Cerrahpaşa Med J 2026; 50: 1-6 ORIGINAL ARTICLE

Evaluation of Low-Dose Computed Tomography Protocols for Follow-Up Imaging in Intracranial Hemorrhage

Samet Genez[1], Mustafa Hızal[1], Ayşenur Buz Yaşar[1], Rüveyde Begüm Yüzok[2], Hamza Özer[1], Yunus Yılmazsoy[1]

[1]Department of Radiology, Bolu Abant Izzet Baysal University Faculty of Medicine, Bolu, Türkiye
[2]Department of Radiology, Niğde Training and Research Hospital, Niğde, Türkiye

Cite this article as: Genez S, Hızal M, Yaşar AB, Özer H, Yılmazsoy Y. Evaluation of low-dose computed tomography protocols for follow-up imaging in intracranial hemorrhage. *Cerrahpaşa Med J.* 2026, 50, 0084, doi:10.5152/cjm.2026.25084.

What is already known on this topic?

- *Repeated head computed tomography (CT) scans are essential for monitoring intracranial hemorrhage (ICH) but increase cumulative radiation exposure.*
- *Low-dose CT protocols with iterative reconstruction can significantly reduce radiation without major loss of diagnostic accuracy.*
- *However, the optimal balance between radiation reduction and image quality for follow-up ICH imaging remains uncertain.*

What this study adds on this topic?

- *Two optimized low-dose head CT protocols (80 kVp/160 mAs and 80 kVp/320 mAs) were compared in patients with ICH.*
- *Both protocols reduced radiation dose by up to 90% compared with the standard-dose protocol while maintaining diagnostic image quality.*
- *The 80 kVp/160 mAs protocol achieved the greatest dose savings and remained sufficient for hematoma monitoring, supporting its use for serial follow-up imaging.*

Abstract

Objective: To evaluate and compare 2 low-dose non-contrast head computed tomography (CT) protocols for follow-up imaging of intracranial hemorrhage (ICH), focusing on radiation dose reduction and subjective image quality while maintaining diagnostic adequacy.

Methods: This single-center, retrospective, non-randomized study included 58 patients (May 2022–February 2023) who underwent follow-up CT for previously diagnosed ICH. Three protocols were analyzed: standard-dose (SD, 120 kVp, automatic tube current modulation), low-dose 1 (LD1, 80 kVp/160 mAs), and low-dose 2 (LD2, 80 kVp/320 mAs). All scans were reconstructed with the Adaptive Statistical Iterative Reconstruction–V algorithm (60% for SD, 80% for LD protocols). Subjective image quality was rated on a five-point Likert scale assessing overall visual impression, cerebrospinal fluid visibility, gray–white matter differentiation, hematoma conspicuity, ventricular delineation, edema visualization, and basal cisterns. Radiation dose parameters,including computed tomography dose index volume (CTDI_vol) and dose–length product (DLP), werecompared among groups using the Kruskal–Wallis test with post-hoc Dunn–Bonferroni correction.

Results: LD2 achieved significantly higher image quality scores than LD1 for most parameters (overall score 32.3 vs. 25.6, $P < .001$, $r = 0.84$). No significant difference was found between LD1 and LD2 regarding hemorrhage conspicuity ($P = .133$). Median DLP and CTDI(vol) values showed a stepwise increase from LD1 to SD (108 vs. 407 vs. 1136 mGy·cm and 4.8 vs. 20.4 vs. 50.9 mGy; $P < .001$). Both low-dose protocols achieved significant radiation reduction, with LD1 providing nearly 90% dose reduction compared with SD.

Conclusion: Both low-dose protocols preserved diagnostic adequacy for ICH follow-up while markedly reducing radiation exposure. The 80 kVp/160 mAs protocol offers an optimal balance between diagnostic acceptability and dose efficiency, making it suitable for routine follow-up CT of ICH.

