Intraindividual Evaluation of the Influence of Iterative Reconstruction and Filter Kernel on Subjective and Objective Image Quality in Computed Tomography of the Brain

Intraindividueller Vergleich des Einflusses von iterativer Rekonstruktion und Filterkernel auf die subjektive und objektive Bildqualität der Computertomografie des Neurokraniums

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Key words
- brain
- CT
- image manipulation/reconstruction

eingereicht 9.1.2013
akzeptiert 23.5.2013

Bibliography
DOI http://dx.doi.org/10.1055/s-0033-1335937
Published online: 2013
Fortschr Röntgenstr 2013; 185: 741–748 © Georg Thieme Verlag KG Stuttgart · New York · ISSN 1438-9029

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Zusammenfassung

Zielsetzung: Diese Studie untersucht das Potenzial eines Iterativen Rekonstruktionsverfahrens (IR) der 4. Generation hinsichtlich einer möglichen Verbesserung der subjektiven und objektiven Bildqualität der Computertomografie des Neurokraniums (CCT).
Material und Methoden: 31 konsekutive native sequentielle CCT-Rohdatensätze aus der klinischen Routine wurden mit einem prototypischen Rekonstruktionsrechner nachrekonstruiert. Pro Datensatz wurden insgesamt 12 Rekonstruktionen mit folgenden IR Stufen angefertigt: 0 (= gefilterte Rückprojektion = Kontrolle), 1, 3 und 4; jeweils kombiniert mit 3 unterschiedlichen Filterkerneln (weich/standard/hart). Fünf Radiologen mit unterschiedlicher Erfahrung führten die unabhängige Bewertung der Bildqualität nach einer 4-stufigen Ordinalskala durch. Ergänzend wurde eine ROI-Analyse von Bildkontrast und Bildrauschen durchgeführt. Die statistische Auswertung erfolgte in einem Random Intercept Model.
Ergebnisse: Die Kernel „weich“ und „standard“ erhielten höchste subjektive Bewertungen bei niedrigen IR-Stufen mit fallender Tendenz bei ansteigenden IR Stufen, insbesondere den weichen Kernel betreffend. Der Kernel „hart“ erhielt kontinuierlich höhere Bewertungen mit steigender IR-Stufe. Die objektiven Messungen ergaben eine insgesamt ansteigendes Kontrast-zu-Rausch-Verhältnis mit steigender IR-Stufe, der Grau-Weiß-Kontrast nahm mit ansteigender IR-Stufe etwas ab. Alle beobachteten Effekte wiesen keine signifikante Abhängigkeit von der Erfahrung des Betrachters oder von Alter und Geschlecht der Patienten auf.
Schlussfolgerungen: Durch unterschiedliche Kombinationen von IR-Stufe und Filterkernel lässt sich die subjektive und objektive Bildqualität der CCT substantiell beeinflussen.

Abstract

Objectives: To intraindividually evaluate the potential of 4th generation iterative reconstruction (IR) on brain CT with regard to subjective and objective image quality.
Methods: 31 consecutive raw data sets of clinical routine native sequential brain CT scans were reconstructed with IR level 0 (= filtered back projection), 1, 3 and 4; 3 different brain filter kernels (smooth/standard/sharp) were applied respectively. Five independent radiologists with different levels of experience performed subjective image rating. Detailed ROI analysis of image contrast and noise was performed. Statistical analysis was carried out by applying a random intercept model.
Results: Subjective scores for the smooth and the standard kernels were best at low IR levels, but both, in particular the smooth kernel, scored inferior with an increasing IR level. The sharp kernel scored lowest at IR 0, while the scores substantially increased at high IR levels, reaching significantly best scores at IR 4. Objective measurements revealed an overall increase in contrast-to-noise ratio at higher IR levels, which was highest when applying the soft filter kernel. The absolute grey-white contrast decreased with an increasing IR level and was highest when applying the sharp filter kernel. All subjective effects were independent of the raters' experience and the patients' age and sex.
Conclusion: Different combinations of IR level and filter kernel substantially influence subjective and objective image quality of brain CT.

Introduction

Computed tomography (CT) of the brain is one of the most frequently performed radiological examinations in hospitals with emergency rooms or neurological wards. During the history of CT so far, image quality of brain CT scans has always been a topic of research. The anatomy of the neurocranium gives rise to particular challenges when performing CT [1 – 3]: firstly, highest soft-tissue resolution is required to display the normal differentiation of gray matter and white matter, which are very close in X-ray attenuation. This is of special interest in stroke imaging, since slight cortical or basal ganglia hypoattenuation (isodensity to the adjacent white matter) and so-called sulcal effacement are well known to be early CT signs of definite brain tissue damage in ischemic stroke [4]. Secondly, there is always a diagnostic uncertainty regarding the posterior fossa because of skull base-related beam hardening artifacts, which can only partly be overcome by using spiral acquisition techniques, sometimes at the expense of contrast resolution [1, 5 – 7].

