ACR–ASNR–SPR PRACTICE PARAMETER FOR THE PERFORMANCE OF COMPUTED TOMOGRAPHY (CT) OF THE HEAD

The American College of Radiology (ACR) Practice Parameters and Technical Standards are developed to advance the science of radiology and improve the quality and safety of patient care. They provide guidance regarding appropriate training, performance, and practice considerations for radiologic procedures and services. They are intended for educational purposes and to support, but not dictate, professional practice and patient-care decisions. These documents should be applied in light of individual patient circumstances, available resources, applicable regulatory requirements, evolving medical knowledge, and the independent professional judgment of the healthcare professionals involved. They do not establish a legal standard of care or constitute medical, legal, or other professional advice. The ultimate responsibility for patient care and management rests with the healthcare professionals involved in the patient's care. To access the full ACR Guideline Programs Disclaimer and Terms of Use, please visit our website: https://www.acr.org/Clinical-Resources/Clinical-Tools-and-Reference

PREAMBLE

This document is an educational tool designed to assist practitioners in providing appropriate radiologic care for patients. Practice Parameters and Technical Standards are not inflexible rules or requirements of practice and are not intended, nor should they be used, to establish a legal standard of care[1]. For these reasons and those set forth below, the American College of Radiology and our collaborating medical specialty societies caution against the use of these documents in litigation in which the clinical decisions of a practitioner are called into question.

The ultimate judgment regarding the propriety of any specific procedure or course of action must be made by the practitioner considering all the circumstances presented. Thus, an approach that differs from the guidance in this document, standing alone, does not necessarily imply that the approach was below the standard of care. To the contrary, a conscientious practitioner may responsibly adopt a course of action different from that set forth in this document when, in the reasonable judgment of the practitioner, such course of action is indicated by variables such as the condition of the patient, limitations of available resources, or advances in knowledge or technology after publication of this document. However, a practitioner who employs an approach substantially different from the guidance in this document may consider documenting in the patient record information sufficient to explain the approach taken.

The practice of medicine involves the science, and the art of dealing with the prevention, diagnosis, alleviation, and treatment of disease. The variety and complexity of human conditions make it impossible to always reach the most appropriate diagnosis or to predict with certainty a particular response to treatment. Therefore, it should be recognized that adherence to the guidance in this document will not assure an accurate diagnosis or a successful outcome. All that should be expected is that the practitioner will follow a reasonable course of action based on current knowledge, available resources, and the needs of the patient to deliver effective and safe medical care. The purpose of this document is to assist practitioners in achieving this objective.

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1 *Iowa Medical Society and Iowa Society of Anesthesiologists v. Iowa Board of Nursing, 831 N.W.2d 826 (Iowa 2013) Iowa Supreme Court refuses to find that the "ACR Technical Standard for Management of the Use of Radiation in Fluoroscopic Procedures (Revised 2008)" sets a national standard for who may perform fluoroscopic procedures in light of the standard's stated purpose that ACR standards are educational tools and not intended to establish a legal standard of care. See also, Stanley v. McCarver, 63 P.3d 1076 (Ariz. App. 2003) where in a concurring opinion the Court stated that "published standards or guidelines of specialty medical organizations are useful in determining the duty owed or the standard of care applicable in a given situation" even though ACR standards themselves do not establish the standard of care.*

I. INTRODUCTION

This practice parameter was revised collaboratively by the American College of Radiology (ACR), the American Society of Neuroradiology (ASNR), and the Society for Pediatric Radiology (SPR).

Computed tomography (CT) is a technology that produces cross-sectional images of the body using X-rays. CT is used extensively in imaging of the head. This practice parameter outlines the principles for performing high-quality CT imaging of the head in pediatric and adult patients. There should be an effort to minimize radiation exposure, particularly in children. An alternate modality should be considered when possible.

CT of the head is superior to magnetic resonance imaging (MRI) for rapid assessment in emergent/urgent

settings, particularly for the evaluation of osseous structures, acute hemorrhage, and calcifications. These findings can be important for the initial identification of an abnormality or for refinement of a differential diagnosis. CT of the brain is sufficient and diagnostic in many clinical circumstances, such as in acute trauma, intracranial hemorrhage, evaluation of ventricle size, and selected postoperative follow-up. However, CT is less useful than MRI for many conditions that require higher contrast resolution, such as neoplastic, infectious, ischemic, or inflammatory conditions affecting the cranial nerves, brain parenchyma, and meninges. In combination with the clinical history and physical examination findings, CT of the brain is a useful screening tool for indications such as acute mental status change, seizure, acute neurologic deficit, acute headache, and nonacute headache with neurologic findings. While MRI is a more sensitive modality for detection of parenchymal abnormalities, CT can be useful to screen for mass effect and addition of intravenous contrast may increase sensitivity for masses, infection, or vascular abnormalities when MRI is not available. For further information see the ACR Manual on Contrast Media [1].

