European Radiology (2019) 29:985–992
https://doi.org/10.1007/s00330-018-5620-y

PHYSICS

Radiation dose reduction with frame rate conversion in X-ray fluoroscopic imaging systems with flat panel detector: basic study and clinical retrospective analysis

Noriyuki Sakai[1] · **Katsuyuki Tabei**[1] · **Jiro Sato**[1] · **Toshikazu Imae**[1] · **Yuichi Suzuki**[1] · **Shigeharu Takenaka**[1] · **Keiichi Yano**[1] · **Osamu Abe**[1]

Received: 15 March 2018 / Revised: 9 June 2018 / Accepted: 19 June 2018 / Published online: 9 July 2018

Abstract

Objectives To (a) evaluate the interpolation frames of frame rate conversion (FRC) compared with fluoroscopic frames of conventional method, and (b) compare radiation dose and fluoroscopy time between various clinical examinations without and with FRC retrospectively.

Methods This study consisted of a basic study and a clinical retrospective analysis. The radiation dosimetry, visual assessment and measurements of contrast to noise ratio were examined. Similarity between interpolation frames and fluoroscopic frames was evaluated using normalised cross-correlation values. In the clinical retrospective analysis approved by the institutional review board, we extracted 270 examinations performed without FRC (conventional group, 12.5 pulses/s) and with FRC (FRC group, 6.25 pulses/s) from 23 May to 31 December 2016. The fluoroscopy parameters and demographics of the two groups of the clinical examinations were compared. Statistical analyses were performed with Wilcoxon signed-rank test, Brunner–Munzel test and χ^2 test.

Results In the basic study, the only significant difference was that the radiation dose of FRC was approximately half that of the conventional method in the same fluoroscopy time ($p = .031$). The interpolation frames of FRC were similar to the fluoroscopic frames of the conventional method. In the clinical retrospective analysis, the only significant difference was that FRC reduced the fluoroscopy dose by 48% and the total dose by 31% compared with the conventional method ($p < .001$). There was no significant difference in the others.

Conclusion FRC significantly reduced the radiation dose without extending the fluoroscopy time and maintaining the image quality compared to the conventional method.

Key Points

• *Although X-ray fluoroscopic techniques are widely used for various clinical purposes, X-ray fluoroscopic examinations have radiation risks.*
• *Frame rate conversion is an image processing technique for radiation dose reduction.*
• *Clinical retrospective analysis showed that FRC reduces radiation doses of patients.*

Keywords Fluoroscopy · Retrospective studies · Comparative study · X-rays · Radiation dosage

Abbreviations

CNR Contrast to noise ratio
DAP Dose area product
FPD Flat panel detector
FRC Frame rate conversion
NCC Normalised cross-correlation

✉ Noriyuki Sakai
noriyuki.sakai0602@gmail.com

[1] Department of Radiology, The University of Tokyo Hospital, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8655, Japan

Introduction

X-ray fluoroscopic techniques are widely used for various clinical purposes. However, some reports on radiation risks have reported an increase of cancer risk from X-ray examinations [1]. Radiation-induced skin injuries from angiography have been reported [2, 3]. Therefore, radiation dose reduction is an important issue in X-ray fluoroscopic examinations. A nationwide survey was launched to establish national reference levels for dose-intensive procedures [4]. Techniques and tactics for managing radiation dose have been reported [5], including reports of fluoroscopy dose reduction with a flat panel detector (FPD) system [6–8].

The image processing technique of frame rate conversion (FRC) was recently developed in X-ray fluoroscopic examinations for the reduction of radiation dose. The conventional X-ray systems generate a series of fluoroscopic images at the same frame rate as the X-ray pulse. Frame rate conversion, however, provides images at a frame rate twice the X-ray pulse rate by interpolating from two consecutive fluoroscopic images. For example, when an X-ray pulse rate is 6.25 pulses per second (p/s), the FRC provides 12.5 frames per second images. These interpolation frames are created on the basis of a motion tracking technique that detects the vector of the motion of objects. However, there are no reports on the basic evaluation of interpolation images obtained by FRC and the reduction of radiation dose using FRC in X-ray fluoroscopic examinations. We hypothesised that FRC would reduce the radiation dose in X-ray fluoroscopic examinations without extending the fluoroscopy time. The primary aim of this study was to evaluate the interpolation frames of the FRC method compared with the fluoroscopic frames of the conventional method. Our secondary purpose was to retrospectively compare radiation dose and fluoroscopy time between various clinical examinations with and without FRC.