All major vendors of CT systems have recently introduced iterative reconstruction (IR) algorithms as a product. Since image noise is reduced compared to the traditional filtered back projection (FBP) reconstruction method, IR can be used in the clinical setting with two different major aims: firstly, to achieve reduction of patient dose exposure by reducing the exposure settings; secondly, to achieve a possible improvement in image quality by reduction of image noise and beam hardening artifacts [8 – 18]. Other possible fields of applying IR include e. g. reduction of metal artifacts or scatter compensation, which may become even more important in the future [19, 20].

Some recent studies have sought to demonstrate a potential effect of IR techniques in brain CT [8, 17, 21]. The intention of this study is to present an intraindividual comparison of different settings of the 4th generation IR technique iDose™ (Philips Healthcare, Best, The Netherlands) in combination with different filter kernels without having to perform additional scans in the clinical setting. Conventional filtered back projection reconstructions serve as the standard of reference.

Compared to earlier generations of IR tools and artifact reduction algorithms, iDose™ reveals a noise power spectrum, which is very close to that of FBP [22]. Therefore reconstructions applying iDose™ can be expected to have an image appearance that is familiar to clinicians. An additional parameter is the iDose™ level, which ranges from 1 – 7 and is used to define the strength of the iterative reconstruction technique in reducing image quantum mottle noise (range: 11 – 55 % noise reduction relative to a corresponding FBP reconstruction) [22]. The level can be defined independently from the radiation dose at which an acquisition is performed.

Materials and Methods

The local institutional review board approved this study (WF-003/12). The requirement for written informed consent was waived.

Data acquisition and reconstruction

Raw data of brain CT acquisitions of 31 consecutive patients (13 male, 18 female; median age 63 years; age range: 21 – 97 years) were collected and used for this study. All exams were performed in the department's standard sequential mode on a Brilliance iCT 256™ scanner (Philips Healthcare, Best, The Netherlands). A summary of the acquisition parameters is listed in **Table 1**. All exams were performed during the clinical routine and therefore always initially reconstructed with FBP according to the standard parameters of the department; followed by regular radiological reporting.

Raw image data for study evaluation were transferred to a prototype reconstruction processor featuring iDose^{4}™ software (Philips Healthcare, Best, The Netherlands) in order to perform the new iterative reconstructions using the following settings: iDose™ level 0 (= filtered back projection), 1, 3 and 4, respectively. With this selection the percentage change in image noise from one level to the next is almost the same (about 12 % on average). Additionally for each setting 3 different brain filter kernels (UA = smooth, UB = standard, UC = sharp) were applied, which resulted in 12 different stacks of CT images for each patient. The slice thickness was 2.5 mm for the infratentorial space and 5 mm supratentorially, according to the department's standard. The department's default reconstruction settings were FBP with standard filter kernel UB.

Subjective image evaluation

Two experienced radiologists (J. B. and M. R., > 6 years experience) and three less experienced radiologists (A. L., H. S. and D. H. < 2 years experience in clinical radiology or no experience in reading brain CT) performed scoring of the image data. The rationale for having different levels of experience was to find out if confirmed habits might influence the perception of the IR reconstructions and hence the subjective scores.

Scoring was performed by applying a precisely defined 4-point scale with regard to artifact load, gray-white matter differentiation and overall image impression (1 = worst, 4 = best), in analogy to former work on the same topic [9, 12, 23]. The particular criteria for image evaluation as used in the current study are summarized in **Table 2**. Image viewing was performed on a PACS-Workstation (PACS IW, GE Healthcare, Milwaukee, MI). For scoring, the images of every reconstructed dataset were displayed anonymously in the department's standard window settings (infratentorial: WW = 90, WL = 30; supratentorial: WW = 60, WL = 35) and under reporting conditions. The raters were allowed to scroll

Table 1 Summary of key CT acquisition parameters. The slice collimation during sequential acquisition was 16 × 0.625 mm. The reconstructed slice thickness was 2.5 mm infratentorial and 5 mm supratentorial.