II. INDICATIONS

Indications for CT of the brain include, but are not limited to, the following:

A. Primary Indications

1. Acute head trauma [2-6]
2. Suspected acute intracranial hemorrhage [7-9]
3. Follow-up for known intracranial hemorrhages
4. Detection or evaluation of calcification [10]
5. Postoperative evaluation following intracranial surgery [11]
6. Mental status change [12], including drug toxicity [12-15]
7. Headache [16, 17]
8. Acute neurologic deficits [18], including cranial nerve dysfunction [19-21] and ataxia [22]
9. Intracranial infection [23-27]
10. Hydrocephalus [28, 29], including shunt malfunctions or shunt revisions [28]
11. Congenital skull and brain lesions (such as, but not limited to, craniosynostosis, macrocephaly, and microcephaly) [7, 30, 31]
12. Suspected mass or tumor [32-36], including brain herniation syndromes [3, 4] and increased intracranial pressure [4, 5]
13. CT guidance, image integration, and 3-D planning [37-45]
14. Skull lesions (such as, but not limited to, fibrous dysplasia, Paget disease, histiocytosis, osteolytic lesions, and skeletal tumors)
15. Abusive head trauma and postmortem forensic investigations [15, 46-49]
16. Seizures [50-54]

B. Secondary Indications (when MRI is unavailable or contraindicated, or if the supervising physician determines CT to be appropriate [54])

1. Epilepsy [50-54]
2. Neurodegenerative disease [55-58]
3. Developmental delay [29, 59]
4. Evaluating psychiatric disorder [60]
5. Autoimmune conditions

For the pregnant or potentially pregnant patient, see the ACR–SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Patients with Ionizing Radiation [61].

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Diagnostic Computed Tomography (CT) [62].

IV. SPECIFICATIONS OF THE EXAMINATION

The written or electronic request for CT of the head should provide sufficient information to demonstrate the medical necessity of the examination and allow for the proper performance and interpretation of the examination.

Documentation that satisfies medical necessity includes 1) signs and symptoms and/or 2) relevant history (including known diagnoses). The provision of additional information regarding the specific reason for the

examination or a provisional diagnosis would be helpful and may at times be needed to allow for the proper performance and interpretation of the examination.
The request for the examination must be originated by a physician or other appropriately licensed health care provider. The accompanying clinical information should be provided by a physician or other appropriately licensed health care provider familiar with the patient's clinical problem or question and consistent with the state scope of practice requirements. (ACR Resolution 35 adopted in 2006 – revised in 2016, Resolution 12-b)

A. The supervising physician must have adequate understanding of the indications, risks, and benefits of the examination, as well as alternative imaging procedures. The physician performing CT interpretation must have a clear understanding and knowledge of the anatomy and pathophysiology relevant to the examination.

   General Considerations

   CT protocols for brain imaging should be designed to answer the specific clinical question. The supervising physician should be familiar with the indications for each examination, relevant patient history, and potential adverse reactions to contrast media. The supervising physician should be familiar with how individual CT settings affect radiation dose and image quality, including field of view, collimation, pitch, automated exposure control, image reconstruction algorithms such as iterative reconstruction [63] and, when available, newer scanning techniques such as dual-energy CT or photon-counting CT [64, 65]. The goal of CT scanning is to obtain diagnostic information from images of sufficient quality. Protocols should be optimized to deliver the lowest dose required to achieve appropriate image quality and should be reviewed and updated as needed in light of new clinically applicable developments [65-74].

B. Brain Imaging

   CT brain imaging is performed for the evaluation of a variety of pathologies that require appropriate techniques for acquisition and viewing. CT brain imaging may be performed with a sequential single-slice technique, multislice helical (spiral) protocol, or multidetector multislice algorithm [75, 76]. The mechanism of detection includes conventional energy integrating detector (EID) and newer photon counting technologies. Use of these techniques is dependent on clinical indication, scanner capability, and image quality requirements. For CT of the brain, contiguous or overlapping axial slices should be acquired with a slice thickness of no greater than 5 mm. In addition to directly acquired axial images, reformatted images in coronal, sagittal, true axial, or other more complex planes may be constructed from the axial data set to answer specific clinical questions. Additionally, axial reconstructed images should be presented with at least 2 different kernels, using both a brain/soft tissue and bone kernel. Brain images should be reviewed at dedicated workstations and with window settings appropriate for demonstrating brain, bone, and soft-tissue abnormalities, including hemorrhage.

   For further information, see the American Association of Physicists in Medicine Routine (AAPM) Adult Head (Brain) Protocols [77].

C. Contrast Studies

   Certain indications require administration of IV contrast media or intrathecal contrast (eg, cisternography, ventriculography) during imaging of the brain. Contrast administration should be performed using appropriate injection protocols and be in accordance with the ACR–SPR Practice Parameter for the Use of Intravascular Contrast Media [78]. Cerebrospinal fluid contrast administration requires the use of nonionic agents appropriate for intrathecal use and should be performed using appropriate protocols as outlined in the ACR–ASNR–SPR Practice Parameter for the Performance of Myelography and Cisternography [79].

D. Advanced Applications

   Postprocessing by physicians, radiologic technologists, or appropriately trained staff is recommended. Furthermore, images may be manipulated to allow selective visualization of specific tissues, such as in CT perfusion, CT volumetry, CT angiography (CTA)/venography, multimodality image fusion, and

neuronavigational mapping techniques. Such applications are better performed with helical, volume, dual-energy, or photon-counting data sets rather than routine axial sequential data [37, 43, 74, 80-96]. Also see the ACR–ASNR–SPR Practice Parameter for the Performance of Computed Tomography (CT) Perfusion in Neuroradiologic Imaging [97] and the ACR–ASNR–SPR Practice Parameter for the Performance and Interpretation of Cervicocerebral Computed Tomography Angiography (CTA) [98]. Pre- and postcontrast imaging are not recommended in pediatric patients for most indications.

V. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [99].

VI. EQUIPMENT SPECIFICATIONS

For specific issues regarding CT quality control, see the ACR Practice Parameter for Performing and Interpreting Diagnostic Computed Tomography (CT) [62].

Equipment monitoring should be in accordance with the ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Computed Tomography (CT) Equipment [100].

