Title
Advantages of Colour-Coded Dual-Energy CT Venography in Emergency Neuroimaging

Journal
British Journal of Radiology, 94(1127)

ISSN
0007-1285

Authors
Campo, Camilo A
Czajkowski, Bryan
Sodickson, Aaron D

Publication Date
2021-11-01

DOI
10.1259/bjr.20201309

Peer reviewed

BJR
© 2021 The Authors. Published by the British Institute of Radiology
https://doi.org/10.1259/bjr.20201309

Received: 05 November 2020 | Revised: 07 May 2021 | Accepted: 24 July 2021

Cite this article as:
Campo CA, Czajkowski B, Sodickson AD. Advantages of Colour-Coded Dual-Energy CT Venography in Emergency Neuroimaging. *Br J Radiol* 2021; **94**: 20201309.

PICTORIAL REVIEW

Advantages of Colour-Coded Dual-Energy CT Venography in Emergency Neuroimaging

[1,2]CAMILO A CAMPO, MD, [3]BRYAN CZAJKOWSKI and [2,3]AARON D SODICKSON, MD, PhD

[1]Department of Radiology and Biomedical Imaging, University of California San Francisco, San Francisco, CA, USA
[2]Harvard Medical School, Boston, MA, USA
[3]Department of Radiology, Brigham and Women's Hospital, Boston, MA, USA

Address correspondence to: Dr Aaron D Sodickson
E-mail: *asodickson@bwh.harvard.edu*

ABSTRACT:
The objective of this Pictorial Review is to describe the use of colour-coded Dual-Energy CT (DECT) to aid in the interpretation of CT Venography (CTV) of the head for emergent indications. We describe a DE CTV acquisition and post-processing technique that can be readily incorporated into clinical workflow. Colour-coded DE CTV may aid the identification and characterization of dural venous sinus abnormalities and other cerebrovascular pathologies, which can improve diagnostic confidence in emergent imaging settings.

INTRODUCTION

CT venography (CTV) of the head is commonly used to evaluate the intracranial venous circulation, and enables rapid detection of pathologies such as venous sinus thrombosis or active intracranial haemorrhage. Advances in dual-energy CT (DECT) technology have enabled multiple clinical applications, many of which are particularly well suited for emergent imaging settings in which CT is critical for rapid diagnosis of acute brain injuries and cerebrovascular pathologies.[1,2] DECT differentiates materials based on their energy-dependent X-ray absorption characteristics. These capabilities can be used to differentiate the iodine content of contrast agents from haemorrhage to diagnose ongoing active extravasation or contrast staining following neuro-interventional procedures.[3,4] Alternatively, DECT can be used to perform robust bone subtraction for routine head CT or CT angiography (CTA), which allows for better visualization of subdural haematomas or other pathology adjacent to the calvarium, and improves vascular delineation in regions of surrounding bone.[2,5–7] In non-contrast imaging, DECT post-processing can differentiate calcium from haemorrhage.[8,9]

IODINE POST-PROCESSING AND COLOUR-OVERLAY DISPLAY

By differentiating materials based on their energy-dependent X-ray absorption characteristics, DECT post-processing in CTV of the head can accurately highlight the attenuation attributable to iodine (Figure 1). The DECT iodine contents can be presented in different ways, including iodine-selective images or colour-coded overlays (Figure 2). Iodine-selective images display only the portions of the image that are calculated to contain iodine in the DECT post-processing algorithm, producing an iodine map, which may be presented in grey-scale or in colour (Figure 2B). These images alone typically need to be viewed in concert with a conventional image to gain anatomic context. Conversely, the DECT post-processing algorithm can also subtract the iodine content from a grey-scale image, creating a virtual non-contrast (VNC) image (Figure 2C). Putting these two components together, DECT results can be presented using colour-coded overlay images, as has been popularized in PET/CT. Here, the colour-coded overlay value (*e.g.,* FDG avidity in PET) is superimposed on top of a greyscale image that conveys greater anatomic information, such as a conventional CT scan. In DECT, the colour-coded iodine content of the iodine map is superimposed upon the perfectly co-registered anatomic information in the VNC image, making localization easy and intuitive (Figure 2D). As a result, colour-coded iodine overlay images have become the mainstay of interpretation for iodine DECT reconstructions in our practice. By using colour-coded overlay images in the setting of CTV of the head, iodine content in the dural venous system can be more clearly differentiated from other surrounding hyperattenuating materials, such as haemorrhage or calcification (Figure 2D).