Keywords: Intracranial hemorrhage, iterative reconstruction, low-dose CT, radiation dose

Introduction

The increasing use of computed tomography (CT) worldwide has led to a steady rise in the total population exposed to ionizing radiation.[1] Non-contrast head CT remains the cornerstone for evaluating neurological emergencies such as stroke, trauma, and particularly intracranial hemorrhage (ICH).[2] Although CT provides rapid and highly sensitive detection of hemorrhage and fractures, it carries a cumulative radiation risk, which is especially concerning in younger or critically ill patients requiring repeated imaging.[3,4]

A key principle of modern radiology is the ALARA concept ("As Low As Reasonably Achievable"), emphasizing dose minimization while maintaining diagnostic quality.[5] This principle is critical in ICH follow-up, where serial CT scans are frequently obtained to monitor hematoma evolution. Reducing tube voltage (kVp) and current (mAs), together with advanced reconstruction algorithms, not only limits radiation exposure but also enables safer serial imaging by decreasing cumulative radiation burden and improving long-term radiation safety in patients requiring repeated neuroimaging.[6,7]

Received: October 17, 2025 **Revision Requested:** November 3, 2025 **Last Revision Received:** November 19, 2025
Accepted: November 29, 2025 **Publication Date:** January 30, 2026
Corresponding author: Genez S, Department of Radiology, Bolu Abant Izzet Baysal University Faculty of Medicine, Bolu, Türkiye **e-mail:** sametgenez@hotmail.com
DOI: 10.5152/cjm.2026.25084

Content of this journal is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

Iterative reconstruction (IR) techniques, such as Adaptive Statistical Iterative Reconstruction (ASIR) and iDose4, compensate for noise introduced by dose reduction and have demonstrated radiation savings of 20%-70% without compromising diagnostic quality.[8,9] Prior studies have shown that for high-contrast lesions like hemorrhage, standard-dose (SD) CT protocols may be unnecessarily high, and low-dose techniques can achieve dose reductions of 50% or more while preserving image interpretability.[2,10,11]

Given the need to minimize cumulative radiation in patients undergoing serial head CTs, this study compares 2 optimized low-dose CT protocols for ICH follow-up. The aim was to assess the balance between radiation dose reduction and subjective image quality to identify the most effective and safe protocol for routine clinical practice.

Methods

This was a single-center, retrospective, non-randomized study conducted between May 2022 and February 2023. Patients of any age or sex who had been previously diagnosed with ICH on an SD non-contrast head CT and showed no significant change in hemorrhage size or other intracranial findings were included, as they were considered suitable for follow-up imaging. Exclusion criteria were ischemic stroke patients with hemorrhagic transformation and those showing evidence of herniation on either of the first 2 SD CT examinations. The study was approved by the InstitutionalReview Board of Bolu Abant İzzet Baysal University Non-Interventional Clinical Research Ethics Committee (Decision no.: 2023/42, Date: March 14, 2023), and written informed consent was obtained from all participants.

All CT examinations were performed on a 64-detector scanner (Revolution EVO, GE Healthcare, Waukesha, WI, USA). The SD (Group 3) protocol used 120 kVp with automatic tube current modulation. Two different low-dose protocols were applied: 80 kVp/160 mAs (LD1, Group 1, n = 33) and 80 kVp/320 mAs (LD2, Group 2, n = 25). The ASIR-V iterative reconstruction algorithm was used, with 60% blending for the SD protocol and 80% for the low-dose protocols. The 160 mAs and 320 mAs settings were selected based on preliminary phantom optimization studies in the department, demonstrating that 160 mAs provided the minimum acceptable noise threshold for hemorrhage follow-up, while 320 mAs yielded improved soft-tissue and ventricular detail. The ASIR-V blending percentages were determined according to vendor recommendations and prior low-dose neuroimaging literature. Prior to clinical imaging, a quality control phantom was used to confirm that all relevant intracranial structures could be adequately visualized at each dose level.

For each examination, the CTDI(vol) and DLP values were recorded directly from the scanner's dose report. All images were reconstructed in 5-mm axial slices and transferred to a dedicated workstation (Advantage Workstation 4.4, GE Healthcare) for evaluation. Two radiologists with 3 and 7 years of experience in neuroimaging independently reviewed all images in consensus, blinded to acquisition protocol and patient information. Image quality assessment was performed according to the EUR 16262 guideline criteria for brain CT.