A. Performance Standards

To achieve acceptable clinical CT scans of the brain, the CT scanner should meet or exceed the following specifications:

1. Scan times: per slice or image not more than 2 seconds
2. Slice thickness: acquired slice thickness should be 2 mm or less, whereas reconstructed slice thickness should be 5 mm or less
3. Interscan delay: no more than 4 seconds; however, this may be longer if intravascular contrast media is not used (not applicable with helical scanners)
4. Limiting spatial resolution: must be measured to verify that it meets the unit manufacturer's specifications. Limiting spatial resolution should be >;10 lp/cm for a display field of view <;24 cm
5. Table pitch: no greater than 2 for most CT scanners; pitch may be increased for dual-energy scanners for sole evaluation of bone anatomy (craniofacial)
6. For advanced applications (eg, perfusion imaging or CTA, cine-capable scanners are preferable with tube rotation ≤1 second and continuous cine imaging ≥60 seconds. See the ACR–ASNR–SPR Practice Parameter for the Performance of Computed Tomography (CT) Perfusion in Neuroradiologic Imaging [97].

B. Patient monitoring equipment and facilities for cardiopulmonary resuscitation, including vital signs monitoring equipment and support equipment, should be immediately available.

Appropriate emergency equipment and medications must be immediately available to treat adverse reactions associated with administered medications. The equipment and medications should be monitored for inventory and drug expiration dates on a regular basis. The equipment, medications, and other emergency support must also be appropriate for the range of ages or sizes in the patient populations. Radiologists, technologists, and staff members should be available to assist with procedures, patient monitoring, and patient support. A written policy should be in place for dealing with emergencies, such as cardiopulmonary arrest.

VII. RADIATION SAFETY IN IMAGING

Radiologists, medical physicists, non-physician radiology providers**,** radiologic technologists, and all supervising physicians have a responsibility for safety in the workplace by keeping radiation exposure to staff, and to society as a whole, "as low as reasonably achievable" (ALARA) and to assure that radiation doses to individual patients are appropriate, taking into account the possible risk from radiation exposure and the diagnostic image quality necessary to achieve the clinical objective. All personnel who work with ionizing radiation must understand the key principles of occupational and public radiation protection (justification, optimization of protection, application of dose constraints and limits) and the principles of proper management of radiation dose to patients (justification, optimization including the use of dose reference levels). https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1775_web.pdf

Nationally developed guidelines, such as the ACR's Appropriateness Criteria®, should be used to help choose the most

appropriate imaging procedures to prevent unnecessary radiation exposure.

Facilities should have and adhere to policies and procedures that require ionizing radiation examination protocols (radiography, fluoroscopy, interventional radiology, CT) to vary according to diagnostic requirements and patient body habitus to optimize the relationship between appropriate radiation dose and adequate image quality. Automated dose reduction technologies available on imaging equipment should be used, except when inappropriate for a specific exam. If such technology is not available, appropriate manual techniques should be used.

Additional information regarding patient radiation safety in imaging is available from the following websites – Image Gently® for children (www.imagegently.org) and Image Wisely® for adults (www.imagewisely.org). These advocacy and awareness campaigns provide free educational materials for all stakeholders involved in imaging (patients, technologists, referring providers, medical physicists, and radiologists).

Radiation exposures or other dose indices should be periodically measured by a Qualified Medical Physicist in accordance with the applicable ACR Technical Standards. Monitoring or regular review of dose indices from patient imaging should be performed by comparing the facility's dose information with national benchmarks, such as the ACR Dose Index Registry and relevant publications relying on its data, applicable ACR Practice Parameters, NCRP Report No. 172, Reference Levels and Achievable Doses in Medical and Dental Imaging: Recommendations for the United States or the Conference of Radiation Control Program Director's National Evaluation of X-ray Trends; 2006, 2009, amended 2013, revised 2023 (Res. 2d).

When possible, CT imaging of the head should consider the following to minimize radiation dose and maintain image quality:

1. Center the patient in the gantry [101]
2. Remove unnecessary objects from the patient
3. Use of iterative reconstruction technique, if available

Higher radiation doses are typically needed to assess the brain parenchyma compared with specific structures such as the bones, facial soft tissues, and ventricles. As such, dose-minimization CT techniques should be used for imaging scenarios in which the brain parenchyma itself does not need to be evaluated, such as in the evaluation of shunt placement/malfunction, routine paranasal sinus evaluation, and craniosynostosis in the pediatric population [102].

Diagnostic Reference Levels and Achievable Doses are national benchmarks for radiation protection and optimization that provide a comparison for facilities in order to review techniques and determine whether acceptable image quality can be achieved at lower doses. Published levels are available [103]. For further information, see the ACR–AAPM–SPR Practice Parameter for Diagnostic Reference Levels and Achievable Doses in Medical X-Ray Imaging [104].

Attention to dose is particularly important but also particularly challenging in the pediatric population, when age- and size-specific protocols should be considered [105]. Photon counting CT can achieve 80% reduction in ionizing radiation exposure while achieving the same or superior image quality when compared with EID CT. MRI may be an alternative to CT in monitoring the size of intracranial fluid collections, such as the ventricles in shunted hydrocephalus, size of arachnoid cysts, or size of nonacute subdural collections. Rapid-MRI protocols to include susceptibility and diffusion-weighted imaging sequences have been used in the setting of acute stroke. For trauma, accessibility and technical limitations may preclude the use of MRI. MRI is more sensitive in detecting areas of parenchymal brain injury that may not be obvious on CT [106], and may also be appropriate for follow-up of findings on CT [107].