Tab. 1 Darstellung der wesentlichen CT-Akquisitionsparameter. Die Schichtkollimation bei der inkrementellen Akquisition war 16 × 0,625 mm; rekonstruierte Schichtdicken waren 2,5 mm infratentoriell und 5 mm supratentoriell.

	kV	mAs	mean scan length (mm) ± SD	mean CTDIvol (mGy) ± SD	mean DLP (mGy × cm) ± SD	mean effective dose (mSv) ± SD
infratentorial	120	333	50.7 ± 4.4	61.5 ± 0	311.5 ± 27.2	0.65 ± 0.06
supratentorial	120	310	97.4 ± 7.3	57.2 ± 0	557.2 ± 41.7	1.17 ± 0.09

Table 2 Definition of subjective image evaluation criteria.

Tab. 2 Definition der subjektiven Kriterien der Bildbewertung.

score	rating	Criteria
1	non-diagnostic	excessive image noise and hardening artifacts delineation of gray and white matter mostly impossible
2	suboptimal quality, barely diagnostic	substantial image noise and hardening artifacts delineation of gray and white matter feasible
3	average diagnostic quality	some image noise and hardening artifacts ordinary delineation of gray and white matter
4	excellent diagnostic quality	very little image noise, no hardening artifacts easy delineation of gray and white matter

Table 3 Results of the ROI-based contrast and noise measurements, see also **Fig. 3** for graphical illustration of the results and location of the ROIs.

Tab. 3 Ergebnisse der ROI-Messung von Kontrast und Bildrauschen, siehe auch graphische Darstellung der Ergebnisse und Lage der ROIs in **Abb. 3**.

filter kernel	iDose level	UA (brain smooth)	UB (brain standard)	UC (brain sharp)
gray-white contrast (HU) ± SD	0	11.0 ± 0.6	11.9 ± 0.5	14.4 ± 0.7
	1	9.9 ± 0.6	10.9 ± 0.5	13.3 ± 0.7
	3	8.9 ± 0.5	9.9 ± 0.4	12.0 ± 0.6
	4	8.2 ± 0.5	9.2 ± 0.5	11.3 ± 0.5
image noise (HU) ± SD	0	1.9 ± 0.1	2.3 ± 0.1	3.4 ± 0.1
	1	1.8 ± 0.1	2.1 ± 0.1	3.0 ± 0.1
	3	1.4 ± 0.1	1.7 ± 0.1	2.6 ± 0.1
	4	1.3 ± 0.1	1.6 ± 0.1	2.3 ± 0.1
contrast-to-noise ratio ± SD	0	5.9 ± 0.3	5.3 ± 0.2	4.3 ± 0.1
	1	5.7 ± 0.4	5.1 ± 0.3	4.4 ± 0.1
	3	6.3 ± 0.5	5.7 ± 0.5	4.7 ± 0.1
	4	6.6 ± 0.7	5.9 ± 0.5	4.8 ± 0.1

through the complete dataset, supra- and infratentorial sections have not been evaluated separately.

Objective image evaluation

For the evaluation of the absolute contrast of gray and white matter, 5 pairs of small rectangular regions of interest (ROI, size: 1.2 × 1.2 mm = 3 × 3 px) in adjacent cortical gray matter and adjacent white matter were defined in each dataset (see fig. 3 for ROI example) using maximum zooming and copied likewise to every reconstruction in order to measure mean CT values (Hounsfield Units, HU). Contrast C is defined as the difference of CT values in the small ROIs referring to gray and white matter. For the evaluation of image noise, one pair of larger rectangular ROIs (size: 6.1 × 6.1 mm = 14 × 14 px) in almost homogeneous areas of cortical gray matter and white matter was defined and copied likewise to every reconstruction in each dataset in order to measure the objective image noise. Image noise N is represented by the average of the standard deviation (SD) of HU in both larger ROIs. The contrast-to-noise ratio (CNR) for each dataset was calculated from the contrast measured in the small ROIs and image noise measured in the larger ROIs. Means for C, N and CNR over all data sets were calculated. The data are presented in **Table 3**, **Fig. 3**.

Statistical analysis

Statistical analysis of the subjective scorings was carried out by applying a random intercept model. All calculations were performed in SPSS 20.0 (SPSS Inc., Chicago, IL). Patients and raters were defined as random intercept, raters were nested within their experience. The following parameters were defined as fixed effects: sex, IR level setting, filter kernel, interaction between IR level setting and filter kernel. The intraclass-correlation coefficient (ICC) was calculated to describe the inter-rater reliability.