Materials and methods

Our institutional review board approved the clinical retrospective analysis, and informed consent was waived. The information of this study was posted on our institutional website, and we informed all patients of their right to opt out. The study consisted of the basic study and a clinical retrospective analysis.

Equipment

X-ray fluoroscopic imaging systems with FPD including FRC as an image processing technique (EXAVISTA, Hitachi Ltd. Healthcare Business Unit) were used in this study. Figure 1 shows the concept of FRC. The range of the usable tube voltage was 40–125 kVp and that of the tube current was 0.1–8.0 mA/s. Each pixel size was 139 × 139 μm. A filter (0.05 mmAl and 0.15 mmCu) and anti-scatter grid (grid ratio, 8:1) were used. The focus–detector distance was 120 cm. The system had a maximum field of view (FOV) of 42 × 42 cm with four magnification modes of 42 × 42 cm, 32 × 32 cm, 26 × 26 cm and 21 × 21 cm. In the basic study, the magnification mode of 32 × 32 cm was used. The shutter size remained fully open and that was not changed. In the clinical retrospective analysis, physicians selected appropriate magnification modes and then adjusted the shutter size during the clinical examinations.

Basic study

The basic study was divided into radiation dosimetry, assessment of image quality with a technical phantom and assessment of similarity between interpolation frames and fluoroscopic frames. We used multiple phantoms as follows: a dosimetry phantom, a spatial resolution phantom, a contrast resolution phantom and a contrast agent injected into a bottle phantom.

Radiation dosimetry

We measured the radiation dose of the conventional method (12.5 p/s) and FRC (6.25 p/s) using an ionisation chamber dosimeter (model 9015, Radcal Corporation) with a 6 cm^3 thimble ionisation chamber (10X5-6, Radcal Corporation) on 20 stacked acrylic plates (340 × 340 × 10 mm) on an X-ray table. The ionisation chamber was calibrated within 6 months. Fluoroscopy was performed manually by an author. Each measurement time was 30 s. All measurements of radiation dose were repeated six times for each protocol, and the six repeated measurements were averaged.

Assessment of image quality with a technical phantom

We used a technical phantom including high resolution line pairs (0.6, 0.7, 0.8, 0.9, 1.0, 1.2, 1.4, 1.6, 1.8, 2.0, 2.2, 2.5, 2.8, 3.1, 3.4, 3.7, 4.0, 4.3, 4.6, 5.0 line pairs/mm) and low contrast objects (Primus L, IBA Dosimetry GmbH) for the evaluation of image quality [7]. The technical phantom was placed on the centre of the X-ray table. The X-ray tube was moved manually from the end of the X-ray table until the X-ray tube passed through the technical phantom on the centre of the X-ray table. Fluoroscopy of the conventional method (12.5 p/s) and FRC method (6.25 p/s) were performed with the moving X-ray tube (velocities of 5, 7 and 9 cm/s). The fluoroscopy was repeated consecutively six times, and we obtained data sets of the conventional method and FRC method. Each frame of the technical phantom on the centre of FOV in each data set was targeted for the evaluations of image quality. The fluoroscopic frames of the conventional method and the interpolation frames of the FRC method were compared. Figure 2 shows the technical phantom including high resolution line pairs and low contrast objects. Two observers visually assessed spatial resolution using line pairs on the phantom. The two observers were asked to select the minimum lines that could be seen separately. The data sets were randomised in order and independently evaluated by the two observers. To evaluate the image contrast,

