

Understanding errors in diagnostic radiology: proposal of a classification scheme and application to emergency radiology

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Abstract Errors in image interpretation are a common problem in diagnostic radiology. Although many published articles provide trainees with the means to correctly interpret imaging studies, they do not provide a framework for understanding why and how errors occur. In this article, we propose a classification system that allows categorization of errors, which we hope can serve as a basis for peer review, self-education, and quality improvement programs. Our scheme incorporates elements of a classification system proposed by previous authors but also includes novel categories. In this article, we show the usefulness of our scheme by applying it to a specific, and particularly problematic, diagnosis in emergency radiology, namely that of dural sinus thrombosis.

Keywords Error · Classification · Dural sinus thrombosis · Quality assessment

Diagnostic errors in image interpretation are a well-documented and common phenomenon [1]. In multiple

studies, investigators have reported a substantial frequency of reader error, even among experienced readers of imaging studies [1]. Many published articles, lectures and educational media are oriented toward providing trainees with the means to correctly interpret imaging studies. For instance, the Royal College of Radiologists in the United Kingdom has a self-monitored audit system for reporting and tracking errors, which emphasizes potential clinical consequences of such errors [2]. However, such strategies often suffer from lack of emphasis upon the cause of diagnostic errors. It stands to reason that understanding the cause of diagnostic errors is a useful first step in alleviating such errors.

Based on this rationale, we propose a classification system that will allow one to categorize errors and use as an example a common diagnostic error in emergency radiology. The proposed classification system can serve as a basis for peer review, self-education, and quality improvement programs. This system incorporates elements of sources of diagnostic error proposed by previous authors but also includes novel categories. Although this classification system can be applied to a wide variety of radiological diagnoses, for our purposes here, we have applied this system to one specific, and particularly problematic, diagnosis, namely that of dural sinus thrombosis.

A simple approach to errors in image interpretation is to consider all errors as failures of detection or, in other words, perceptual errors, which usually produce false-negative interpretations. However, detection errors represent solely one aspect of the problem of errors of image interpretation. In actual fact, misdiagnosis is often due to non-visual errors. For instance, one author has pointed out the hazards of failure to pursue a second finding after a first abnormality is detected, i.e., so-called satisfaction of search [3]. It is clear that many other types of errors also come into play in image interpretation.

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In 1992, Renfrew et al. proposed a classification scheme for radiology errors provided a list of other possible causes of misdiagnosis [4]. These causes included complacency, faulty reasoning (findings is appreciated but misclassified),

lack of knowledge (misclassification due to lack of knowledge), under-reading (failure to isolate important material or from satisfaction of search), poor communication, miscellaneous (possibly due to technical errors) and complications [4]. We independently formulated our own classification system and subsequently became aware of Renfrew's scheme. Some of the categories in both schemes are very similar and in some ways our proposed scheme can be viewed as a modification of that proposed by Renfrew et al. However, Renfrew's scheme did not fully take into account some additional mechanisms by which errors can be made. Two such mechanisms include (1) recognition of an abnormality but assuming it is a normal finding or an artifact and (2) failure to recognize the limitations of a study. Our scheme differs by taking such additional factors into consideration. We herewith illustrate our classification scheme using a single disease entity, dural sinus thrombosis