Figure 1. Used with permission from Potter et al and RadioGraphics.[1] Three-material decomposition of iodine. A base material line (red line) is defined by the attenuation of cerebrospinal fluid (CSF) and brain parenchyma at low and high kVp. The addition of iodinated contrast (upward blue arrows) increases the attenuation along a characteristic slope, such that everything in the blue-shaded region is attributed to iodine. By projecting back to the base material line along the iodine slope, the attenuation of any voxel (X) in a post-contrast scan can then be decomposed into contributions from the contained iodine and the residual virtual non-contrast (VNC) attenuation.

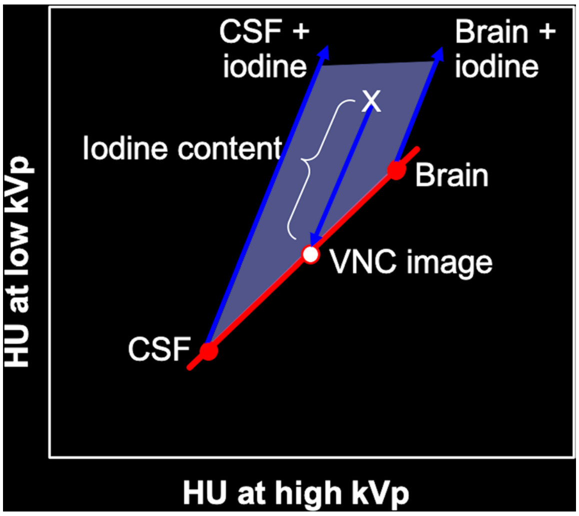
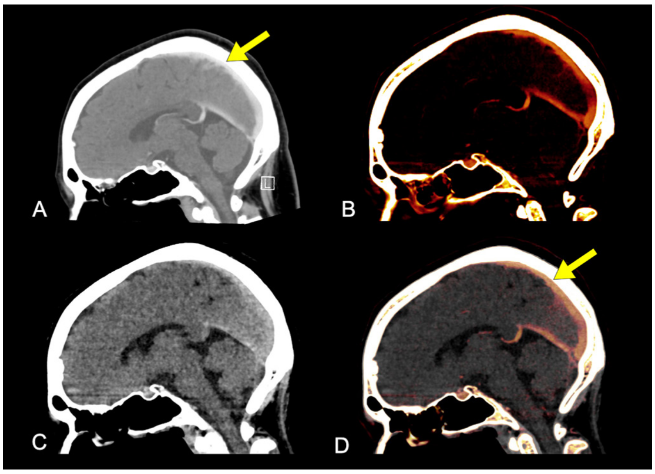


Figure 2. When compared to conventional CTV (A), DECT results can be presented in ways that more clearly differentiate iodine-containing structures from adjacent hyperattenuating structures. (B) Iodine-selective presentation typically displays an iodine map, which highlights the portions of the image that are calculated to contain iodine (*i.e.,* intravenous contrast). (C) DECT post-processing can also subtract the iodine content to create a greyscale virtual non-contrast (VNC) image. (D) Colour-coded overlay presentation superimposes the iodinecontent in colour, on top of the VNC greyscale image, to convey greater anatomic information. Colour-coded iodine content in the dural venous sinuses can be more clearly differentiated from other hyperattenuating materials, such as the adjacent calvarium, when compared to conventional CTV (arrows).