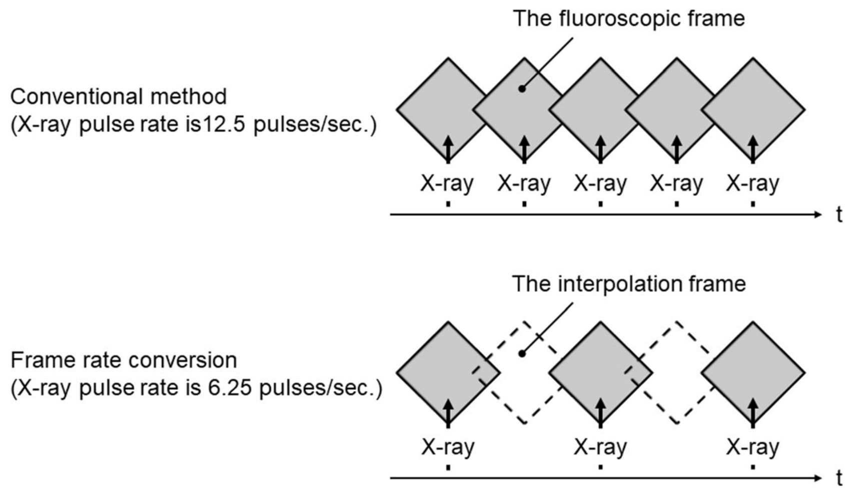

Fig. 1 Concept of frame rate conversion. Frame rate conversion provides images at a frame rate twice the X-ray pulse rate by interpolation of two consecutive fluoroscopic images. For example, when the X-ray pulse rate is 6.25 pulses per second (p/s), frame rate conversion provides 12.5 frames per second images. These interpolation frames are created on the basis of a motion tracking technique that detects the vector of the motion of objects

the contrast to noise ratio (CNR) of a low contrast circular object at a depth of 2.4 mm in the technical phantom was measured at each data set. Regions of interest (ROI) were set on the inside and outside of the low contrast object by one author. In each data set, the CNR was calculated by dividing the contrast (the difference between the mean of the ROI inside and outside the low contrast object) by the standard deviation of the ROI outside the low contrast object.

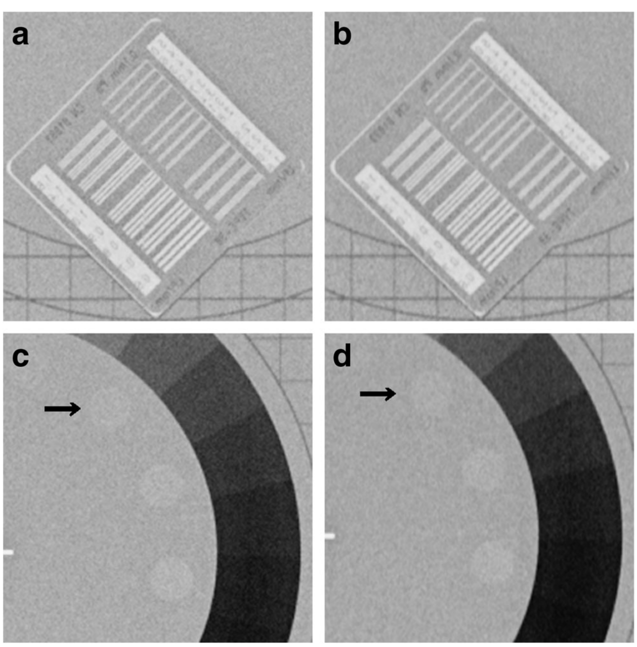

Fig. 2 Technical phantom including high resolution line pairs and low contrast objects. Fluoroscopy was performed on a technical phantom on an X-ray table with a moving X-ray tube (velocity, 5, 7 and 9 cm/s) by both the conventional method (12.5 p/s) and by FRC (6.25 p/s). **a** High resolution line pairs with conventional method (velocity, 9 cm/s), **b** high resolution line pairs with FRC (velocity, 9 cm/s), **c** low contrast objects with conventional method (velocity, 9 cm/s) and **d** low contrast objects with FRC (velocity, 9 cm/s). The arrows in **c** and **d** indicate the targeted low contrast object for the evaluation of CNR