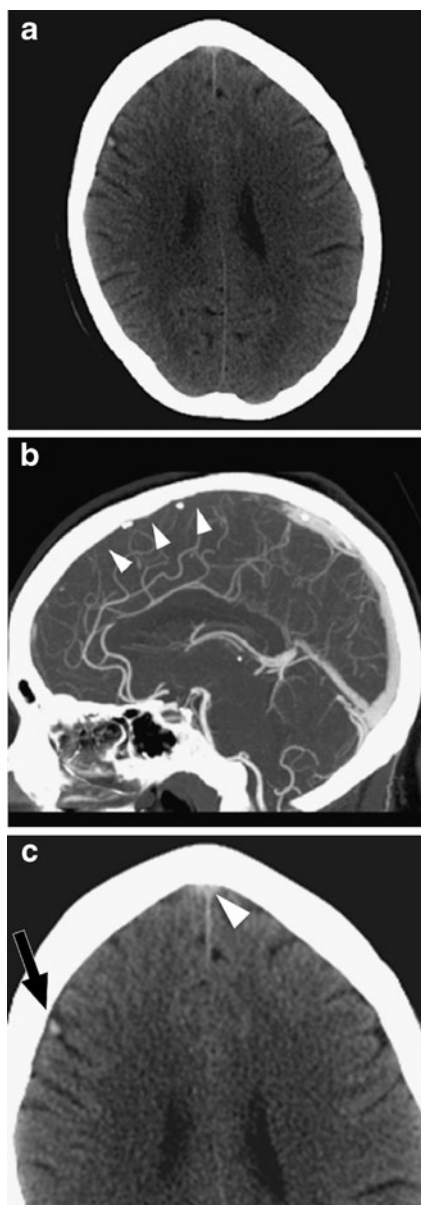


Fig. 1 Example of type 1 error (i.e., failure to detect finding). **a** Unenhanced axial CT shows small hyperdense extra-axial region adjacent to brain cortex consistent with thrombosed vein. The fact that cortical vein thrombosis is uncommon, the small size of the finding and location of the finding on the periphery of the image all contribute to the difficulty in detection. **b** Sagittal maximum intensity projection image from contrast-enhanced CT venogram shows thrombosis of much of the superior sagittal sinus (*arrowheads*). **c** Enlarged image of Fig. 1a shows the thrombosed vein (*arrow*) as well as a hyperdense appearance of the anterior portion of the superior sagittal sinus, consistent with thrombosis

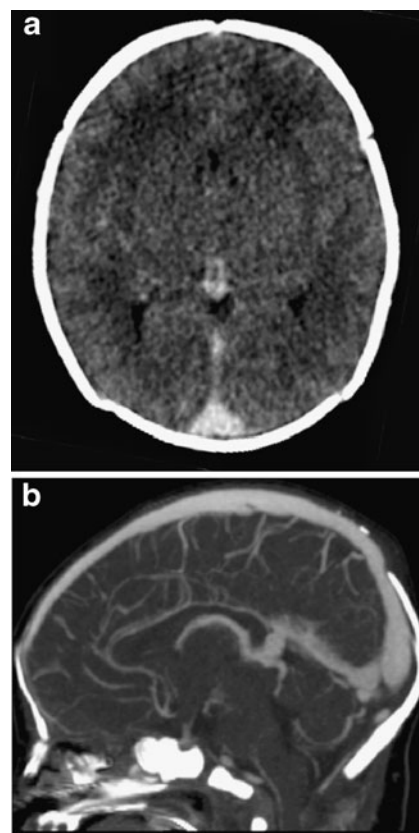


Fig. 2 Example of type 2 error (i.e., wrongly interpreting finding as abnormal). **a** Unenhanced axial CT in newborn infant shows hyperdense appearance of dural sinuses and internal cerebral veins potentially representing thrombosis. **b** Sagittal maximum intensity projection image from contrast-enhanced CT venogram shows the superior sagittal sinus and internal cerebral veins are patent. The cause of the hyperdense appearance of these vessels in **a** was the result of the high hematocrit normally seen in a newborn infant

(DST), which in the experience of the authors pose particular diagnostic challenges.

Error categorization scheme

Type 1—fail to detect finding (“miss”)

One of the most commonly recognized types of image interpretation errors is the failure of detection of an abnormality. For instance, in the experience of the authors, one most common causes of failure to diagnose DST on MR images is failure to detect absence of a normal flow void within a dural sinus. Here, the actual difficulty resides in failure to note that a *normal* finding is *absent* (as opposed to failing to note that an *abnormal* finding is *present*). Another common form of error may be due to lack of conspicuity of the abnormality, i.e., the contrast between the finding and adjacent normal tissue. As an example, the density of an abnormal structure seen on CT may not sufficiently differ from that of surrounding tissue. Such is the case when the density of a thrombosed dural sinus is only slightly higher than that of adjacent brain. However, as will be discussed later, failure to diagnose DST in such