Results

▼

The consecutive collection of datasets represents a typical mixture of findings. In 14 subjects (45 %) no pathological findings occurred. White matter lesions as signs of microangiopathy were frequently observed (10 subjects, 32 %, thereof 6 female), 3 subjects had residuals of territorial stroke (no acute stroke patient in the collective), 3 intracranial bleedings occurred, 1 subject presented with intracranial metastases.

Illustrating images of typical supratentorial reconstructions in a male subject with small lacunar infarction at the level of the right basal ganglia are presented in **Fig. 1a**; additionally the subjective scores are annotated. It has to be noted that the differences appear visually more evident when directly compared on a reading screen of the PACS workstation. Additional illustrating images show a typical infratentorial slice with constant skull base artifacts (**Fig. 1b**) and a supratentorial slice with hemorrhagic metastases (**Fig. 1c**).

Subjective image evaluation

Inter-rater reliability was high with an ICC = 0.97 (adjusted for the effect of different levels of professionalism). No significant influence of the different levels of professionalism was observed ($p = 0.203$).

The analysis of the scores revealed significant ($p < 0.05$) differences in the mean scorings of nearly every combination filter kernel and iDose level. All adjusted mean scores (± 95 % confidence intervals, CI) are graphically displayed in **Fig. 2**. With an increasing iDose level, a substantial increase of the scores of the reconstructions when applying the sharp filter kernel (UC) was present with eventually significantly best scores at iDose level 4 ($p < 0.001$). An opposite trend was observed regarding the reconstructions when applying the smooth filter kernel (UA), which scored nearly equally well with the intermediate kernel (UB) at iDose level 0 ($p = 0.75$) and declined in scores with increasing iDose levels. The intermediate kernel (UB) scored significantly best at iDose levels 0 and 1, and still slightly higher than UC at iDose level 3 (not statistically significant, $p = 0.142$).

The overall adjusted mean score of datasets of female subjects was 3.05 (95 % CI: 2.77 – 3.32) compared to the mean score of male subjects with 2.86 (95 % CI: 2.58 – 3.13). Although the confidence intervals overlap, the difference reaches statistical significance ($p = 0.023$).

The bone-related beam hardening artifacts at the level of the skull base have not been influenced by the different iDose level settings (see **Fig. 1b**).