Assessment of similarity between interpolation frames and fluoroscopic frames

A contrast agent (concentration 370 mgI/mL, Gastrografin, Bayer) was filled in a syringe and manually injected into a water-moistened gauze placed in a polyethyleneterephthalate bottle under fluoroscopy. The fluoroscopy was performed with the conventional method (12.5 p/s) at just one time. From the data of the conventional method (12.5 p/s), we generated data for a conventional method (6.25 p/s) by extracting even frames with the aid of the manufacturer. Moreover, we obtained data for FRC (6.25 p/s) by applying FRC to the data of the conventional method (6.25 p/s). The data of the conventional method (12.5 p/s) and the data of the FRC method (6.25 p/s) were compared. The similarity between two methods was evaluated by normalised cross-correlation (NCC) values representing the similarity between the two images [9–11]. We calculated the NCC values between the two methods at each frame, and we examined the characteristics of FRC compared with those of the conventional method graphically and quantitatively. The range of NCC values is from – 1.0 to 1.0. The higher the similarity between the two images, the closer the NCC value is to 1.0. We identified the fluoroscopic or interpolation frame depending on whether the frame number was even or odd. The first frame is always a fluoroscopic frame in FRC, and the fluoroscopic frames and interpolation frames are displayed alternately. Therefore, the interpolation frame is displayed when the frame number is even, and the fluoroscopic frame is displayed when the frame number is odd.

Clinical retrospective analysis

We extracted examinations performed without FRC (conventional group, 12.5 p/s) and with FRC (FRC group, 6.25 p/s) from 23 May 2016 to 31 December 2016. Exclusion criteria were (a) examinations with changed fluoroscopy conditions during the examination (e.g. from FRC with 6.25 p/s to conventional method with 12.5 p/s); (b) lack of patient information (e.g. examination of patients who did not measure their height); (c) examinations where multiple procedures were performed (e.g. patients who had two nerve root blocks at the same time) and (d) examinations of patients who requested not to use their own data. Table 1 shows the demographic characteristics of the 270 extracted clinical examinations. Multiple physicians performed the procedures, because many kinds of clinical examinations were included. Although using FRC was expected to reduce radiation exposure by about a half, it involves delaying the display of fluoroscopic images by one frame as a result of image processing. Physicians were instructed about the characteristics of FRC and they were allowed to select the conventional method or the FRC method. They were also able to switch the method during the examinations. The conventional method was used if the radiology technologist on duty did not understood the characteristics of FRC. Gastroenterologists used the conventional method in clinical examinations where catheters must be manipulated finely, such as endoscopic retrograde cholangiopancreatography. We compared the fluoroscopy time, cumulative dose area products (DAP) of fluoroscopy, number of radiographs (defined as radiographies performed during each examination), cumulative DAP of radiography and cumulative total dose (sum of fluoroscopy and radiography) between the conventional group and FRC group.

Statistical analysis

To compare the radiation dose and image quality between the conventional method and FRC, we used the Wilcoxon signed-rank test. Interobserver agreement was evaluated by weighted κ statistics in visual assessment [12]. The Brunner–Munzel test was used in the clinical retrospective analysis, because the *F* test did not show the equality of variances. The demographic characteristics of the clinical retrospective analysis were analysed by the Brunner–Munzel test or χ^2 test. In all statistical analyses of this study, a *P* value less than .05 was considered significant. The Wilcoxon signed-rank test and χ^2 test were used in commercially available software (JMP Pro 9.0.2, SAS Institute) as was the Brunner–Munzel test (BellCurve for Excel ver. 2.00, Social Survey Research Information Co., Ltd.).

Results

Basic study

Radiation dosimetry

The mean cumulative fluoroscopy doses of the conventional method and FRC were 2.24 and 1.09 mGy, respectively. The standard deviations of the conventional method and FRC were 0.02 and 0.01 mGy, respectively. The difference in cumulative

Table 1 Demographics of clinical retrospective analysis

Parameter	Conventional group (n = 111)	FRC group (n = 159)	p value
Age (year)	64.7 ± 13.4 (11–82)	64.1 ± 14.5 (11–94)	.81
Sex			.77
No. of male	80	112	
No. of female	31	47	
Height (m)	1.62 ± 0.13 (0.67–1.88)	1.62 ± 0.12 (0.67–1.83)	.84
Weight (kg)	58.1 ± 13.6 (31.6–112)	59.5 ± 13.1 (22.1–92)	.35
Body mass index (kg/m^2)	22.9 ± 11.9 (15.7–141)	23.1 ± 10.2 (11.9–141)	.37
Type of examination			.59
Upper gastrointestinal series	29	34	
Urography	22	35	
Fistulography	20	24	
Nerve root block	10	21	
Myelography	9	22	
Small bowel series	11	15	
Joint dislocation reduction	1	1	
Examination such as removing ileus tube	9	7	

Data are mean ± standard deviation and data in parentheses are range. *P* values are a comparison between conventional group and FRC group calculated by the Brunner–Munzel test or χ^2 test

FRC frame rate conversion

fluoroscopy dose between the conventional method and FRC was significant ($p = .031$).