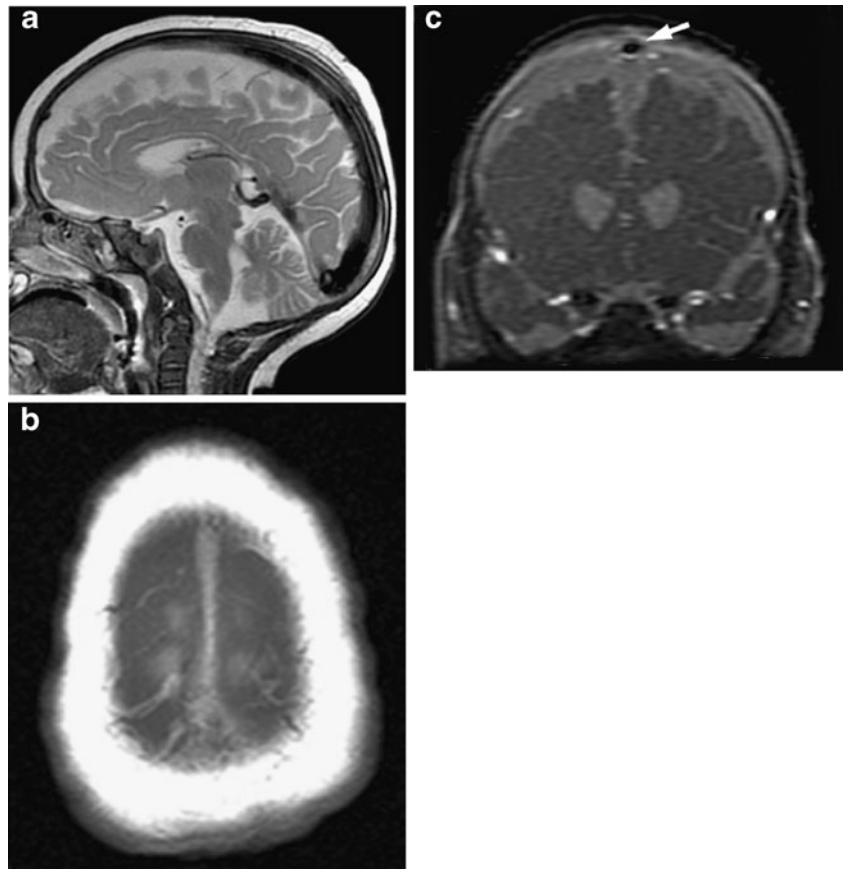
cases also involves another type of error, i.e., lack of appreciation of the fact that DST frequently is not manifested by a hyperdense dural sinus. Similarly, cortical vein thrombosis can be very difficult to diagnose because diagnosis is uncommon and the thrombosed vein is small and on the periphery of the region on which attention is usually focused (Fig. 1).

The remaining categories of error are not perceptual in nature but are due to incorrect assumptions about a finding that is perceived (types 2–4) or about the diagnostic capability of a test (type 5).

Type 2—wrongly interpret a finding as abnormal (“overcall”)

Another form of error is that of incorrectly classifying a finding as abnormal (i.e., a false-positive finding), or what is commonly referred to as an overcall. This phenomenon is often due to being overcautious and is likely more common among radiology trainees and inexperienced radiologists rather than more experienced radiologists. Many types of misdiagnosis of DST fall into this category. A discussion providing examples of this type of error follows.

Fig. 3 Example of type 3 error (i.e., recognize abnormality but dismiss as normal). **a** Sagittal T2-weighted image in a four-month-old boy shows hypointense appearance of superior sagittal sinus, which could be interpreted as normal flow, an example of an abnormality that can easily be dismissed as a normal finding. **b** Axial unenhanced T1-weighted image shows absence of flow void in superior sagittal sinus. Because the finding is present on the last image in this pulse sequence, it is easy to overlook and fail to correlate with the appearance on T2-weighted images. **c** Coronal source image from MR venogram shows normal flow-related enhancement in cortical veins but absence of flow in the superior sagittal sinus (*arrow*)



On unenhanced CT, high density within one or more dural sinuses due to causes other than thrombosis can produce a false-positive finding. This finding can be seen in some normal states (e.g., during early childhood) (Fig. 2) as well as in certain disease states (e.g., polycythemia vera).

On MR imaging, one of the most commonly encountered potential causes of error is that of asymmetry of size of the transverse or sigmoid sinuses. In this setting, the smaller of the two sinuses can be two sinuses can be falsely considered to be thrombosed. This mistake is most commonly made when solely reconstructed MR venography images, rather than source images, are examined. On reconstructed images, an apparent discontinuity in the column of flowing blood can be seen at the thinnest portion of the dural sinus. This problem can usually be readily resolved by respecting to inspection of the source images, on which the flow-related enhancement of flowing blood in the congenitally narrowed channel will be recognized.