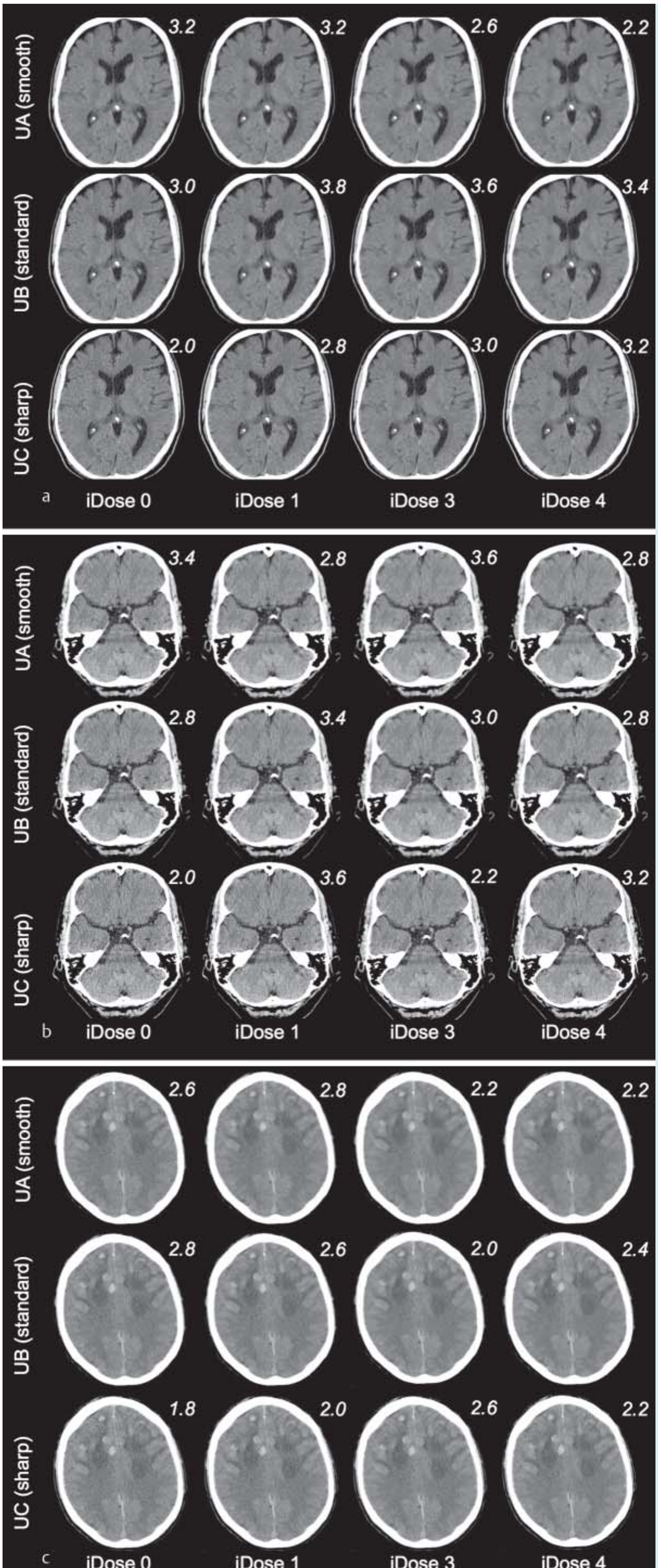

Fig. 1 Presented in **a** is a representative set of reconstructions of a supratentorial slice in a 69-year-old male patient with a small lacunar infarction on the level of the right basal ganglia (WL/WW = 35/60). The IR level increases from left to right, iDose 0 equals filtered back projection (FBP). Numbers in indexes represent the mean subjective score of the respective reconstruction for this particular case that can vary significantly from case to case. **b** shows a similar collection of reconstructions of an infratentorial slice in a 55-year-old female patient (WL/WW = 30/90) illustrating the unchanged skull base artifacts regardless of the iDose level. **c** shows a collection of reconstructions of a supratentorial slice in a 59-year-old male patient suffering from multiple hemorrhagic cerebral metastases (WL/WW = 35/60) illustrating the influence of iDose level and filter kernel on image noise. Lesion conspicuity does not benefit from higher iDose levels.

Abb. 1 **a** zeigt repräsentative Rekonstruktionen einer supratentoriellen Schicht bei einem 69-jährigen Patienten mit kleinem lakunärem Infarktresiduum in den Basalganglien rechtsseitig (WL/WW = 35/60). Die IR-Stufe steigt von links nach rechts an, iDose 0 entspricht gefilterter Rückprojektion alleine. Die Ziffern in den Indices zeigen den mittleren subjektiven Score der jeweiligen Rekonstruktion, welcher von Fall zu Fall allerdings stark variiert. **b** zeigt eine vergleichbare Anordnung an Rekonstruktionen einer infratentoriellen Schicht bei einer 55-jährigen Patientin (WL/WW = 30/90). Die Artefakte an der Schädelbasis sind unverändert, unabhängig von der iDose-Stufe. **c** zeigt eine Anordnung von Rekonstruktionen einer supratentoriellen Schicht bei einem 59-lährigen Patienten mit multiplen hemorrhagischen Metastasen (WL/WW = 35/60). Der Einfluss von iDose Stufe und Filterkernel auf das Bildrauschen ist deutlich erkennbar, die Abgrenzbarkeit der Läsionen profitiert nicht von höheren iDose-Stufen.

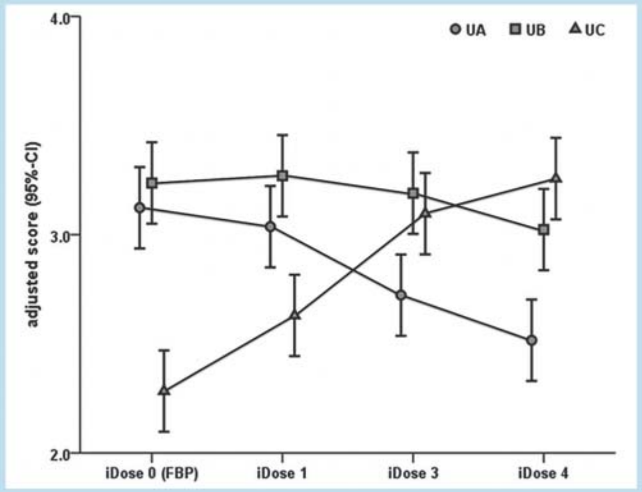

Fig. 2 The graph displays the adjusted subjective scores (error bars represent the 95 % confidence interval) of the different combinations of iDose level and filter kernel. A continuous increase in score is only observed when applying the sharp kernel UC, resulting in the significantly best score at iDose level 4 (versus UB, p < 0.001).