Subjective image quality was graded on a five-point Likert scale, with SD images accepted as reference quality (score = 5). The scoring system was defined as follows: 1 – non-diagnostic, 2 – poor, 3 – moderate, 4 – good, and 5 – excellent. The following image quality parameters were evaluated: overall visual impression, cerebrospinal fluid (CSF) visibility, gray–white matter differentiation, hematoma conspicuity, ventricular delineation, edema visualization, and visibility of the basal cisterns.

Statistical Analysis

All statistical analyses were performed using R software (version 4.3.1; R Foundation for Statistical Computing, Vienna, Austria). The Shapiro–Wilk test was applied to assess data normality. As all variables exhibited non-normal distribution, nonparametric tests were used. Comparisons between the 2 low-dose groups were conducted using the Mann–Whitney *U*-test, while comparisons among the 3 groups for radiation dose parameters (CTDI(vol) and DLP) were performed with the Kruskal–Wallis test, followed by post-hoc Dunn–Bonferroni correction for pairwise analyses. Effect sizes (r) were calculated for Mann–Whitney *U*-tests to estimate the magnitude of group differences. A P value < .05 was considered statistically significant.

Results

Subjective Image Quality

Image quality scores were significantly higher in the 80 kVp/320 mAs group compared with the 80 kVp/160 mAs group for nearly all parameters (Table 1). Median (interquartile range, IQR) scores for the 80 kVp/320 mAs versus 80 kVp/160 mAs protocols were as follows: visual impression 4.0 vs 3.6 (P = .0002, r = 0.49), CSF 4.8 vs. 3.5 (P < .001, r = 0.76), gray–white matter differentiation 4.7 vs. 3.6 (P < .001, r = 0.69), ventricle 4.8 vs. 3.9 (P < .001, r = 0.79), edema 4.4 vs. 3.4 (P < .001, r = 0.61), and basal cisterns 4.7 vs. 3.0 (P < .001, r = 0.79). The overall image quality score was significantly higher for the 80 kVp/320 mAs protocol (median 32.3 vs. 25.6, P < .001, r = 0.84).

No statistically significant difference was observed between the 2 low-dose groups regarding hemorrhage size (median 4.9 vs 4.6, P = .133, r = 0.13). All examinations acquired with both low-dose protocols were rated as diagnostically acceptable, and no scans had to be excluded due to inadequate image quality.

Radiation Dose

There were no significant differences in patient age among the 3 groups (median 63-65 years, P = .99). A statistically significant

Table 1. Comparison of Subjective Image Quality Between Low-Dose Protocols

Parameter	Effect Size (*r*)	80 kVp/160 mAs (n = 33)	80 kVp/320 mAs (n = 25)	*P*
Visual impression	0.49	3.6	4.0	.0002
Cerebrospinal fluid visibility	0.76	3.5	4.8	<.001
Gray–white matter differentiation	0.69	3.6	4.7	<.001
Hemorrhage conspicuity	0.13	4.6	4.9	.133
Ventricular delineation	0.79	3.9	4.8	<.001
Edema visualization	0.61	3.4	4.4	<.001
Basal cisterns	0.79	3.0	4.7	<.001
Overall score (sum of all parameters)	0.84	25.6	32.3	<.001

Values represent median subjective image quality scores based on a five-point Likert scale (1 = non-diagnostic, 5 = excellent). *P* values were calculated using the Mann–Whitney *U*-test.

increase was observed in both DLP and CTDI(vol) values, showing a gradual rise from the lowest to the SD protocol (Group 3) ($P < .001$ for both parameters; Table 2). The distribution of DLP and CTDI(vol) values across the 3 groups is illustrated in Figure 1A-B.

Median DLP values were 108 (IQR 10.9), 407 (IQR 31.1), and 1136 (IQR 206) mGy·cm for Groups 1, 2, and 3, respectively. Post-hoc pairwise comparisons showed significant differences between all groups (Group 1 vs. 2, $P = .0017$; Group 1 vs 3, $P < .001$; Group 2 vs 3, $P < .001$). Similarly, median CTDI(vol) values were 4.8 (IQR 0), 20.4 (IQR 0), and 50.9 (IQR 12.1) mGy ($P < .001$), with all pairwise comparisons remaining significant (Group 1 vs 2, $P = .001$; Group 1 vs 3, $P < .001$; Group 2 vs 3, $P < .001$).