On MR imaging, a number of other potential causes of false-positive findings can be encountered, including misinterpreting the bright signal from flow-related enhancement (entry slice phenomenon) or in-plane flow as thrombus. Similarly, on contrast-enhanced T1-weighted

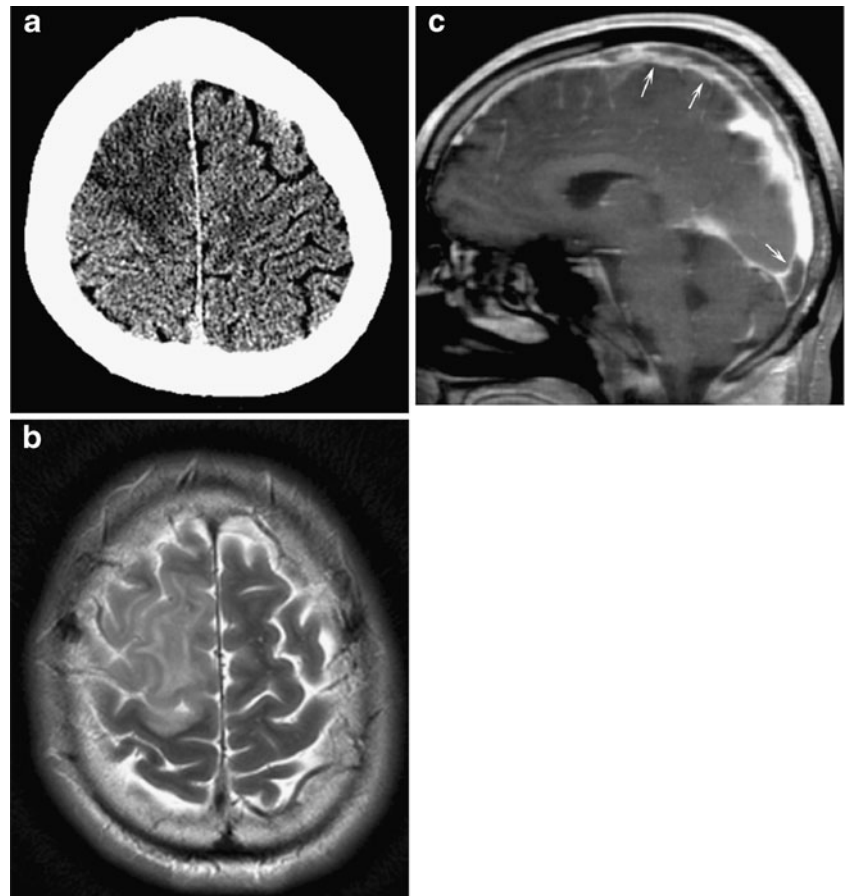
images, the dark signal produced by an arachnoid granulation can potentially be mistaken for thrombosis.

Two categories of error are not due to failure to perceive an abnormality but instead to misinterpret that abnormality. These types of errors can be due to failure to recognize a finding as abnormal (type 3 error) or to recognize a finding as abnormal but assign an incorrect etiology (type 4 error). These forms of error are described below.

Type 3—recognize abnormality but dismiss as normal or artifact (“under-call”)

This type of error is due to failure to interpret an abnormal finding as being abnormal [4]. Some authors have used the term faulty reasoning to describe this type of error [4]. In many instances, such errors occur subconsciously, without deliberation about the nature of the finding. For example, DST can appear dark on T2-weighted images and thus simulate a flow void [5] (Fig. 3). If particular attention is not made to the appearance of the dural sinus on other pulse sequences, an incorrect diagnosis can easily be provided. In other instances, the reader consciously deliberates about the finding in an attempt to establish its cause but simply

Fig. 4 Example of type 4 error (i.e., recognize abnormality but assign incorrect etiology). **a** Unenhanced axial CT in a 48-year-old man shows large hypodense region consistent with infarction. Because arterial infarcts are much more common than venous infarcts, a common error is to assume that the infarction shown is arterial in origin. However, the infarct involves two arterial territories, i.e., both the right middle cerebral artery and right anterior cerebral artery territories, which would be a relatively uncommon type of arterial infarction. **b** Axial T2-weighted image shows the infarct shown in **a** in both the right anterior cerebral artery (near midline) and right middle cerebral artery territories. These findings are more typical of venous infarction than arterial infarction. **c** Contrast-enhanced sagittal T1-weighted image shows lack of contrast enhancement most of the superior sagittal sinus (*arrows*) consistent with thrombosis. The infarction shown in **a** and **b** is, in fact, venous in origin



comes to the wrong conclusion. Another example can be seen in over-reliance on the presence of contrast enhancement of a dural sinus as an indication of patency. Although in the vast majority of cases, contrast enhancement of a sinus is indeed due to flow of contrast material within the sinus, on occasion, a thrombosed dural sinus can contrast enhance [6].