The use of shields for radiation protection of superficial organs, such as the lens of the eye or the thyroid gland, is controversial. The goal of shielding is to limit unnecessary irradiation to nontarget, radiosensitive organs, and bismuth shields, which have been shown to reduce anterior surface dose, are available. However, shielding has several disadvantages, not the least of which is unpredictable results when combined with automated exposure control features. Alternative methods, such as a global reduction in dose together with iterative reconstruction to reduce image noise, as mentioned above in Section IV.A, can achieve the same goal. For further information, see the AAPM Position Statement on the Use of Bismuth Shielding for the Purpose of Dose Reduction in CT Scanning [108].

In addition to CT radiation safety and quality control, appropriateness studies, and utilization review, a facilitating best practices for CT brain imaging should also be considered and encouraged as part of a comprehensive continuous quality improvement program [46, 109-117].

VIII. QUALITY CONTROL AND IMPROVEMENT, SAFETY, INFECTION CONTROL, AND PATIENT EDUCATION

Policies and procedures related to quality, patient education, infection control, and safety should be developed and implemented in accordance with the ACR Policy on Quality Control and Improvement, Safety, Infection Control, and Patient Education appearing under the heading *ACR Position Statement on Quality Control and Improvement, Safety, Infection Control and Patient Education* on the ACR website (https://www.acr.org/Advocacy-and-Economics/ACR-Position-Statements/Quality-Control-and-Improvement).

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REFERENCES

1. American College of Radiology. ACR Committee on Drugs and Contrast Media. Manual on Contrast Media. Available at: https://www.acr.org/Clinical-Resources/Clinical-Tools-and-Reference/Contrast-Manual.
2. Harden SP, Dey C, Gawne-Cain ML. Cranial CT of the unconscious adult patient. Clin Radiol. 2007 May;62(5):404-15.
3. Hijaz TA, Cento EA, Walker MT. Imaging of head trauma. Radiol Clin North Am. 2011 Jan;49(1):81-103.
4. Jacobs B, Beems T, van der Vliet TM, Diaz-Arrastia RR, Borm GF, Vos PE. Computed tomography and outcome in moderate and severe traumatic brain injury: hematoma volume and midline shift revisited. J Neurotrauma. 2011 Feb;28(2):203-15.
5. Miller MT, Pasquale M, Kurek S, et al. Initial head computed tomographic scan characteristics have a linear relationship with initial intracranial pressure after trauma. J Trauma. 2004 May;56(5):967-72; discussion 972-3.
6. Schachar JL, Zampolin RL, Miller TS, Farinhas JM, Freeman K, Taragin BH. External validation of the New Orleans Criteria (NOC), the Canadian CT Head Rule (CCHR) and the National Emergency X-Radiography Utilization Study II (NEXUS II) for CT scanning in pediatric patients with minor head injury in a non-trauma center. Pediatr Radiol. 2011;41(8):971-979.
7. Mohan S, Rogan EA, Batty R, et al. CT of the neonatal head. [Review]. Clin Radiol. 68(11):1155-66, 2013 Nov.
8. Perry JJ, Stiell IG, Sivilotti ML, et al. Clinical decision rules to rule out subarachnoid hemorrhage for acute headache. JAMA. 310(12):1248-55, 2013 Sep 25.
9. Perry JJ, Sivilotti MLA, Sutherland J, et al. Validation of the Ottawa Subarachnoid Hemorrhage Rule in patients with acute headache. CMAJ. 2017 Nov 13;189(45):E1379-E1385.
10. Akpinar E. The tram-track sign: cortical calcifications. Radiology. 2004 May;231(2):515-6.
11. Jung JM, Lee JY, Phi JH, et al. Value of routine immediate postoperative brain computerized tomography in pediatric neurosurgical patients. Childs Nervous System. 28(5):673-9, 2012 May.
12. Tamrazi B, Almast J. Your brain on drugs: imaging of drug-related changes in the central nervous system. Radiographics. 2012;32(3):701-19.
13. Martín-Santos R, Fagundo AB, Crippa JA, et al. Neuroimaging in cannabis use: a systematic review of the literature. Psychol Med. 2010 Mar;40(3):383-98.
14. Taheri MS, Moghaddam HH, Moharamzad Y, Dadgari S, Nahvi V. The value of brain CT findings in acute methanol toxicity. Eur J Radiol. 2010 Feb;73(2):211-4.
15. Winklhofer S, Surer E, Ampanozi G, et al. Post-mortem whole body computed tomography of opioid (heroin and methadone) fatalities: frequent findings and comparison to autopsy. Eur Radiol. 2014 Jun;24(6):1276-82.
16. Buethe J, Nazarian J, Kalisz K, Wintermark M. Neuroimaging Wisely. AJNR Am J Neuroradiol. 2016 Dec;37(12):2182-2188.
17. Patterson BW, Pang PS, AlKhawam L, et al. The Association Between Use of Brain CT for Atraumatic Headache and 30-Day Emergency Department Revisitation. AJR Am J Roentgenol. 207(6):W117-W124, 2016 Dec.
18. Kawano H, Hirano T, Nakajima M, Inatomi Y, Yonehara T. Diffusion-weighted magnetic resonance imaging may