RADIATION DOSE CONSIDERATIONS

A common misconception regarding the use of DECT is that patients are exposed to increased radiation because of the need to obtain two data acquisitions at low and high energies. However, studies have shown that in practice, the DECT radiation dose is typically split between the acquired low and high energy data such that the total dose can be readily made equivalent to, or even lower than, that of a comparable single-energy CT scan.[10,11]

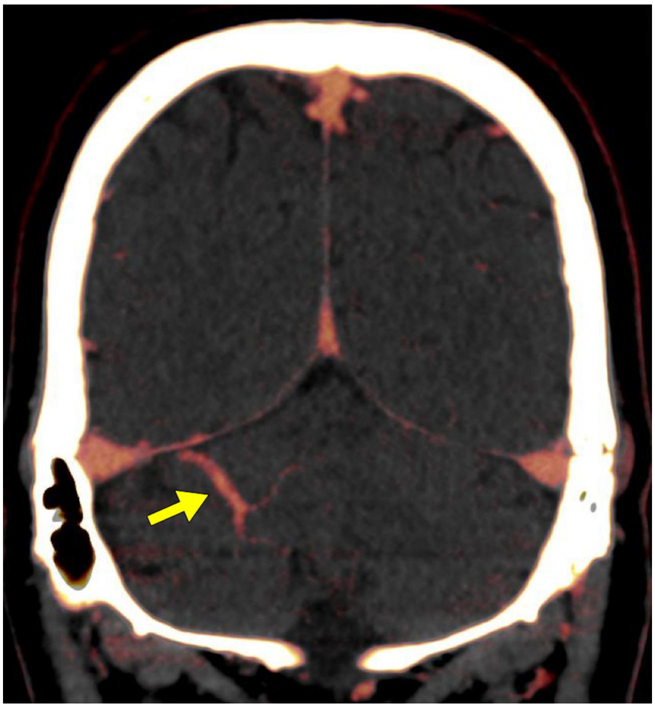
Therefore, the objective of this Pictorial Review is to describe DE CTV acquisition and post-processing, and to showcase the potential use of colour-coding to aid the identification and characterisation of dural venous sinus abnormalities and other cerebrovascular pathologies.

TECHNIQUE: DUAL-ENERGY CTV IMAGE ACQUISITION AND POST-PROCESSING

We acquire our CTV phase using a dual-source CT scanner (Somatom Flash, Siemens Healthineers, Forchheim Germany) with tubes operating at 100 and Sn140 kVp (Sn denotes the added tin filter used to increase spectral separation between tubes), and detector configuration 40 × 0.6 mm on each tube. Tube current modulation (CareDose4D) is used with a reference value of 300 mAs on each tube. Conventional CTV images are reconstructed as a weighted average of the low and high kVp image sets (mixing ratio 0.4) using a soft-tissue kernel (J40f) and iterative reconstruction (SAFIRE strength 2). 0.75 × 0.5 mm low and high kVp images (Q34f kernel, SAFIRE strength 2) are sent to thin-client server software (Syngo.via), configured to post-process 3 × 2 mm axial and coronal iodine overlay images as well as axial VNC images, and to transmit them to PACS in a fully automated workflow. The "Brain Hemorrhage" application described in Figure 1 is used, with iodine overlay images created by superimposing the colour-coded iodine images (using the "Liver VNC 3" lookup table with window width/center of 150/75 HU) on the greyscale VNC images (window width/center of 80/40 HU).