These findings confirm that substantial radiation dose reduction can be achieved using both low-dose protocols, particularly the 80 kVp/160 mAs setting, while maintaining acceptable diagnostic image quality for follow-up evaluation of ICH (Figures 2 and 3).

Discussion

Minimizing radiation exposure while maintaining diagnostic fidelity is a cornerstone of modern neuroimaging, where CT remains indispensable for both acute assessment and follow-up of ICH.[12] Patients with ICH often require repeated CT examinations to monitor hematoma evolution and ventricular changes, resulting in increased cumulative radiation exposure.[13,14] This study addressed this concern by evaluating 2 optimized low-dose protocols combining reduced kVp acquisition and high IR blending for ICH follow-up.

Both low-dose protocols achieved substantial radiation savings compared with the SD protocol. The LD1 (80 kVp/160 mAs) reduced median DLP from 1136 to 108 mGy·cm and CTDI(vol) from 50.9 to 4.8 mGy, corresponding to nearly 90% dose reduction. These findings are consistent with previous studies reporting 40%-70% reductions using IR-based low-dose neuroimaging.[7,10,13] The ASIR-V algorithm, applied with 80% blending, effectively mitigated image noise, enabling such extreme dose efficiency.[8,9] As age distribution was comparable across groups ($P = .99$), these reductions can be attributed solely to technical protocol optimization.

A clear dose–image quality trade-off was observed. The LD2 protocol achieved significantly higher image quality scores than LD1 across most parameters, with a large overall effect size ($r = 0.84$). Structures most sensitive to image noise—CSF, basal cisterns, and gray–white matter differentiation—showed the greatest decline at 160 mAs. This suggests that LD1, while diagnostically acceptable for high-contrast targets, may be suboptimal for general emergency imaging requiring subtle soft-tissue evaluation. Nevertheless, both protocols maintained diagnostic adequacy for the study's primary objective: assessing hemorrhage size. No significant difference was found between LD1 and LD2 for hemorrhage conspicuity ($P = .133$), confirming that low-dose imaging remains reliable for follow-up of established high-contrast lesions. Prior research similarly indicates that for ICH—characterized by inherently high contrast-to-noise ratio—dose reductions up to 70% preserve diagnostic confidence.[15,16]

The findings demonstrate that a tailored low-dose CT approach can safely reduce radiation exposure without compromising the clinical task of hematoma monitoring. The LD1 protocol provides the best balance between dose and diagnostic sufficiency, offering nearly 90% reduction in radiation while maintaining interpretability for hematoma evolution. LD2 may be preferable when a detailed evaluation of ventricular configuration, edema, or subtle perilesional changes is required. Implementing such protocols exemplifies adherence to the ALARA principle and can substantially lower cumulative radiation risk in patients requiring

Table 2. Comparison of Radiation Dose Parameters Among Standard- and Low-Dose Computed Tomography Protocols

Parameter	80 kVp/160 mAs	80 kVp/320 mAs	SD (120 kVp, ATCM)	P
Age (years)	65 (IQR 22.3)	63 (IQR 25.0)	65 (IQR 25.0)	.99
DLP (mGy·cm)	108 (IQR 10.9)	407 (IQR 31.1)	1136 (IQR 206)	<.001
CTDI(vol) (mGy)	4.8 (IQR 0)	20.4 (IQR 0)	50.9 (IQR 12.1)	<.001

Post-hoc Dunn–Bonferroni test results: DLP: Group 1 vs 2, $P = .0017$; Group 1 vs 3, $P < .001$; Group 2 vs 3, $P < .001$. CTDI(vol): Group 1 vs 2, $P = .001$; Group 1 vs 3, $P < .001$; Group 2 vs 3, $P < .001$. Values represent median (interquartile range, IQR).
ATCM, automatic tube current modulation; CTDI(vol), computed tomography dose index volume ; DLP, dose length product; SD, standard dose.