Type 4—recognize abnormality but assign incorrect etiology

Like the type 3 error, the type 4 error is not due to failure to perceive an abnormality. However, unlike a type 3 error, in a type 4 error the mistake is not in assuming that the abnormal finding is normal; instead, it resides in failure to correctly explain the abnormality. Whereas the type 3 error incorrectly interprets an abnormality as being normal, the type 4 abnormality assigns an incorrect cause to the abnormal finding (Fig. 4).

On occasion, an important clue to the diagnosis of DST is the presence of a venous infarction. Such infarctions are often subcortical in location and hemorrhagic [7]. These findings are a clue for the radiologist to search the imaging study for a thrombosed vein or dural sinus. One of the more common errors in interpreting studies in patients with DST is to mistakenly interpret a venous infarct (when present) as an arterial infarct (Fig. 4). As a result, the radiologist may easily fail to direct appropriate attention to the dural sinuses and fail to establish the correct diagnosis.

Another example can be found in the abnormal dural enhancement that can be seen on contrast-enhanced CT and MR studies of patients with DST, likely due to flow of contrast material in collateral vessels [8]. This contrast enhancement can simulate other disease states, e.g., neurosarcoidosis or dural metastases [9].

Type 5—failure to recognize limitations of imaging technique/recommend next imaging step (next step)

One under-appreciated cause of image interpretation errors is failure to take the limitations of an imaging study into consideration when interpreting images. For instance, in many cases, an imaging study lacks sufficient sensitivity to detect a finding. For instance, the referring physician may request an imaging study to exclude a specific diagnosis but be unaware of the limitations of that study for establishing a diagnosis. If the referring clinician is unaware of the inability of a study to fully address the clinical question, the clinician may be subject to a variant of satiety of search that is intellectual rather than perceptual. Alternatively, the radiologist may be unaware of the limitations of the imaging study for establishing a specific diagnosis or be aware but fail to communicate the limitation to the referring

physician [3]. Stated differently, if a Type 1 error is an error of the eye, a type 5 error is an error of the mind. As result of this thinking error, the radiologist may then commit the additional error of failing to recommend the next most appropriate study, e.g., contrast-enhanced CT, CT venography, or some form of MR imaging.

One common example of this type of error with regard to diagnosis of DST is failure to recognize that an unenhanced CT has a low degree of sensitivity for the diagnosis (Fig. 5). This error is, in essence, a thinking error based on misinterpreting the fact that a hyperdense sinus is highly suggestive of DST to mean that a hyperdense dural

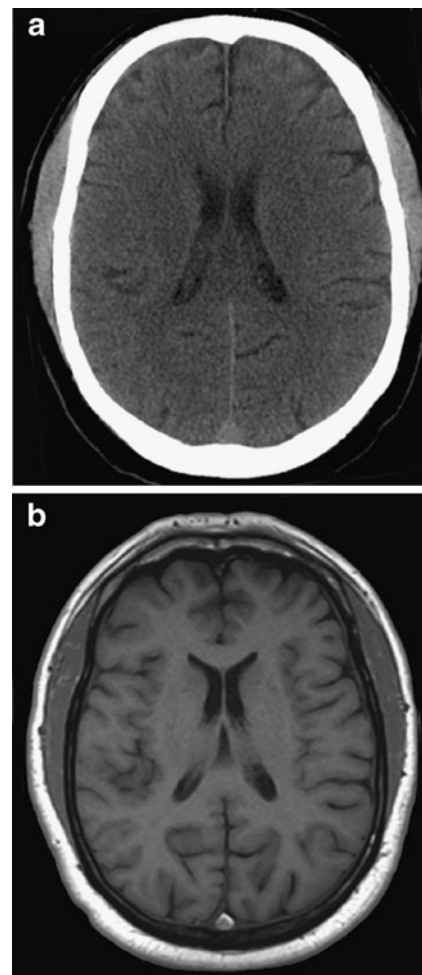


Fig. 5 Example of type 5 error (i.e., failure to understand limitations of imaging study) in a 57-year-old man with the worst headache of his life. The referring clinician suspected dural sinus thrombosis as a diagnostic possibility but did not recognize the low sensitivity of unenhanced CT for the diagnosis of dural sinus thrombosis. Because the suspected diagnosis was not related to the radiologist, the radiologist could not recommend the next most appropriate imaging examination. **a** Unenhanced axial CT image shows no apparent abnormality. **b** Unenhanced axial T1-weighted MR image shows hyperintense appearance of superior sagittal sinus consistent with thrombosis