The CTV acquisition using the parameters above results in a mean ± stdev CTDIvol of 48.9 ± 3.8 mGy (166 consecutive CTV acquisitions performed between 03/14/2019 and 11/29/2020, using data extracted from our departmental radiation dose database). This protocol has identical acquisition parameters as our routine non-contrast DECT head CT performed on the same Emergency Department scanner. For comparison, our conventional single-energy CTV doses performed on our inpatient scanner (Siemens Definition Edge, detector configuration 40 × 0.6 mm, reference mAs 360, kernel J40s with Safire strength 2) have CTDIvol of 45.8 ± 5.4 mGy (571 consecutive delayed head acquisitions performed in the same time interval). The dual energy doses are thus about 7% higher than those on the single source scanner, with $p < 0.001$ (2-tailed t-test assuming unequal variances). These differences could be easily offset if desired with slight changes in the selected reference mAs values. Regardless, these exposure values are well below the Diagnostic Reference level of 75 mGy used in ACR accreditation.

Figure 3. Coronal iodine overlay DE CTV image, in which iodine content is colour-coded in orange, superimposed upon grey-scale VNC images. Uniform colour filling the dural venous sinuses makes it easy to assess patency. A prominent right cerebellar developmental venous anomaly (arrow) is also nicely delineated in colour.

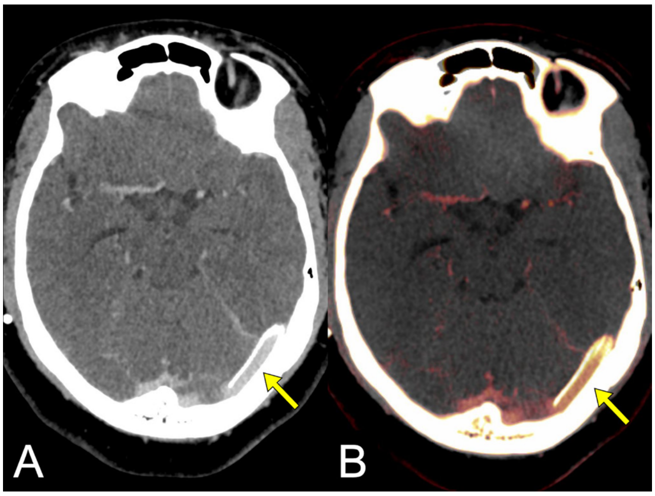


DISCUSSION

DECT permits material characterization by taking advantage of differences in the energy-dependent X-ray absorption characteristics of the materials. In the setting of CTV of the head, iodine content can be more clearly differentiated from other hyperattenuating materials, particularly haemorrhage and calcification. DECT is readily incorporated into CTV acquisition, and post-processing can be configured to display colour-coded iodine overlay images. These may aid in CTV interpretation as they can increase the conspicuity of cerebrovascular pathology. As a result, normal scans may be interpreted more rapidly by negating the need to adjust window settings to differentiate venous iodine from the adjacent calvarium. Additionally, normal scans may be read with a higher degree of confidence. For example, Figure 3 demonstrates the typical appearance of widely patent dural venous sinuses on colour-coded iodine overlay images, as well as clear delineation of variant venous anatomy. In Figure 4 of a patient with a dural venous stent, patency can be readily confirmed by the presence of colour-coded iodine content within the stent.

In cases of cerebrovascular pathology, CTV diagnostic tasks can be simplified by using colour-coded overlay images. Venous thrombosis can be more clearly visualised as a colour void within the iodine-filled sinus when compared with conventional CTV (Figure 5). Additionally, extra axial collections can be distinguished from adjacent dural sinuses, and venous patency and extrinsic compression are more clearly delineated (Figure 6).

Figure 4. Patent left transverse sinus stent in a 44-year-old female with history of idiopathic intracranial hypertension presenting to the ED with headache. (A) Conventional CTV demonstrates hyperattenuating contents within the stent (arrow). (B) DE CTV iodine overlay image definitively identifies colour-coded iodinated contrast within the stent (arrow), indicating stent patency rather than stent thrombosis.