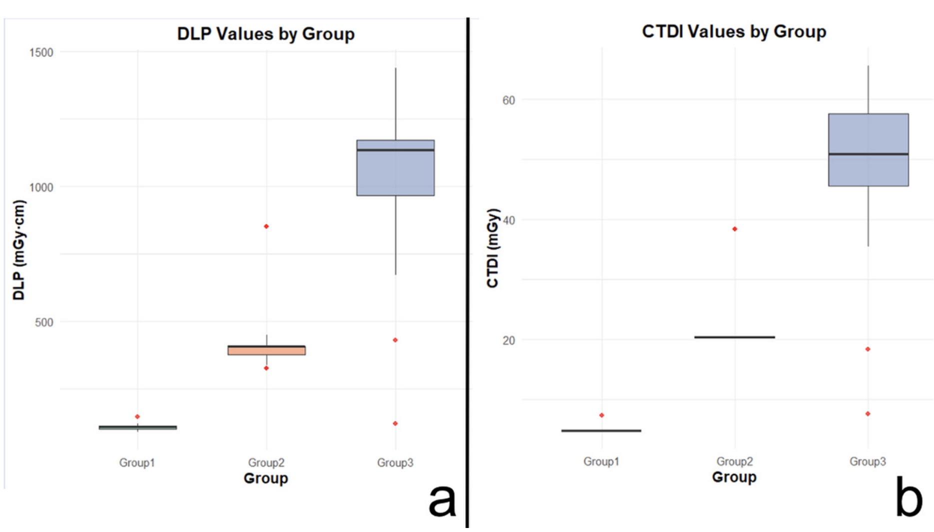

Figure 1. Boxplots showing significant stepwise increases in DLP (a) and CTDI(vol) (b) across low- and standard-dose CT protocols ($P < .001$, Kruskal–Wallis test).