Abb. 2 Der Graph zeigt die adjustierten subjektiven Scores (die Fehlerbalken zeigen das 95 % Konfidenzintervall) der unterschiedlichen Kombinationen von iDose Stufe und Filterkernel. Ein kontinuierlicher Anstieg des Scores zeigt sich nur bei Anwendung des harten Filterkernels UC, signifikant beste Werte werden bei iDose Stufe 4 erreicht (versus UB, p < 0,001).

Objective image evaluation

The detailed results of the objective evaluation are presented in **Table 3** and graphically displayed in **Fig. 3a–c**; additionally an illustration of the ROI placement is presented in **Fig. 3 d**.

Gray-white contrast was best when applying the sharp filter kernel (UC) and worst when applying the smooth filter kernel (UA) regardless of the iDose level. With an increasing iDose level, a uniform decrease of the contrast level by about 2.5 HU from iDose level 0 to iDose level 4 was measured for every filter kernel applied.

Image noise was highest when applying the sharp filter kernel (UC) and lowest when applying the smooth filter kernel (UA) regardless of the iDose level. With an increasing iDose level, a substantial decrease of the image noise was measured, which was most pronounced when applying the sharp kernel (absolute noise decrease from iDose 0 to iDose 4: UC: 1.1 HU; UB: 0.7 HU; UA: 0.6 HU).

At every filter kernel the resulting CNR increased moderately with an increasing IR level. The best CNR as well as the strongest increase over the range of iDose levels were observed when applying the smooth filter kernel (UA: 0.7 points increase versus 0.6 at UB and 0.5 at UC).

Discussion

Discussing IR techniques in CT, dose reduction is the most important issue with respect to different body regions [8, 10 – 13, 16, 18, 24, 25]. Compared to the closely adjacent ocular lens, the brain is not that sensitive to radiation exposure. However, all named organs would seriously benefit from dose reduction and the associated reduction of scattered radiation in brain CT.

Image quality of brain CT might be of even greater interest, particularly regarding the discrimination of gray and white matter and the well-known skull base-related artifacts, which have been a research topic for decades [1, 2, 5, 7]. Many reports of the application of different IR techniques in thoracic, abdominal and cardiovascular CT imaging have been published and have raised hopes concerning a possible improvement of image quality also in brain CT [10, 12, 13, 23, 26 – 28].

Therefore, this study addressed the intraindividual effects that can be possibly achieved when applying a certain IR technique (iDose) and the other main component of CT reconstruction (i. e., the filter kernel) on constant raw data input.

The key result of both the subjective as well as the objective evaluation is that there is a major interdependence between the two key variables of image reconstruction (contrast and noise), which is obviously similarly recognized by inexperienced raters not familiar with reading brain CT. In subjective scoring this results in significant trends towards a better image impression at sharper filter kernels with an increasing IR level and subsequent decrease of subjective quality at softer kernels with an increasing IR level.

However, the standard of reference, which is FBP without IR, scored equally well in the subjective evaluation compared to the best-scoring combination at higher IR levels, when a standard kernel was used in FBP. The good results of the sharp kernel at higher IR levels are not obviously supported by the objective evaluation since the CNR is higher and the image noise is lower for smooth and standard kernels with an increasing IR level compared to the sharp kernel, regardless of the IR level applied (see **Fig. 3b, c**).

On the other hand, due to the distinct modulation transfer functions (MTF) of the filter kernels, the gray-white contrast is substantially better when applying a sharp kernel compared to smooth and standard kernels. Additionally, these absolute CT values actually defining the contrast between gray and white matter converge with an increasing IR level, regardless of the filter kernel applied. In other words: The contrast is somewhat reduced as the IR level increases, but keeps best when applying a sharp kernel. Here we may find some objective support for the result of the subjective scoring.

The apparent mismatch between objective evaluation in terms of CNR and subjective evaluation demonstrates that CNR may fail as an indicator of objective image quality in the case of CCT. Instead, image noise and contrast should be regarded independently. If the image contrast is low as with filter UA, the subjective image quality is reduced at higher IR levels despite reduced noise, as image contrast becomes even lower. If the image contrast is high as with filter UC, the subjective image quality is improved at higher IR levels, as reduced noise is perceived more positively than the reduction in image contrast.

From the clinical point of view, and this is what is represented by the subjective evaluation, which did not particularly discriminate between image noise and contrast, the combination sharp kernel/iDose 4 scored very well. However, the image impression is very similar to a FBP image with a smooth or standard filter kernel, which scored equally high (see also **Fig. 1, 2**). Therefore – although there was no significant difference between the experienced and the inexperienced raters –, we might have been observing an effect of a department's preference or a group's familiarization with a certain kind of image characteristics preferring moderate contrast combined with low noise, which would also be in line with the lack of variability between the raters.