In cases of intracranial haemorrhage, ongoing bleeding (the "spot sign") can be more easily identified in colour on DE CTV, aiding in the rapid identification of subtle foci of haemorrhage

Figure 5. Left transverse sinus thrombosis in a 21-year-old male with history of unprovoked deep venous thrombosis, presenting to the ED with headache. (A) Conventional CTV demonstrates a normally enhancing right transverse sinus (arrowhead), but slightly diminished attenuation within the left transverse sinus (arrow), suspicious for thrombosis. (B) DE CTV iodine overlay image displays the iodine content in orange, with uniform filling of the right transverse sinus (arrowhead) but a long segment void in the left transverse sinus (arrow), allowing confident diagnosis of sinus thrombosis even in the setting of suboptimal contrast opacification in which venous attenuation is similar to that of thrombus on conventional images.

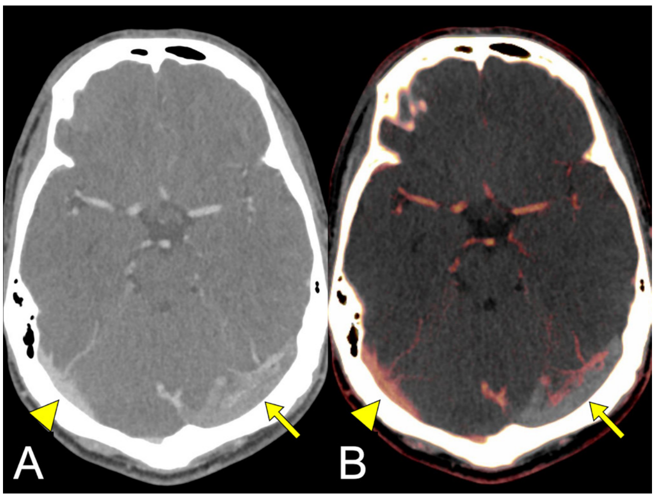


Figure 6. Venous epidural haematoma in a 21-year-old male presenting to the ED after a fall. (A) Non-contrast CT head reveals a non-displaced left occipital bone fracture (not shown) with an underlying hyperattenuating extra axial collection (arrow), best visualised in a soft tissue window to differentiate it from the overlying calvarium. (B) This collection is better demonstrated in a brain window on DECT bone subtraction images that remove the adjacent calvarium (arrow) and is located in the vicinity of the left transverse sinus, raising suspicion for sinus thrombosis or injury. (C) Conventional CTV and (D) colour-coded DECT iodine overlay image demonstrate the collection (arrows) to be a venous epidural haematoma located between the calvarium and the underlying transverse sinus, which is patent but extrinsically compressed.