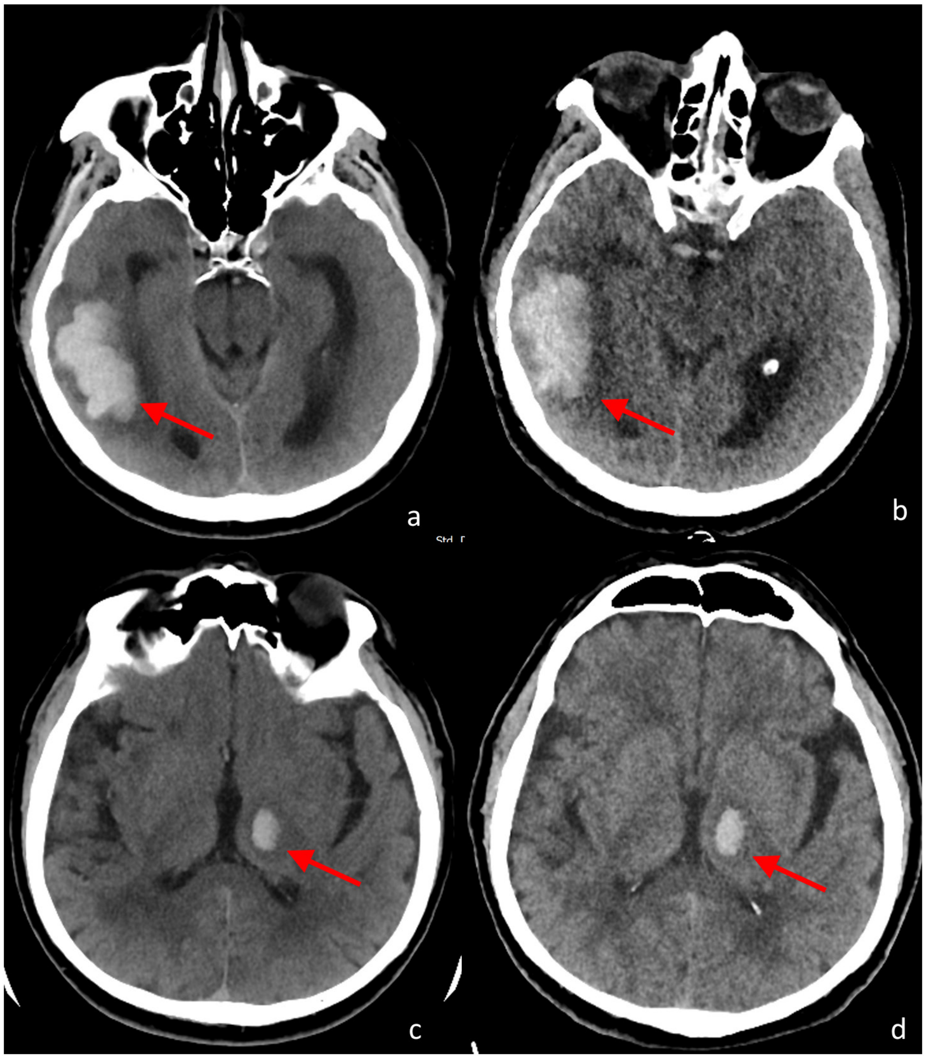

Figure 2. Axial non-contrast CT images from 2 patients with intracerebral hemorrhage obtained using different dose protocols. (a, c) Standard-dose (120 kVp, ATCM) images show clearly defined hematomas with preserved gray–white matter differentiation. (b) Low-dose protocol LD1 (80 kVp/160 mAs) demonstrates increased noise but adequate hemorrhage visibility. (d) Low-dose protocol LD2 (80 kVp/320 mAs) provides improved overall image quality, comparable to standard-dose acquisition. Arrows indicate the hemorrhagic foci. ATCM, automatic tube current modulation.

serial CT scans.[17,18] Integrating these low-dose protocols into routine clinical workflow is feasible, as they require no additional acquisition time or post-processing and allow meaningful long-term reductions in radiation exposure without disrupting standard practice. This strengthens their translational applicability and supports their adoption as a standard approach for follow-up ICH imaging.

This study has several limitations. It was a single-center, retrospective, non-randomized study, which may limit the generalizability of its findings across different CT systems and institutional protocols. Image quality was assessed subjectively by 2 readers, and despite blinding, high IR texture might have introduced subtle recognition bias. Moreover, inter-observer variability could not be statistically assessed because all image quality evaluations were performed in consensus, representing another methodological limitation. Another limitation is the lack of organ/tissue-specific dose estimates for radiosensitive structures such as the brain, eye lenses, and salivary glands. Because this retrospective study relied on scanner-reported CTDI(vol) and DLP values, organ-level dosimetry could not be performed, as it requires dedicated modeling tools or specialized dosimetry software that were not available for this dataset.

Future research should include multicenter validation to assess reproducibility across different scanner types, as vendor-specific IR algorithms and detector technologies may influence image noise characteristics and dose performance. Objective quantitative analysis using metrics such as contrast-to-noise ratio, noise power spectrum, or task-based image quality assessment may further strengthen the evidence supporting low-dose neuroimaging. Additionally, low-dose techniques may provide particular benefit for pediatric populations and patients requiring long-term serial imaging, who are especially vulnerable to cumulative radiation exposure.

In conclusion, both 80 kVp/160 mAs and 80 kVp/320 mAs low-dose CT protocols provided diagnostically acceptable image quality for follow-up of ICH while substantially reducing radiation exposure compared with SD acquisition. The 80 kVp/160 mAs protocol yielded the most efficient dose reduction, making it a suitable option for serial imaging, whereas the 80 kVp/320 mAs protocol may be preferred when superior parenchymal detail is

