M. E., Karim, W., Bullen, J. A., Primak, A, N., Dong, F. F. and Herts, B. R. (2015) ‘Estimated patient dose indexes in adult and pediatric MDCT: comparison of automatic tube voltage selection with fixed tube current, fixed tube voltage, and weight-based protocols’, *American Journal of Roentgenol*, 205(3), pp. 592–598. doi:10.2214/AJR.14.13242

Beeres, M., Römer, M., Bodelle, B., Lee, C., Gruber-Rouh, T., Mbalisike, E., Kerl, J. M., Wichmann, J. L., Schulz, B., Vogl, T. and Bauer, R. W. (2014) ‘Chest-abdomen-pelvis CT for staging in cancer patients: dose effectiveness and image quality using automated attenuation-based tube potential selection’, *cancer imaging,* 14(28). doi:10.1186/s40644-014-0028-7

Chae, I. H., Kim, Y., Lee, S. W., Park, J. E., Shim, S. S. and Lee, J. H. (2014) ‘Standard chest CT using combined automated tube potential selection and iterative reconstruction: image quality and radiation dose reduction’, *Clinical Imaging,* 38, pp. 641–647. doi:10.1016/j.clinimag.2014.04.004

Choi, M. H., Lee, Y. J. and Jung, S. E. (2020) ‘A lessons from automatic tube voltage selection: Feasibility of 100kVp in portal Venous phase abdominal CT’, *Radiation Protection Dosimetry*, 302, pp.1–8. doi:10.1093/rpd/ncz302

Higaki, T., Nakamura, Y., Fukumoto, W., Honda, Y., Fatsugami, F. and Awai, K. (2019) ‘Clinical applications of radiation dose reduction at abdominal CT’, *European Journal of Radiology,* 111, pp.68–76. doi:10.1016/j.ejrad.2018.12.018

ICRP (2006) ‘The Optimisation of Radiological Protection - Broadening the Process’, *ICRP Publication*, 36(3), Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/518487/PHE-CRCE-026_-_V1-1.pdf

Kaasalainen, T., Mäkeläa, T. and Kortesniemia, M. (2019) ‘The effect of vertical centering and scout direction on automatic tube’, *European Journal of Radiology,* 6, pp. 24–32. doi:10.1016/j.ejro.2018.12.001

Kalra, M. K., Sodickson, A. D. and Mayo-Smith, W. W. (2015) ‘CT Radiation: Key Concepts for Gentle and Wise Use’, *Radiographics,* 35(6), pp. 1706–1721. doi:10.1148/rg.2015150118

Lü, P., Liu, J., Zhang, R., Jia, Y., & Gao, J. (2015) ‘Combined Use of Automatic Tube Voltage Selection and Current Modulation with Iterative Reconstruction for CT Evaluation of Small Hypervascular Hepatocellular Carcinomas: Effect on Lesion Conspicuity and Image Quality’, *Korean journal of radiology*, *16*(3), pp. 531–540. doi:10.3348/kjr.2015.16.3.531

Mangold, S., De Cecco, C. N., Wichmann, J. L., Canstein, C., Varga-Szemes, A., Caruso, D., Fuller, S. R., Bamberg, F., Nikolaou, K. and Schoepf. J. (2016) ‘Effect of automated tube voltage selection, integrated circuit detector and advanced iterative reconstruction on radiation dose and image quality of 3rd generation dual-source aortic CT angiography: An intra-individual comparison’, *European Journal of Radiology,* 85(5), pp. 972–978. doi:10.1016/j.ejrad.2016.02.021

O’Hora, L. and Foley, S. J. (2018) ‘Iterative reconstruction and automatic tube voltage selection reduce clinical CT radiation doses and image noise’, *Radiography,* 24, pp. 18–32. doi:10.1016/j.radi.2017.08.010

Public Health England (2010) ‘*Ionising Radiation Exposure of the UK Population: 2010 Review’,* Available at: https://www.gov.uk/government/publications/ionising-radiation-exposure-of-the-uk-population-2010-review (Accessed: 22 March 2020)

Shimonobo, T., Funama, Y., Utsunomiya, D., Nakaura, T., Oda, S., Kiguchi, M., Masuda, T,, Sakabe, D., Yamashita, Y. and Awai, K. (2016) ‘Low-tube-voltage selection for non-contrast-enhanced CT: Comparison of the radiation dose in pediatric and adult phantoms’, *Physica Medica,* 32(1), pp. 197–201. doi:10.1016/j.ejmp.2015.12.005

World Health Organisation (2016) *Ionizing radiation, health effects and protective measures.* Available at: https://www.who.int/news-room/fact-sheets/detail/ionizing-radiation-health-effects-and-protective-measures (Accessed 24 March 2020)

Yu, L., Fletcher, J. G. and McCollough, C. H. (2010) ‘Automatic Selection of Tube Potential for Radiation Dose Reduction in CT: A General Strategy’, *Medical Physics*, 37(1), pp. 234-243.