Assessment of image quality with a technical phantom

Table 2 shows the results of the visual assessment for spatial resolution using high resolution line pairs at each X-ray tube velocity. Table 3 shows the results of measurements of CNR for the evaluation of image contrast at each X-ray tube velocity. For the visual assessment and measurements of CNR, there was no significant difference between the conventional method and FRC at any X-ray tube velocity ($p > .05$). The interobserver agreement of visual assessment had a weighted κ value of 0.99.

Assessment of similarity between interpolation frames and fluoroscopic frames

Figure 3 shows the fluoroscopic frames of the conventional method and the interpolation frames of FRC at frame numbers of 140 and 290. Figure 4 shows a graph of the NCC values at each frame number. Odd frames were frames obtained by X-ray pulses, and even frames were frames synthesised by interpolation. The mean and standard deviation of NCC values at odd frame numbers (fluoroscopic frames of conventional method vs fluoroscopic frames of FRC) were 0.90 and 0.03, respectively. The mean and standard deviation of NCC values at even frame numbers (fluoroscopic frames of conventional method vs interpolation frames of FRC) were 0.79 and 0.04, respectively. The mean and standard deviation of NCC value at all frames was 0.84 and 0.06, respectively.

Clinical retrospective analysis

Table 4 shows the results of comparisons of the conventional method and FRC in clinical retrospective analysis. There were significant differences in cumulative DAP of fluoroscopy and cumulative total dose between the conventional group and the FRC group ($p < .001$). Compared to the conventional method, FRC reduced the fluoroscopy dose by 48% and the total dose by 31%. There was no significant difference in the height, body weight, body mass index, fluoroscopy time, number of radiographs and cumulative DAP of radiography ($p > .05$).

Table 3 Evaluation of image contrast using CNR at various X-ray tube velocities

Velocity of X-ray tube	Conventional method	FRC method	*p* value
5 cm/s	0.71 ± 0.18	0.73 ± 0.17	.44
7 cm/s	0.78 ± 0.20	0.82 ± 0.03	.84
9 cm/s	0.81 ± 0.23	0.93 ± 0.27	.31

Data are value of CNR and mean ± standard deviation. *P* values are a comparison between conventional group and FRC group calculated by the Wilcoxon signed-rank test. The depth of the targeted low contrast object was 2.4 mm

FRC frame rate conversion

Discussion

The radiation dose of FRC was approximately half that of the conventional method in the same fluoroscopy time. This is attributed to the fact that the frequency of X-ray irradiation of FRC is half that of the conventional method. It was assumed that fluoroscopy time was not exactly identical between the two methods, because the fluoroscopy was performed manually. Therefore, the radiation dose of FRC was not exactly half of that of the conventional method. With regard to the image quality with the technical phantom, FRC maintained spatial resolution and image contrast. In the assessment of similarity between frames obtained by the conventional method and FRC using NCC values, the interpolation frames of FRC showed high similarity. However, even comparisons between fluoroscopic frames of the conventional method and fluoroscopic frames of FRC did not match entirely (NCC value was not 1.0), because the results of the image

Table 2 Visual assessment for spatial resolution using high resolution line pairs at various x-ray tube velocities

	Velocity of X-ray tube	Conventional method	FRC method	*p* value
Observer 1	5 cm/s	1.40 ± 0.00 LP/mm	1.37 ± 0.07 LP/mm	1.00
	7 cm/s	1.30 ± 0.10 LP/mm	1.20 ± 0.00 LP/mm	.25
	9 cm/s	1.23 ± 0.07 LP/mm	1.20 ± 0.00 LP/mm	1.00
Observer 2	5 cm/s	1.40 ± 0.00 LP/mm	1.40 ± 0.12 LP/mm	1.00
	7 cm/s	1.37 ± 0.07 LP/mm	1.27 ± 0.09 LP/mm	.25
	9 cm/s	1.37 ± 0.07 LP/mm	1.20 ± 0.00 LP/mm	.63