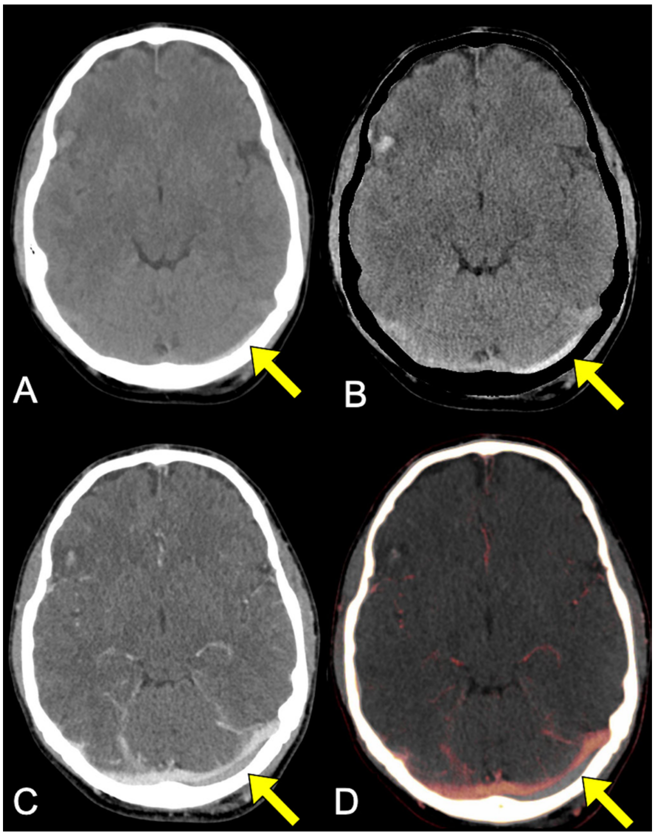
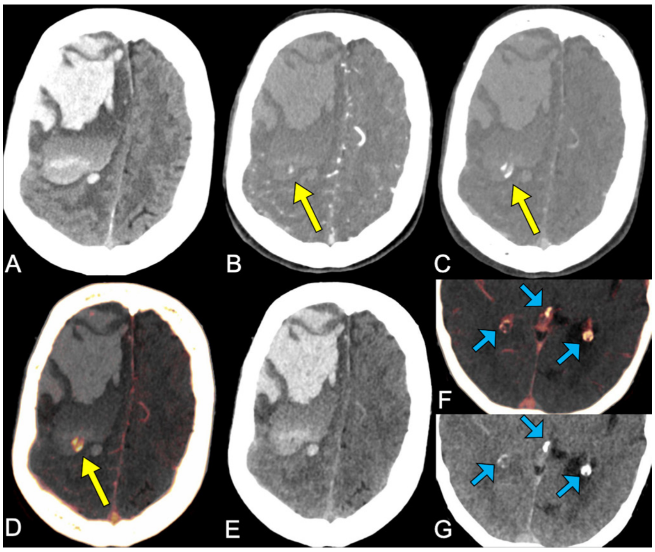


Figure 7. Active parenchymal haemorrhage ("spot sign") in a 97-year-old female presenting with left-sided neurologic deficits and aphasia. (A) Non-contrast head CT demonstrates a large mixed attenuation right frontal parenchymal haemorrhage with associated leftward midline shift. (B) CTA demonstrates a focus of active bleeding (arrow). (C) The focus of active bleeding increases in size and changes in morphology on conventional CTV (arrow). (D) DE CTV highlights this active extravasation as colour-coded iodine content (arrow), which disappears on the matching VNC image (E). Also note similarity of the VNC image to the true non-contrast image in (A). (F) On the other hand, calcifications within the choroid plexi and the pineal gland (blue arrows) also appear in the colour-coded iodine map, but, unlike iodine, persist on the VNC image (G).



that might otherwise be easy to overlook on conventional greyscale images (Figure 7), which require meticulous side-by-side comparison of post-contrast to pre-contrast images. However, there is an important pitfall to keep in mind when interpreting DECT colour-coded iodine images: Since calcium has a dual-energy slope that falls between that of iodine and the base material line of Figure 1, it is decomposed roughly half into the iodine map and half into the VNC images. This means that not everything seen on an iodine map represents iodine.[12] If it disappears on VNC images, it represents iodine (Figure 7D, 7E). If it does not, it represents calcium or another hyperattenuating material (Figure 7F, 7G).

This Pictorial Review contributes to the growing body of literature on the applications of DECT in neuroimaging by highlighting its potential use in CTV of the head. Although the application of DECT to cerebrovascular imaging is not new, most of this work has showcased its use for CTA applications. The reviews by Postma et al. and Naruto et al. addressed DECT for CTV of the head, primarily by emphasising bone subtraction to aid identification of dural venous sinus pathology.[6,7] Our work complements theirs by showcasing the additional advantages of colour-coded overlay imaging.

In conclusion, incorporation of DECT acquisition and post-processing has the potential to increase the ease of CTV interpretation, particularly in the setting of emergency neuroimaging. By reliably identifying iodine content, DE CTV can more clearly differentiate iodine from other hyperattenuating materials, such as calcium in the calvarium, and haemorrhage. Colour-coded DE CTV can increase the conspicuity of cerebrovascular pathology and may aid in the rapid assessment of dural venous sinus abnormalities and brain haemorrhage.