underestimate acute ischemic lesions: cautions on neglecting a computed tomography-diffusion-weighted imaging discrepancy. Stroke. 2013 Apr;44(4):1056-61.
19. Giesemann AM, Kontorinis G, Jan Z, Lenarz T, Lanfermann H, Goetz F. The vestibulocochlear nerve: aplasia and hypoplasia in combination with inner ear malformations. Eur Radiol. 2012 Mar;22(3):519-24.
20. Joshi VM, Navlekar SK, Kishore GR, Reddy KJ, Kumar EC. CT and MR imaging of the inner ear and brain in children with congenital sensorineural hearing loss. Radiographics. 32(3):683-98, 2012 May-Jun.
21. Miyasaka M, Nosaka S, Morimoto N, Taiji H, Masaki H. CT and MR imaging for pediatric cochlear implantation: emphasis on the relationship between the cochlear nerve canal and the cochlear nerve. Pediatr Radiol. 2010 Sep;40(9):1509-16.
22. Kaczmarczyk K, Wit A, Krawczyk M, Zaborski J, Gajewski J. Associations between gait patterns, brain lesion factors and functional recovery in stroke patients. Gait Posture. 2012 Feb;35(2):214-7.
23. Mullins ME.. Emergent neuroimaging of intracranial infection/inflammation. [Review]. Radiol Clin North Am. 49(1):47-62, 2011 Jan.
24. Bhalla A, Suri V, Singh P, Varma S, Khandelwal N. Imaging in adult patients with acute febrile encephalopathy: what is better computerized tomography or magnetic resonance imaging. Indian J Med Sci. 2011 May;65(5):193-202.
25. Dung NM, Turtle L, Chong WK, et al. An evaluation of the usefulness of neuroimaging for the diagnosis of Japanese encephalitis. J Neurol. 2009 Dec;256(12):2052-60.
26. García HH, Gonzalez AE, Rodriguez S, et al. Neurocysticercosis: unraveling the nature of the single cysticercal granuloma. Neurology. 2010 Aug 17;75(7):654-8.
27. Rath TJ, Hughes M, Arabi M, Shah GV. Imaging of cerebritis, encephalitis, and brain abscess. Neuroimaging Clin N Am. 2012 Nov;22(4):S1052-5149(12)00060-3.
28. Toma AK, Holl E, Kitchen ND, Watkins LD. Evans' index revisited: the need for an alternative in normal pressure hydrocephalus. Neurosurgery. 2011 Apr;68(4):939-44.
29. Sivaganesan A, Krishnamurthy R, Sahni D, Viswanathan C. Neuroimaging of ventriculoperitoneal shunt complications in children. Pediatr Radiol. 2012 Sep;42(9):1029-46.
30. Abdel-Salam GM, Zaki MS, Saleem SN, Gaber KR. Microcephaly, malformation of brain development and intracranial calcification in sibs: pseudo-TORCH or a new syndrome. Am J Med Genet A. 2008 Nov 15;146A(22):2929-36.
31. Rao P, Bekhit E, Ramanauskas F, Kumbla S. CT head in children. Eur J Radiol. 82(7):1050-8, 2013 Jul.
32. Chen Q, Chen XZ, Wang JM, Li SW, Jiang T, Dai JP. Intracranial meningeal hemangiopericytomas in children and adolescents: CT and MR imaging findings. AJNR Am J Neuroradiol. 2012 Jan;33(1):195-9.
33. Eran A, Ozturk A, Aygun N, Izbudak I. Medulloblastoma: atypical CT and MRI findings in children. Pediatr Radiol. 2010 Jul;40(7):1254-62.
34. Han L, Qiu Y, Xie C, et al. Atypical teratoid/rhabdoid tumors in adult patients: CT and MR imaging features. AJNR Am J Neuroradiol. 2011 Jan;32(1):103-8.
35. Prabhakar R, Haresh KP, Ganesh T, Joshi RC, Julka PK, Rath GK. Comparison of computed tomography and magnetic resonance based target volume in brain tumors. J Cancer Res Ther. 2007;3(2):121-3.
36. Skogen K, Ganeshan B, Good C, Critchley G, Miles K. Measurements of heterogeneity in gliomas on computed tomography relationship to tumour grade. J Neurooncol. 2013 Jan;111(2):213-9.
37. D'Haese PF, Pallavaram S, Konrad PE, Neimat J, Fitzpatrick JM, Dawant BM. Clinical accuracy of a customized stereotactic platform for deep brain stimulation after accounting for brain shift. Stereotact Funct Neurosurg. 2010;88(2):81-7.
38. Hebb AO, Miller KJ. Semi-automatic stereotactic coordinate identification algorithm for routine localization of Deep Brain Stimulation electrodes. J Neurosci Methods. 2010 Mar 15;187(1):114-9.
39. Holloway K, Docef A. A quantitative assessment of the accuracy and reliability of O-arm images for deep brain stimulation surgery. Neurosurgery. 2013 Mar;72(1 Suppl Operative):47-57.
40. Lefranc M, Le Gars D. Robotic implantation of deep brain stimulation leads, assisted by intra-operative, flat-panel CT. Acta Neurochir (Wien). 2012 Nov;154(11):2069-74.
41. Marsh JC, Gielda BT, Herskovic AM, Wendt JA, Turian JV. Sparing of the hippocampus and limbic circuit during whole brain radiation therapy: A dosimetric study using helical tomotherapy. J Med Imaging Radiat Oncol. 2010 Aug;54(4):375-82.
42. Meshkini A, Shahzadi S, Zali A, Parsa K, Afrough A, Hamdi A. Computed tomography-guided stereotactic biopsy of intracranial lesions in pediatric patients. Childs Nerv Syst. 2011 Dec;27(12):2145-8.
43. Pallavaram S, Dawant BM, Remple MS, et al. Effect of brain shift on the creation of functional atlases for deep brain stimulation surgery. Int J Comput Assist Radiol Surg. 2010 May;5(3):221-8.