Data are mean ± standard deviation. *P* values are a comparison between conventional group and FRC group calculated by the Wilcoxon signed-rank test

FRC frame rate conversion *LP/mm* line pairs per millimetre

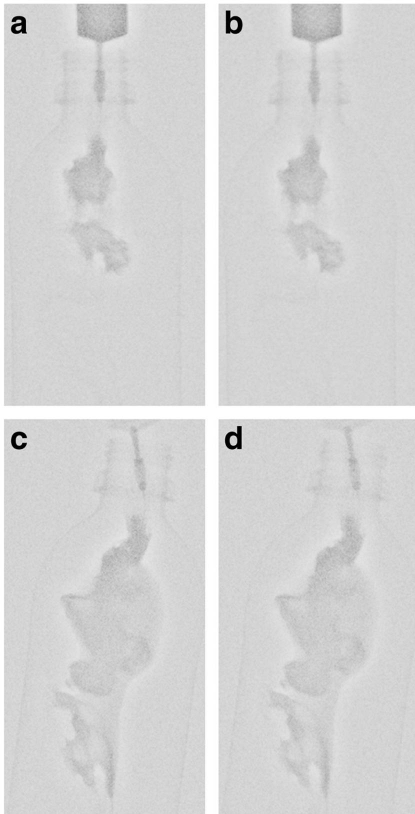

Fig. 3 Images of fluoroscopic frames and interpolation frames. A contrast agent (concentration 370 mgI/mL, Gastrografin, Bayer) was filled in a syringe and manually injected into a water-moistened gauze placed in a polyethyleneterephthalate bottle under fluoroscopy (12.5 p/s). **a** A fluoroscopic frame obtained by the conventional method (12.5 p/s) at frame number 140, **b** an interpolation frame obtained by the FRC (6.25 p/s) at frame number 140, **c** a fluoroscopic frame obtained by the conventional method (12.5 p/s) at frame number 290 and **d** an interpolation frame obtained by FRC (6.25 p/s) at frame number 290

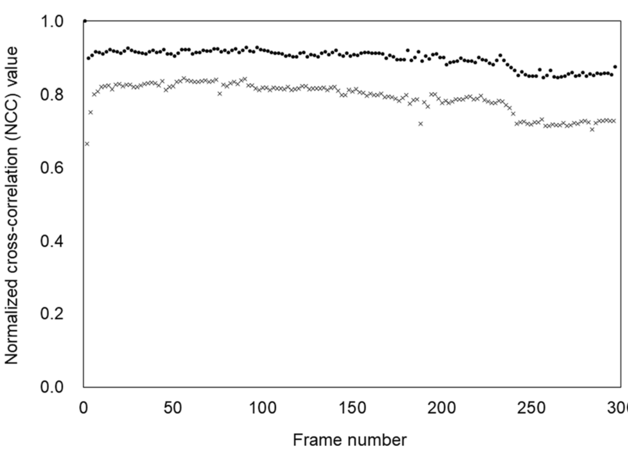

Fig. 4 Assessment of similarity between frames obtained by conventional method and FRC using NCC values. The range of NCC values is from – 1.0 to 1.0. The higher the similarity between the two images, the closer the NCC value is to 1.0. The interpolation frames of FRC showed high similarity. Closed circles, odd frame numbers (fluoroscopic frames in conventional method vs fluoroscopic frames in FRC). Crosses, even frame numbers (fluoroscopic frames in conventional method vs interpolation frames in FRC)

processing technique based on motion tracking were different because of the different X-ray exposure intervals of the two methods (conventional method, 12.5 p/s; FRC, 6.25 p/s). The NCC value of odd frame numbers (fluoroscopic frames of conventional method vs fluoroscopic frames of FRC) was higher than that of the even frame numbers (fluoroscopic frames of conventional method vs interpolation frames of FRC), because the interpolation frames were created on the basis of the fluoroscopic frames of FRC whose NCC value was 0.90. For example, the maximum NCC value of an interpolation frame created by two fluoroscopic frames with NCC values of 0.90 would be 0.81. Therefore, our data suggested that the FRC image processing technique to interpolate frames was working properly, and the interpolation frames of FRC were similar to the fluoroscopic frames of the conventional method. Our basic study results indicated that FRC can perform X-ray fluoroscopy and maintain image quality with half the fluoroscopy dose of the conventional method with identical fluoroscopy times.