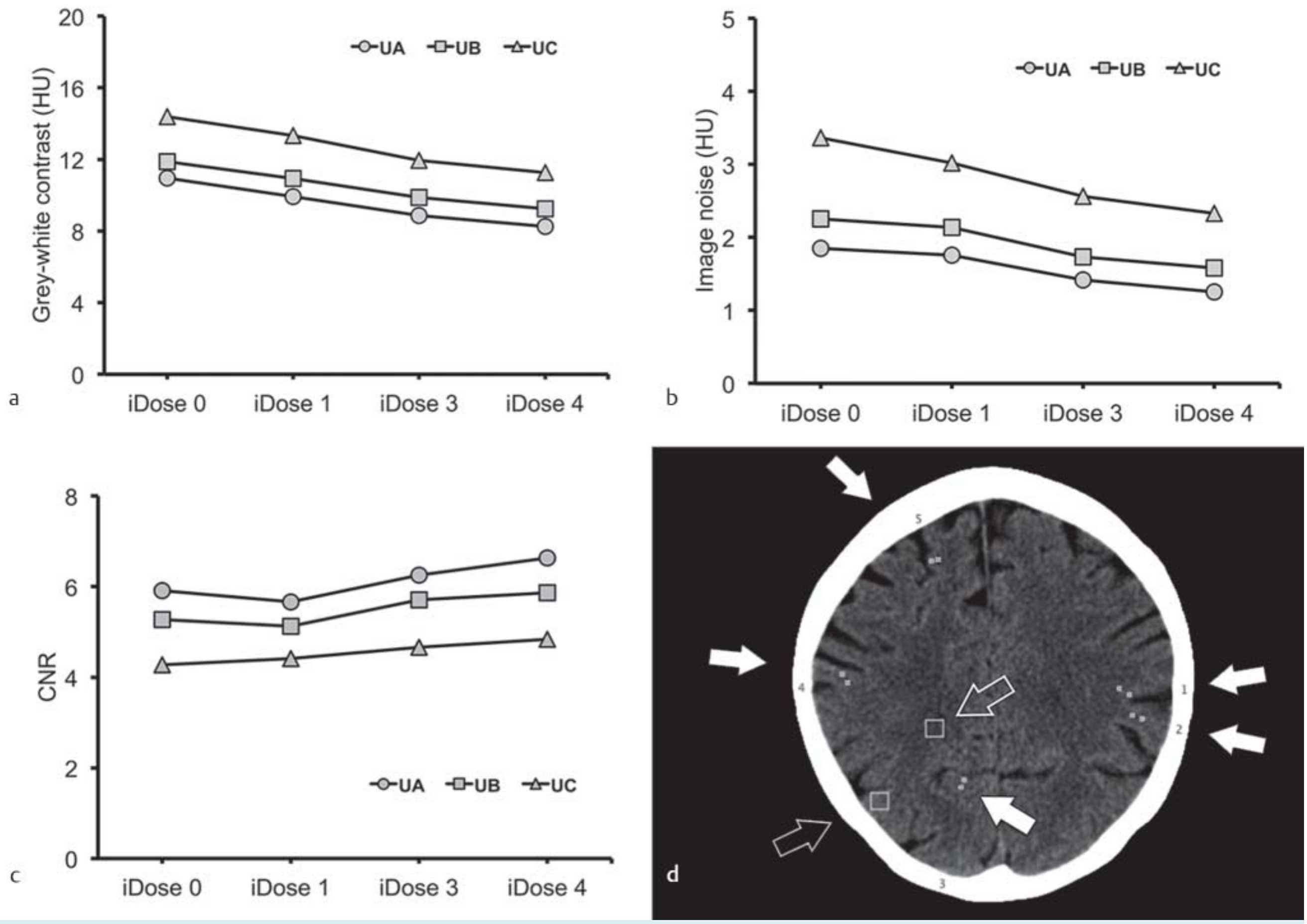

Fig. 3 The gray-white contrast was measured as the difference of mean CT value in 5 small adjacent ROIs in white and cortical gray matter (1.2 × 1.2 mm = 3 × 3 px) as indicated in **d** (closed arrows). The graph **a** presents the means over all cases that show a similar decline by more than 2 HU with an increasing IR level up to iDose 4; at every IR setting the highest measured contrast is achieved when applying the sharp filter kernel (UC). Image noise was measured in larger ROIs in white and cortical gray matter (6.1 × 6.1 mm = 14 × 14 px) as indicated in **d** (open arrows). Image noise decreases with an increasing IR level, and the strongest effect is observed at the sharp filter kernel (UC), as shown in graph **b**. The contrast-to-noise ratio (CNR, graph **c**) as calculated from the contrast measured in the small ROIs and image noise measured in the larger ROIs shows a moderate increase with an increasing IR level, which is similar at every filter kernel. The best CNR at all IR levels is observed when applying the smooth filter kernel (UA).