44. Ruijters D, Homan R, Mielekamp P, van de Haar P, Babic D. Validation of 3D multimodality roadmapping in interventional neuroradiology. Phys Med Biol. 2011 Aug 21;56(16):5335-54.
45. Uhl E, Zausinger S, Morhard D, et al. Intraoperative computed tomography with integrated navigation system in a multidisciplinary operating suite. Neurosurgery. 2009 May;64(5 Suppl 2):231-9; discussion 239-40.
46. Barnes PD. Imaging of nonaccidental injury and the mimics: issues and controversies in the era of evidence-based medicine. Radiol Clin North Am. 2011 Jan;49(1):205-29.
47. Levy AD, Harcke HT, Mallak CT. Postmortem imaging: MDCT features of postmortem change and decomposition. Am J Forensic Med Pathol. 2010 Mar;31(1):12-7.
48. Tartaglione T, Filograna L, Roiati S, Guglielmi G, Colosimo C, Bonomo L. Importance of 3D-CT imaging in single-bullet cranioencephalic gunshot wounds. Radiol Med. 2012 Apr;117(3):461-70.
49. Shih RY, Burns J, Ajam AA, et al. ACR Appropriateness Criteria® Head Trauma: 2021 Update. J Am Coll Radiol 2021;18:S13-S36.
50. Gelfand JM, Wintermark M, Josephson SA. Cerebral perfusion-CT patterns following seizure. Eur J Neurol. 2010 Apr;17(4):594-601.
51. Hess CP, Barkovich AJ. Seizures: emergency neuroimaging. Neuroimaging Clin N Am. 2010 Nov;20(4):619-37.
52. Hsieh DT, Chang T, Tsuchida TN, et al. New-onset afebrile seizures in infants: role of neuroimaging. Neurology. 2010; 74(2):150-156.
53. Nair PP, Kalita J, Misra UK. Role of cranial imaging in epileptic status. Eur J Radiol. 2009 Jun;70(3):475-80.
54. Phuttharak W, Sawanyawisuth K, Kawiwungsanon A, Tiamkao S. The appropriate neuroimaging study in persons with epilepsy. Neurol Sci. 32(5):969-71, 2011 Oct.
55. Harder S, Gourgaris A, Frangou E, et al. Clinical and neuroimaging findings of Cree leukodystrophy: a retrospective case series. AJNR Am J Neuroradiol. 31(8):1418-23, 2010 Sep.
56. Koob M, Laugel V, Durand M, et al. Neuroimaging in Cockayne syndrome. AJNR Am J Neuroradiol. 2010 Oct;31(9):1623-30.
57. Tang Z, Pi X, Chen F, et al. Fifty percent reduced-dose cerebral CT perfusion imaging of Alzheimer's disease: regional blood flow abnormalities. Am J Alzheimers Dis Other Demen. 2012 Jun;27(4):267-74.
58. Olesen PJ, Guo X, Gustafson D, et al. A population-based study on the influence of brain atrophy on 20-year survival after age 85. Neurology. 76(10):879-86, 2011 Mar 08.
59. Shevell M, Ashwal S, Donley D, et al. Practice parameter: evaluation of the child with global developmental delay [RETIRED]: report of the Quality Standards Subcommittee of the American Academy of Neurology and The Practice Committee of the Child Neurology Society. Neurology. 2003 Feb 11;60(3):367-80.
60. Khandanpour N, Hoggard N, Connolly DJ. The role of MRI and CT of the brain in first episodes of psychosis. Clin Radiol. 68(3):245-50, 2013 Mar.
61. American College of Radiology. ACR–SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Patients with Ionizing Radiation. Available at: https://gravitas.acr.org/PPTS/GetDocumentView?docId=23+&releaseId=2.
62. American College of Radiology. ACR–SPR Practice Parameter for Performing and Interpreting Diagnostic Computed Tomography (CT). Available at https://gravitas.acr.org/PPTS/GetDocumentView?docId=132+&releaseId=2
63. O'Hora L, Foley SJ. Iterative reconstruction and automatic tube voltage selection reduce clinical CT radiation doses and image noise. Radiography (Lond). 2018 Feb;24(1):S1078-8174(17)30138-4.
64. Abel F, Schubert T, Winklhofer S. Advanced Neuroimaging With Photon-Counting Detector CT. Invest Radiol. 2023 Jul 01;58(7):472-481.
65. Jarunnarumol N, Kamalian S, Lev MH, Gupta R. Neuroradiology Applications of Dual and Multi-energy Computed Tomography. Radiol Clin North Am. 2023 Nov;61(6):S0033-8389(23)00135-5.
66. Mahesh M, Scatarige JC, Cooper J, Fishman EK. Dose and pitch relationship for a particular multislice CT scanner. AJR Am J Roentgenol. 2001 Dec;177(6):1273-5.
67. Diekmann S, Siebert E, Juran R, et al. Dose exposure of patients undergoing comprehensive stroke imaging by multidetector-row CT: comparison of 320-detector row and 64-detector row CT scanners. AJNR Am J Neuroradiol. 31(6):1003-9, 2010 Jun.
68. Yamauchi-Kawara C, Fujii K, Aoyama T, Yamauchi M, Koyama S. Radiation dose evaluation in multidetector-row CT imaging for acute stroke with an anthropomorphic phantom. Br J Radiol. 2010 Dec;83(996):1029-41.
69. Reimann AJ, Davison C, Bjarnason T, et al. Organ-based computed tomographic (CT) radiation dose reduction to the lenses: impact on image quality for CT of the head. J Comput Assist Tomogr. 2012;36(3):334-8.
70. Vorona GA, Zuccoli G, Sutcavage T, Clayton BL, Ceschin RC, Panigrahy A. The use of adaptive statistical iterative reconstruction in pediatric head CT: a feasibility study. AJNR Am J Neuroradiol. 2013 Jan;34(1):205-11.