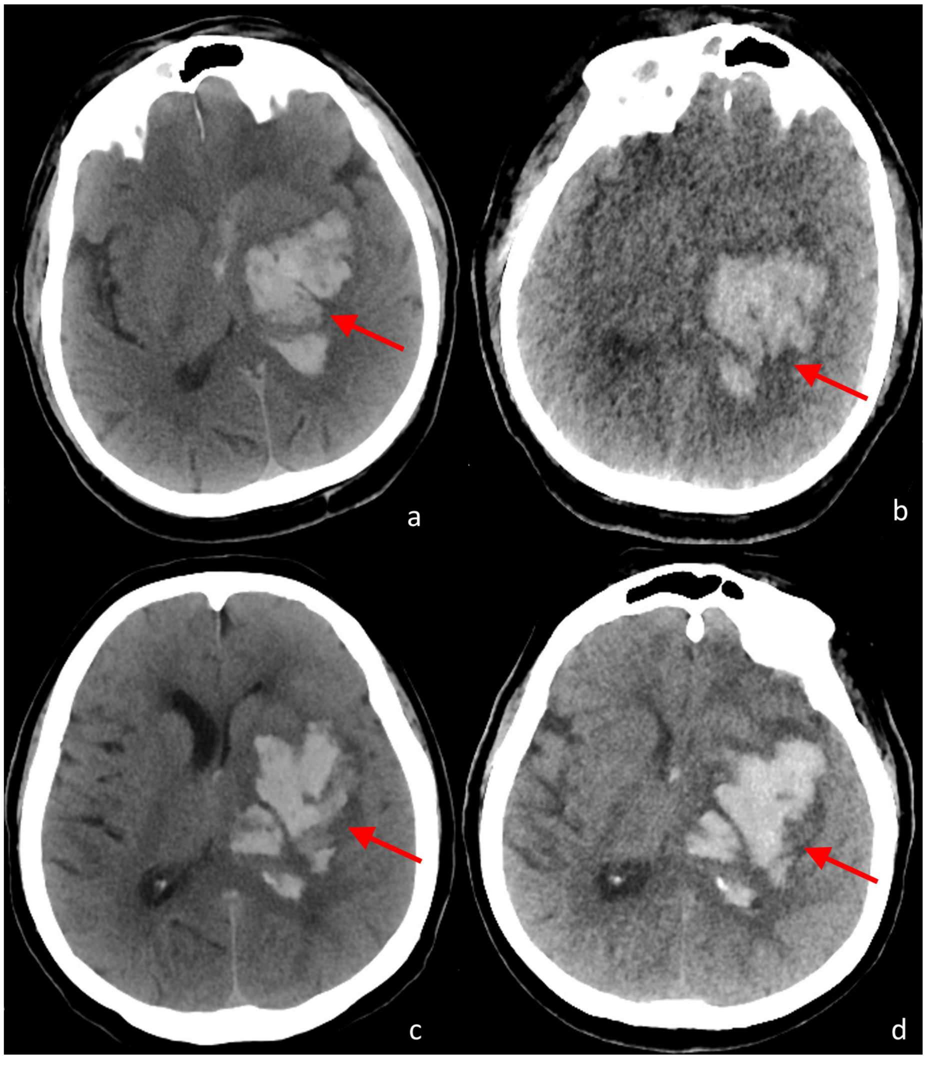

Figure 3. Baseline standard-dose and follow-up low-dose non-contrast CT examinations in 2 patients with intracerebral hemorrhage. (a, c) Standard-dose (120 kVp, ATCM) axial images from 2 different patients demonstrate large intraparenchymal hematomas with preserved gray–white matter differentiation. (b) Follow-up low-dose examination obtained with protocol LD1 (80 kVp/160 mAs) shows persistent but well-delineated hemorrhage despite increased image noise. (d) Follow-up low-dose examination obtained with protocol LD2 (80 kVp/320 mAs) provides improved overall image quality while maintaining clear visualization of the hematoma. Arrows indicate the hemorrhagic foci. ATCM, automatic tube current modulation.

required. These results support the wider clinical implementation of tailored low-dose CT techniques in routine neuroimaging practice, promoting radiation safety without compromising diagnostic confidence. Prospective studies with larger patient cohorts are encouraged to further validate the reproducibility and clinical performance of these low-dose protocols.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

Ethics Committee Approval: Ethical committee approval was received from the Institutional Review Board of Bolu Abant Izzet Baysal University Non-Interventional Clinical Research Ethics Committee Approval (Approval No.: 2023/42; Date: March 14, 2023).

Informed Consent: Written informed consent was obtained from all patients who participated in this study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – M.H.; R.B.Y.; Design – M.H.; R.B.Y.; Supervision – S.G.; A.B.Y.; Resources – H.Ö.; Y.Y.; Materials – H.Ö.; Y.Y.; Data Collection and/or Processing – R.B.Y.; Analysis and/or Interpretation – A.B.Y.; Literature Search – S.G.; Writing Manuscript – S.G.; A.B.Y.; Critical Review – S.G.