sinus is a common finding in DST. In fact, however, a hyperdense dural sinus is reported in between 25% and 60% of cases of DST [8, 10]. Another error of this type is to fail to recognize that a study has been improperly performed. In the case of DST, lack of appreciation that a bolus of contrast material has been poorly timed could lead to a false-positive diagnosis of DST [11].

Yet another example of this type of error can be seen when an imaging technique produces artifacts that are difficult to visually detect but nonetheless exert substantial effects that may affect image interpretation. As one example, use of saturation pulses in MR angiography or venography may produce artifactual alterations in the appearance of flowing blood. For instance, in MR venography, an arterial saturation pulse (which is placed caudad to the imaging slice in two-dimensional MR angiography) is frequently used to diminish the signal generated by flowing blood in arteries. This pulse sequence serves to saturate blood flowing cephalad, regardless of whether the flow is within arteries or veins. Because the anterior portion of the superior sagittal sinus is directed cephalad, on occasion, the saturation pulse can obliterate the signal generated by flowing venous blood in the anterior portion of the superior sagittal sinus. As a result, the MR venogram may appear to show absence of flow in the superior sagittal sinus and a false-positive diagnosis of thrombosis may be provided.

Summary

We have proposed an error classification scheme that includes some elements of the scheme proposed by Renfrew et al. [4]. Our proposed scheme can be considered more robust because it also accounts for other types of errors not fully previously elucidated. Application of this

scheme to a common problem in emergency neuroradiology shows that it can explain many of the fundamental types of errors encountered. Further evaluation of this scheme to other diagnostic problems in emergency radiology will be needed to assess its full value.

References

1. Enoch JM (1960) Natural Tendencies in Visual Search of a Complex Display. *In: Symposium on Visual Search Techniques*. Publication 712. National Academy of Sciences-National Research Council, Washington, D. C
2. <http://www.rcr.ac.uk/publications.aspx?PageID=310> (Accessed July 3, 2011)
3. Pinto A, Brunese L (2010) Spectrum of diagnostic errors in radiology. *World J Radiol* 2:377–383
4. Renfrew DL, Franken EA Jr, Berbaum KS, Weigelt FH, Abu-Yousef MM (1992) Error in radiology: classification and lessons in 182 cases presented at a problem case conference. *Radiology* 183:145–150
5. Hinman JM, Provenzale JM (2002) Hypointense thrombus on T2-weighted MR imaging: a potential pitfall in the diagnosis of dural sinus thrombosis. *Eur J Radiol* 41:147–152
6. Dormont D, Sag K, Biondi A, Wechsler B, Marsault C (1995) Gadolinium-enhanced MR of chronic dural sinus thrombosis. *AJNR* 16:1347–1352
7. Keiper MD, Ng SES, Grossman RI (1995) Subcortical hemorrhage: marker for Radiographically occult cerebral vein thrombosis on CT. *J Comput Assist Tomogr* 19:527–531
8. Virapongse C, Cazenave C, Quisling R, Sarwar M, Hunter S (1987) The empty delta sign: frequency and significance in 76 cases of dural sinus thrombosis. *Radiology* 162:779–785
9. Provenzale JM, Joseph GJ, Barboriak DP (1998) Dural sinus thrombosis: findings on CT and MR imaging and diagnostic pitfalls. *AJR* 170:777–783
10. Tang PH, Chai J, Chan YH, Chng SM, Lim CC (2008) Superior sagittal sinus thrombosis: subtle signs on neuroimaging. *Ann Acad Med Singapore* 37:397–401
11. Rodallec MH, Krainik A, Feydy A et al (2006) Cerebral venous thrombosis and multidetector CT angiography: tips and tricks. *Radiographics* 26(suppl 1):S5–S18