71. Brady Z, Ramanauskas F, Cain TM, Johnston PN. Assessment of paediatric CT dose indicators for the purpose of optimisation. Br J Radiol. 2012 Nov;85(1019):1488-98.
72. Perisinakis K, Seimenis I, Tzedakis A, Papadakis AE, Damilakis J. The effect of head size/shape, miscentering, and bowtie filter on peak patient tissue doses from modern brain perfusion 256-slice CT: how can we minimize the risk for deterministic effects?. Med Phys. 2013 Jan;40(1):011911.
73. Kilic K, Erbas G, Guryildirim M, et al. Quantitative and qualitative comparison of standard-dose and low-dose pediatric head computed tomography: a retrospective study assessing the effect of adaptive statistical iterative reconstruction. J Comput Assist Tomogr. 2013;37(3):377-81.
74. Hoang JK, Wang C, Frush DP, et al. Estimation of radiation exposure for brain perfusion CT: standard protocol compared with deviations in protocol. AJR Am J Roentgenol. 2013 Nov;201(5):W730-4.
75. Ertl-Wagner B, Eftimov L, Blume J, et al. Cranial CT with 64-, 16-, 4- and single-slice CT systems-comparison of image quality and posterior fossa artifacts in routine brain imaging with standard protocols. Eur Radiol. 2008 Aug;18(8):1720-6.
76. Jones TR, Kaplan RT, Lane B, Atlas SW, Rubin GD. Single- versus multi-detector row CT of the brain: quality assessment. Radiology. 2001 Jun;219(3):750-5.
77. American Association of Physicists in Medicine. Adult routine head CT protocols. Available at: https://www.aapm.org/pubs/ctprotocols/documents/adultroutineheadct.pdf.
78. American College of Radiology. ACR–SPR Practice Parameter for the use of Intravascular Contrast Media. Available at https://gravitas.acr.org/PPTS/GetDocumentView?docId=142+&releaseId=2
79. American College of Radiology. ACR–ASNR–SPR Practice Parameter for the Performance of Myelography and Cisternography. Available at: https://gravitas.acr.org/PPTS/GetDocumentView?docId=64+&releaseId=2
80. Adeshina AM, Hashim R, Khalid NE, Abidin SZ. Multimodal 3-D reconstruction of human anatomical structures using SurLens Visualization System. Interdiscip Sci. 2013 Mar;5(1):23-36.
81. Campbell BC, Christensen S, Levi CR, et al. Cerebral blood flow is the optimal CT perfusion parameter for assessing infarct core. Stroke. 2011 Dec;42(12):3435-40.
82. Chen W, Belle A, Cockrell C, Ward KR, Najarian K. Automated midline shift and intracranial pressure estimation based on brain CT images. J. vis. exp.. (74), 2013 Apr 13.
83. Friedman JA, Goerss SJ, Meyer FB, et al. Volumetric quantification of Fisher Grade 3 aneurysmal subarachnoid hemorrhage: a novel method to predict symptomatic vasospasm on admission computerized tomography scans. J Neurosurg. 2002 Aug;97(2):401-7.
84. Gupta V, Ambrosius W, Qian G, et al. Automatic segmentation of cerebrospinal fluid, white and gray matter in unenhanced computed tomography images. Acad Radiol. 2010 Nov;17(11):1350-8.
85. Hanson EH, Roach CJ, Day KJ, et al. Assessment of the tracer delay effect in whole-brain computed tomography perfusion: results in patients without known neuroanatomic abnormalities. J Comput Assist Tomogr. 37(2):212-21, 2013 Mar-Apr.
86. Hoeffner EG, Quint DJ, Peterson B, Rosenthal E, Goodsitt M. Development of a protocol for coronal reconstruction of the maxillofacial region from axial helical CT data. Br J Radiol. 2001 Apr;74(880):323-7.
87. Kamiya K, Kunimatsu A, Mori H, et al. Preliminary report on virtual monochromatic spectral imaging with fast kVp switching dual energy head CT: comparable image quality to that of 120-kVp CT without increasing the radiation dose. Jpn J Radiol. 2013 Apr;31(4):293-8.
88. Kim JH, Nuyts J, Kuncic Z, Fulton R. The feasibility of head motion tracking in helical CT: a step toward motion correction. Med Phys. 2013 Apr;40(4):041903.
89. Matsumoto M, Kodama N, Endo Y, et al. Dynamic 3D-CT angiography. AJNR Am J Neuroradiol. 2007 Feb;28(2):299-304.
90. Milchenko M, Marcus D. Obscuring surface anatomy in volumetric imaging data. Neuroinformatics. 2013 Jan;11(1):65-75.
91. Murayama K, Katada K, Nakane M, et al. Whole-brain perfusion CT performed with a prototype 256-detector row CT system: initial experience. Radiology. 2009 Jan;250(1):202-11.
92. Nowinski WL, Puspitasari F, Volkau I, Orrison WW, Knopp MV. Quantification of the human cerebrovasculature: a 7Tesla and 320-row CT in vivo study. J Comput Assist Tomogr. 2013;37(1):117-22.
93. Ono Y, Abe K, Suzuki K, et al. Usefulness of 4D-CTA in the detection of cerebral dural sinus occlusion or stenosis with collateral pathways. Neuroradiol J. 2013 Aug;26(4):428-38.
94. 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 Jun;33(6):1088-94.
95. Qian X, Wang J, Guo S, Li Q. An active contour model for medical image segmentation with application to brain CT image. Med Phys. 2013 Feb;40(2):021911.