Clinical retrospective analysis showed no significant difference in the demographic characteristics including age, sex, height, weight, body mass index and type of examination between the two groups (Table 1). It was assumed that the difference in physique between the two groups did not affect the fluoroscopy dose and radiography dose, and there was little bias based on demographic characteristics in the study. The number of FRC X-ray exposures was half that of the conventional method, because the fluoroscopy time was not increased by using FRC. Therefore, FRC reduced the fluoroscopy dose by 48%. There was no significant difference in the radiography radiation dose between the two groups, because the number of radiographs was not increased by using FRC. The mean radiography dose of FRC group was higher than that of the conventional group, although the difference was not significantly. This is attributed to the large difference of the maximum radiography dose between the two groups. It was assumed that the large maximum radiography dose of FRC group raised the mean radiography dose of FRC group. As a result, FRC reduced the total dose by 31% by decreasing the fluoroscopy dose without increasing the radiography dose.

Several investigations demonstrated that a new C-arm imaging platform consisted of optimised acquisition parameters and several real-time image processing algorithms reduced radiation exposure while maintaining image quality [13–15]. These reports focused on digital fluoroscopy, digital subtraction angiography or cone beam computed tomography in diagnostic and interventional neuroradiological procedures, or transarterial chemoembolisation. The approaches of radiation dose reduction, X-ray fluoroscopy imaging systems and type of subjects are different from our study. If these techniques can coexist, further dose reduction is expected to be achieved.

Table 4 Comparisons of conventional method and FRC in clinical retrospective analysis

Parameter	Conventional group (n = 111)	FRC group (n = 159)	p value
Fluoroscopy time (s)	240 ± 313 (13–2093)	218 ± 335 (16–3035)	.26
Cumulative DAP of fluoroscopy (mGy cm^2)	5056 ± 7322 (252–52,061)	2648 ± 4422 (145–34,542)	< .001
No. of radiographs	6.49 ± 7.05 (1–59)	6.06 ± 6.83 (1–62)	.37
Cumulative DAP of radiography (mGy cm^2)	1418 ± 1375 (40–9286)	1831 ± 4851 (96–58,769)	.67
Cumulative total dose (mGy cm^2)	6473 ± 7973 (531–56,117)	4479 ± 7082 (304–60,250)	< .001

Data are mean ± standard deviation and data in parentheses are range. Cumulative total dose was defined as sum of fluoroscopy dose and radiography dose. *P* values are a comparison between conventional group and FRC group calculated by the Brunner–Munzel test

FRC frame rate conversion, *DAP* dose area product

This study had several limitations. First, only one comparison of the conventional method with 12.5 p/s and FRC with 6.25 p/s was evaluated. One investigation demonstrated that radiation risks of paediatric patients should not be disregarded in voiding cystourethrography [16], and the radiation dose reduction in paediatric patients is an important issue in X-ray fluoroscopic examinations. We were not able to include the paediatric population, because the number of paediatric cases was small. It is desirable to investigate the efficacy of FRC at lower X-ray pulse rates such as FRC with 3.125 p/s. Second, clinical examinations to finely move catheters such as endoscopic retrograde cholangiopancreatography were not included in our clinical retrospective analysis. Frame rate conversion was not applied to such clinical examinations in our institution, because the display of FRC fluoroscopic images on the monitor was delayed by one frame because of the principle of the image processing. Further consideration will be needed to evaluate the effect of the FRC display delay time. Third, in our clinical retrospective analysis, the extracted clinical examinations were performed by different physicians and radiology technologists. Our results may include the variability caused by the different experience and techniques of physicians or fluoroscopy dose reduction techniques of radiology technologists. Fourth, the determination of the protocol was not randomised in the clinical retrospective study, because this was a retrospective analysis. Although the demographic characteristics of our study showed the similarity of the two groups, our study was not able to deny the possibility of confounding factors. Fifth, the anterior-posterior lengths of patients were not measured, although our results showed the similarity of the physique of the patients between the two groups. The anterior-posterior length of the patient is an important factor, because the more X-rays would be used in order to generate an image for a thicker patient than for a thinner one. Sixth, we did not assess the radiation exposure of physicians. On the basis of our results, however, FRC is expected to reduce the radiation exposure to the clinician and the interventional radiologist.