Abb. 3 Der Grau-Weiß-Kontrast wurde als Differenz aus mittlerem CT-Wert in 5 kleinen benachbarten ROIs in weißer und grauer Substanz gemessen (1,2 × 1,2 mm = 3 × 3 px), wie in **d** gezeigt (geschlossene Pfeile). Der Graph **a** zeigt die Mittelwerte über alle Fälle, welche eine gleichartige Abnahme über insgesamt mehr als 2 HU mit Anstieg der IR-Stufe auf maximal iDose 4 aufweisen. Der höchste objektive Grau-Weiß-Kontrast besteht immer bei Anwendung des harten Filter-Kernels UC. Das Bildrauschen wurde in größeren ROIs in weißer und grauer Substanz gemessen (6,1 × 6,1 mm = 14 × 14 px), wie in **d** gezeigt (offene Pfeile). Das Bildrauschen nimmt mit zunehmender IR-Stufe ab (Graph **b**), der stärkste Effekt zeigt sich hier bei Anwendung des harten Filterkernels UC. Das Kontrast-zu-Rausch-Verhältnis (Contrast-to-noise ratio, CNR; Graph **c**) ergibt sich als Quotient aus den ROI-Daten zu Kontrast und Bildrauschen. Hier zeigt sich bei allen Kombinationen ein moderater Anstieg mit ansteigender IR-Stufe, höchste Werte werden bei Anwendung des weichen Filterkernels erreicht.

Other departments preferring higher contrast combined with moderate noise might come to different conclusions.

Which iDose feature can now possibly be translated into an improvement for diagnostic CT of the brain? Practically, when applying iDose in brain CT, our department would not go to levels beyond iDose level 3 since the loss in contrast may become too high. However, diagnostic quality is a very subjective matter and therefore may be substantially improved by iterative reconstruction when the radiologist concerned normally prefers images with increased contrast, associated with increased noise (like filter UC). A radiologist normally preferring low noise at moderate contrast (as with filter UA) may not find a benefit in iDose or any other current IR technique.

One can imagine that next generation radiologists will be getting more and more familiar with a certain difference in CT image impression. However, the visual IR effects have to be evaluated in larger cohorts with particular pathological lesions and preferentially in multi-center studies comprising institutes with different preferences concerning contrast and noise.

Due to the retrospective character of the study and since we did not perform repeated scans in the same patients, we were not able to look for possible effects due to variation of dose settings, like has been reported for IR techniques of different vendors [17, 21, 29]. However, in the studies by Korn et al. and by Rapalino et al., helical CT acquisitions have been performed, which are known to carry some advantages regarding skull base-related artifacts, which were not improved by iDose in our collective. The helical acquisition mode in brain CT has not been evaluated very intensively, but the few existing reports refer to some loss in contrast resolution in comparable axial multiplanar reformations

(MPR) compared to sequential CT slices [1, 6, 7]. Therefore, having the decline in contrast resolution with increasing iDose level in mind, helical brain CT might not benefit from IR.

An interesting future application may arise with the upcoming possibilities and growing use of computer-aided diagnostic (CAD) tools working with tissue segmentation, e. g. to detect local swelling in acute stroke [30 – 33]. A speculative but nevertheless imaginable future situation could be a brain CT scan reconstructed in two ways: first, with vastly minimized noise resulting from highest IR level, for CAD; second, with subjectively preferred visual settings, for the human reader.

The most important limitation of this study may be due to the local preconditions regarding personal preferences in perception of noise and contrast in brain CT as well as the relatively narrow default window settings, which have also been applied in this study.

Conclusion

Different combinations of iDose level and filter kernel substantially influence the subjective and objective image quality of brain CT scans. The largest improvement using IR might result for radiologists normally preferring high contrast at the expense of increased noise. In such a setting IR could become an additional instrument of controlling particular image characteristics. Our study does not allow giving recommendations regarding the use of IR as a general dose reduction instrument in brain CT.

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