96. Rorden C, Bonilha L, Fridriksson J, Bender B, Karnath HO. Age-specific CT and MRI templates for spatial normalization. Neuroimage. 2012 Jul 16;61(4):957-65.
97. American College of Radiology. ACR–ASNR–SPR Practice Parameter for the Performance of Computed Tomography (CT) Perfusion in Neuroradiologic Imaging. Available at https://gravitas.acr.org/PPTS/GetDocumentView?docId=170+&releaseId=2
98. American College of Radiology. ACR–NASCI–SIR–SPR Practice Parameter for the Performance and Interpretation of Body Computed Tomography Angiography (CTA). Available at: https://gravitas.acr.org/PPTS/GetDocumentView?docId=164+&releaseId=2.
99. American College of Radiology. ACR Practice Parameter for Communication of Diagnostic Imaging Findings. Available at https://gravitas.acr.org/PPTS/GetDocumentView?docId=74+&releaseId=2
100. American College of Radiology. ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Computed Tomography (CT) Equipment. Available at https://gravitas.acr.org/PPTS/GetDocumentView?docId=131+&releaseId=2
101. Habibzadeh MA, Ay MR, Asl AR, Ghadiri H, Zaidi H. Impact of miscentering on patient dose and image noise in x-ray CT imaging: phantom and clinical studies. Phys Med. 2012 Jul;28(3):191-9.
102. Trattner S, Pearson GDN, Chin C, et al. Standardization and optimization of CT protocols to achieve low dose. J Am Coll Radiol. 2014 Mar;11(3):271-278.
103. Kanal KM, Butler PF, Sengupta D, Bhargavan-Chatfield M, Coombs LP, Morin RL. U.S. Diagnostic Reference Levels and Achievable Doses for 10 Adult CT Examinations. Radiology. 2017 Jul;284(1):120-133.
104. American College of Radiology. ACR–AAPM–SPR Practice Parameter for Diagnostic Reference Levels and Achievable Doses in Medical X-Ray Imaging. Available at https://gravitas.acr.org/PPTS/GetDocumentView?docId=16+&releaseId=2
105. Al Mahrooqi KMS, Ng CKC, Sun Z. Pediatric Computed Tomography Dose Optimization Strategies: A Literature Review. J Med Imaging Radiat Sci. 2015 Jun;46(2):S1939-8654(15)00145-9.
106. Ryan ME, Jaju A, Ciolino JD, Alden T. Rapid MRI evaluation of acute intracranial hemorrhage in pediatric head trauma. Neuroradiology. 58(8):793-9, 2016 Aug.
107. Roguski M, Morel B, Sweeney M, et al. Magnetic resonance imaging as an alternative to computed tomography in select patients with traumatic brain injury: a retrospective comparison. J Neurosurg Pediatrics. 15(5):529-34, 2015 May.
108. American Association of Physicists in Medicine. AAPM position statement on the use of bismuth shielding for the purpose of dose reduction in CT scanning. Available at: https://www.aapm.org/publicgeneral/BismuthShielding.pdf. .
109. Jhaveri KS, Saini S, Levine LA, et al. Effect of multislice CT technology on scanner productivity. AJR Am J Roentgenol. 2001 Oct;177(4):769-72.
110. Jordan MJ, Lightfoote JB, Jordan JE. Quality outcomes of reinterpretation of brain CT imaging studies by subspecialty experts in neuroradiology. J Natl Med Assoc. 2006 Aug;98(8):1326-8.
111. Jordan YJ, Jordan JE, Lightfoote JB, Ragland KD. Quality outcomes of reinterpretation of brain CT studies by subspecialty experts in stroke imaging. AJR Am J Roentgenol. 2012 Dec;199(6):1365-70.
112. Korn A, Fenchel M, Bender B, et al. Iterative reconstruction in head CT: image quality of routine and low-dose protocols in comparison with standard filtered back-projection. AJNR Am J Neuroradiol. 2012 Feb;33(2):218-24.
113. Nelson DW, Nyström H, MacCallum RM, et al. Extended analysis of early computed tomography scans of traumatic brain injured patients and relations to outcome. J Neurotrauma. 2010 Jan;27(1):51-64.
114. Rapalino O, Kamalian S, Kamalian S, Cranial CT with adaptive statistical iterative reconstruction: improved image quality with concomitant radiation dose reduction. AJNR Am J Neuroradiol. 2012 Apr;33(4):609-15.
115. Ren Q, Dewan SK, Li M, et al. Comparison of adaptive statistical iterative and filtered back projection reconstruction techniques in brain CT. Eur J Radiol. 2012 Oct;81(10):2597-601.
116. Tan JS, Tan KL, Lee JC, Wan CM, Leong JL, Chan LL. Comparison of eye lens dose on neuroimaging protocols between 16- and 64-section multidetector CT: achieving the lowest possible dose. AJNR Am J Neuroradiol. 2009 Feb;30(2):373-7.
117. You JJ, Gladstone J, Symons S, Rotstein D, Laupacis A, Bell CM. Patterns of care and outcomes after computed tomography scans for headache. Am J Med. 2011 Jan;124(1):58-63.e1.

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