In conclusion, we found that, compared to the conventional method, FRC maintained image quality and significantly reduced radiation doses without extending the fluoroscopy time in various clinical examinations using X-ray fluoroscopy.

Acknowledgements In our basic study, the image reconstruction from the raw data which includes no clinical information was supported by Hitachi Ltd. Healthcare Business Unit.

Funding This work was partially supported by a Grant-in-Aid from JSPS (Japan Society for the Promotion of Science) KAKENHI JP Scientific Research (C) Grant Number 15K08692.

Compliance with ethical standards

Guarantor The scientific guarantor of this publication is Noriyuki Sakai.

Conflict of interest The authors of this manuscript declare no relationships with any companies whose products or services may be related to the subject matter of the article.

Statistics and biometry No complex statistical methods were necessary for this paper.

Informed consent Written informed consent was waived by the institutional review board.

Ethical approval Institutional review board approval was obtained.

Methodology
- retrospective
- observational and experimental
- performed at one institution

References

1. Berrington de González A, Darby S (2004) Risk of cancer from diagnostic X-rays: estimates for the UK and 14 other countries. Lancet 363:345–351

2. Shope TB (1996) Radiation-induced skin injuries from fluoroscopy. Radiographics 16:1195–1199
3. Berlin L (2001) Radiation-induced skin injuries and fluoroscopy. AJR Am J Roentgenol 177:21–25
4. Aroua A, Rickli H, Stauffer JC et al (2007) How to set up and apply reference levels in fluoroscopy at a national level. Eur Radiol 17:1621–1633
5. Justino H (2006) The ALARA concept in pediatric cardiac catheterization: techniques and tactics for managing radiation dose. Pediatr Radiol 36:146–153
6. Linke SY, Tsiflikas I, Herz K, Szavay P, Gatidis S, Schäfer JF (2016) Ultra low-dose VCUG in children using a modern flat detectorunit. Eur Radiol 26:1678–1685
7. Weis M, Hagelstein C, Diehm T, Schoenberg SO, Neff KW (2016) Comparison of image quality and radiation dose between an image-intensifier system and a newer-generation flat-panel detector system—technical phantom measurements and evaluation of clinical imaging in children. Pediatr Radiol 46:286–292
8. Miraglia R, Maruzzelli L, Cortis K et al (2015) Comparison between radiation exposure levels using an image intensifier and a flat-panel detector-based system in image-guided central venous catheter placement in children weighing less than 10 kg. Pediatr Radiol 45:235–240
9. Morishita J, Katsuragawa S, Kondo K, Doi K (2001) An automated patient recognition method based on an image-matching technique using previous chest radiographs in the picture archiving and communication system environment. Med Phys 28:1093–1097
10. Morishita J, Katsuragawa S, Sasaki Y, Doi K (2004) Potential usefulness of biological fingerprints in chest radiographs for automated patient recognition and identification. Acad Radiol 11:309–315
11. Toge R, Morishita J, Sasaki Y, Doi K (2013) Computerized image-searching method for finding correct patients for misfiled chest radiographs in a PACS server by use of biological fingerprints. Radiol Phys Technol 6:437–443
12. Kundel HL, Polansky M (2003) Measurement of observer agreement. Radiology 228:303–308
13. Schernthaner RE, Duran R, Chapiro J, Wang Z, Geschwind JF, Lin M (2015) A new angiographic imaging platform reduces radiation exposure for patients with liver cancer treated with transarterial chemoembolization. Eur Radiol 25:3255–3262
14. Söderman M, Holmin S, Andersson T et al (2013) Image noise reduction algorithm for digital subtraction angiography: clinical results. Radiology 269:553–560
15. Söderman M, Mauti M, Boon S, Omar A, Marteinsdóttir M, Andersson T et al (2013) Radiation dose in neuroangiography using image noise reduction technology: a population study based on 614 patients. Neuroradiology 55:1365–1372
16. Perisinakis K, Raissaki M, Damilakis J, Stratakis J, Neratzoulakis J, Gourtsoyiannis N (2006) Fluoroscopy-controlled voiding cystourethrography in infants and children: are the radiation risks trivial? Eur Radiol 16:846–851