DISCLOSURES

Camilo Campo: None
Bryan Czajkowski: None
Aaron Sodickson: PI of institutional research grant from Siemens on Dual-Energy CT, travel expenses to speak at a Siemens users conference

REFERENCES

1. Potter CA, Sodickson AD. Dual-Energy CT in emergency neuroimaging: added value and novel applications. *Radiographics* 2016; **36**: 2186–98. doi: https://doi.org/10.1148/rg.2016160069
2. Sodickson AD, Keraliya A, Czakowski B, Primak A, Wortman J, Uyeda JW. Dual energy CT in clinical routine: how it works and how it adds value. *Emerg Radiol* 2021; **28**: 103–17. doi: https://doi.org/10.1007/s10140-020-01785-2
3. Gupta R, Phan CM, Leidecker C, Brady TJ, Hirsch JA, Nogueira RG, et al. Evaluation of dual-energy CT for differentiating intracerebral hemorrhage from iodinated contrast material staining. *Radiology* 2010; **257**: 205–11. doi: https://doi.org/10.1148/radiol.10091806
4. Phan CM, Yoo AJ, Hirsch JA, Nogueira RG, Gupta R. Differentiation of hemorrhage from iodinated contrast in different intracranial compartments using dual-energy head CT. *AJNR Am J Neuroradiol* 2012; **33**: 1088–94. doi: https://doi.org/10.3174/ajnr.A2909
5. Watanabe Y, Uotani K, Nakazawa T, Higashi M, Yamada N, Hori Y, et al. Dual-Energy direct bone removal CT angiography for evaluation of intracranial aneurysm or stenosis: comparison with conventional digital subtraction angiography. *Eur Radiol* 2009; **19**: 1019–24. doi: https://doi.org/10.1007/s00330-008-1213-5
6. Postma AA, Das M, Stadler AAR, Wildberger JE. Dual-Energy CT: what the Neuroradiologist should know. *Curr Radiol Rep* 2015; **3**: 16. doi: https://doi.org/10.1007/s40134-015-0097-9
7. Naruto N, Itoh T, Noguchi K. Dual energy computed tomography for the head. *Jpn J Radiol* 2018; **36**: 69–80. doi: https://doi.org/10.1007/s11604-017-0701-4
8. Hu R, Daftari Besheli L, Young J, Wu M, Pomerantz S, Lev MH, et al. Dual-Energy head CT enables accurate distinction of intraparenchymal hemorrhage from calcification in emergency department patients. *Radiology* 2016; **280**: 177–83. doi: https://doi.org/10.1148/radiol.2015150877
9. Wiggins WF, Potter CA, Sodickson AD. Dual-Energy CT to differentiate small foci of intracranial hemorrhage from calcium. *Radiology* 2020; **294**: 129–38. doi: https://doi.org/10.1148/radiol.2019190792
10. Grajo JR, Sahani DV. Dual-Energy CT of the abdomen and pelvis: radiation dose considerations. *J Am Coll Radiol* 2018; **15**: 1128–32. doi: https://doi.org/10.1016/j.jacr.2017.08.012
11. Tawfik AM, Kerl JM, Razek AA, Bauer RW, Nour-Eldin NE, Vogl TJ, et al. Image quality and radiation dose of dual-energy CT of the head and neck compared with a standard 120-kVp acquisition. *AJNR Am J Neuroradiol* 2011; **32**: 1994–9. doi: https://doi.org/10.3174/ajnr.A2654
12. Wortman JR, Sodickson AD. Pearls, pitfalls, and problems in dual-energy computed tomography imaging of the body. *Radiol Clin North Am* 2018; **56**: 625–40. doi: https://doi.org/10.1016/j.rcl.2018.03.007