Declaration of Interests: The authors declare that they have no competing interests.

Funding: The authors declared that this study has received no financial support.

References

1. Hall EJ, Brenner DJ. Cancer risks from diagnostic radiology. *Br J Radiol*. 2008;81(965):362-378. [CrossRef]
2. Wu D, Wang G, Bian B, Liu Z, Li D. Benefits of low-dose CT scan of head for patients with intracranial hemorrhage. *Dose-Response*. 2020;19(1):1559325820909778. [CrossRef]
3. Morton RP, Reynolds RM, Ramakrishna R, et al. Low-dose head computed tomography in children: A single institutional experience

in pediatric radiation risk reduction: Clinical article. *J Neurosurg Pediatr*. 2013;12(4):406-410. [CrossRef]

4. Bata SC, Yung M. Role of routine repeat head imaging in paediatric traumatic brain injury. *ANZ J Surg*. 2014;84(6):438-441. [CrossRef]
5. Prasad KN, Cole WC, Haase GM. Radiation protection in humans: extending the concept of as low as reasonably achievable (ALARA) from dose to biological damage. *Br J Radiol*. 2004;77(914):97-99. [CrossRef]
6. Paolicchi F, Faggioni L, Bastiani L, et al. Optimizing the balance between radiation dose and image quality in pediatric head CT: findings before and after intensive radiologic staff training. *AJR Am J Roentgenol*. 2014;202(6):1309-1315. [CrossRef]
7. Dieckmeyer M, Sollmann N, Kupfer K, et al. Computed tomography of the head: A systematic review on acquisition and reconstruction techniques to reduce radiation dose. *Clin Neuroradiol*. 2023;33(3):591-610. [CrossRef]
8. Rampinelli C, Origgi D, Bellomi M. Low-dose CT: technique, reading methods and image interpretation. *Cancer Imaging*. 2013;12(3):548-556. [CrossRef]
9. 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 Patient Population*; 2010. www.jcat.org.
10. Kaul D, Kahn J, Huizing L, et al. Dose reduction in paediatric cranial CT via iterative reconstruction: a clinical study in 78 patients. *Clin Radiol*. 2016;71(11):1168-1177. [CrossRef]
11. Scholtz JE, Wichmann JL, Bennett DW, et al. Detecting intracranial hemorrhage using automatic tube current modulation with advanced modeled iterative reconstruction in unenhanced head single- and dual-energy dual-source CT. *AJR Am J Roentgenol*. 2017;208(5):1089-1096. [CrossRef]
12. Reichelt A, Zeckey C, Hildebrand F, et al. Imaging of the brain in polytraumatized patients comparing 64-row spiral CT with incremental (sequential) CT. *Eur J Radiol*. 2012;81(4):789-793. [CrossRef]
13. Priyanka KR, Kadavigere R, Sukumar S. Low dose pediatric CT head protocol using iterative reconstruction techniques: A comparison with standard dose protocol. *Clin Neuroradiol*. 2024;34(1):229-239. [CrossRef]
14. Pearce MS, Salotti JA, Little MP, et al. Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study. *Lancet*. 2012;380(9840):499-505. [CrossRef]
15. Fletcher JG, DeLone DR, Kotsenas AL, et al. Evaluation of lower-dose spiral head CT for detection of intracranial findings causing neurologic deficits. *AJNR Am J Neuroradiol*. 2019;40(11):1855-1863. [CrossRef]
16. Bodelle B, Klein E, Naguib NNN, et al. Acute intracranial hemorrhage in CT: benefits of sinogram-affirmed iterative reconstruction techniques. *AJNR Am J Neuroradiol*. 2014;35(3):445-449. [CrossRef]
17. Bevelacqua JJ. Practical and effective ALARA. *Health Phys*. 2010;98(suppl 2):S39-S47. [CrossRef]
18. Hendee WR, Edwards FM. ALARA and an integrated approach to radiation protection. *Semin Nucl Med*. 1986;16(2):142-150. [CrossRef]