WHITE PAPER

Can the small focal spot be omitted for Direct Radiography?

Simplifying the exposure technique

AGFA

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Introduction

This White Paper questions the widespread use of the small focal spot for specific clinical examinations and acquisition techniques. Current practices, based on international guidelines as well as techniques carried over from (analog) film/screen radiography, can reduce X-ray tube life and hence increase costs, while adding little clinical benefit.

In particular, the White Paper questions the added value of using the small focal spot for images made using direct radiography flat panel detectors (DR FPD) with pixel sizes in the range of 125 – 160 µm, especially for extremity examinations.

A small focal spot size reduces geometric unsharpness, and is traditionally used when a high level of detail is required. The typical focal spot size for small examination areas (e.g. extremities, neonatal, etc.) is 0.6 mm; this compares to a typical focal spot size of 1.0 mm to 1.2 mm for large anatomical areas (where a higher tube loading is required with short exposure times, to decrease movement unsharpness).

Analog film can be considered as an almost continuous medium (due to the very fine grains of the film); small differences between small and large focal spot sizes can therefore be observed in the images. A digital FPD, on the other hand, is a discrete medium (due to its finite pixel size); the differences in focal spot sizes might therefore become imperceptible.

If, in fact, using the small focal spot has no added value for DR – as will be demonstrated in this White Paper –, then multiple advantages become apparent due to use of the large focal spot only:

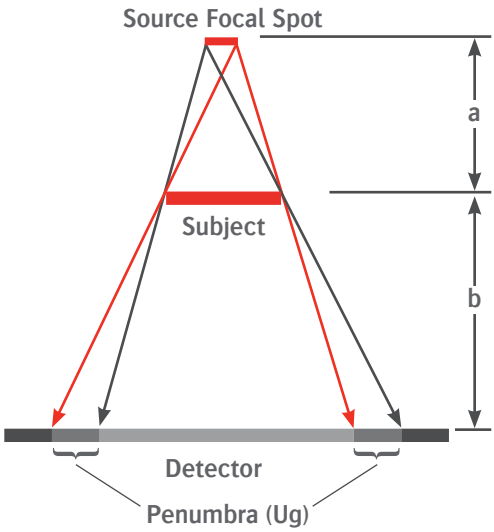
- shorter exposure times and less motion unsharpness
- longer tube lifecycle
- possibility to use mono-track X-ray tubes
- simplification of exposure technique (no focal spot selection)

Geometric unsharpness

Geometric unsharpness refers to the loss of definition resulting from the geometric factors of the radiographic equipment and setup. The area of varying density at the edge of a feature caused by geometric factors is called the *penumbra*. It occurs because the radiation does not originate from a single point, but rather over an area. Three factors control unsharpness: *source size, source-to-object distance and object-to-detector distance*. The source size is obtained by referencing the manufacturer's specifications for a given X-ray source. Medical X-ray tubes typically have focal spot sizes in the 0.6 mm (small focus) to 1.2 mm (large focus) range.

Hypothesis / approach

The drawing and formula provided here illustrate the geometrical unsharpness caused by the focal spot.



Formula for geometrical unsharpness:
Ug = f * b/a
f = source focal-spot size
a = distance from the source to front surface of the object
b = the thickness of the object

For the case when the detector is not placed next to the sample, such as when geometric magnification is being used, the calculation becomes:
Ug = f * b/a
f = source focal-spot size
a = distance from X-ray source to front surface of material/object
b = distance from the front surface of the object to the detector

Source: https://www.nde-ed.org/EducationResources/CommunityCollege/Radiography/Physics/GeometricUnsharp.htm

Table 1 (below) provides some practical (including 'worst case') scenarios for extremities, with respect to exposure set-up and geometric unsharpness.

TABLE 1: SCENARIOS FOR IMAGING EXTREMITIES WITH RESPECT TO EXPOSURE SET-UP AND GEOMETRIC UNSHARPNESS

	f	a	b	Ug [mm]	f	a	b	Ug [mm]	Δ Ug [mm]	SID
hand	0.6	88	4	**0.027**	1.2	88	4	**0.055**	**0.027**	92
hand	0.6	112	3	**0.016**	1.2	112	3	**0.032**	**0.016**	115
foot	0.6	87	6	**0.041**	1.2	87	6	**0.083**	**0.041**	93
knee, panel on table	0.6	70	14	**0.120**	1.2	70	14	**0.240**	**0.120**	84
knee, panel in bucky	0.6	70	21	**0.180**	1.2	70	21	**0.360**	**0.180**	91
knee, panel on table	0.6	83	14	**0.101**	1.2	83	14	**0.202**	**0.101**	97
knee, panel in bucky	0.6	83	21	**0.152**	1.2	83	21	**0.304**	**0.152**	104
knee, panel on table	0.6	103	12	**0.070**	1.2	103	12	**0.140**	**0.070**	115
knee, panel in bucky	0.6	98	19	**0.116**	1.2	98	19	**0.233**	**0.116**	117

The figures in red indicate the geometrical unsharpness for a hand, foot or knee image, calculated using the formula for the small focal spot and for the large focal spot. The grey column indicates the difference between them. As expected, the difference increases with a smaller source-to-image distance (SID) and when the object is thicker or further away from the detector (detector in bucky, e.g. knee exposure with grid).

In all cases, the calculated values are smaller or in the order of magnitude of the physical pixel pitch of the FPD. The study hypothesis is therefore, that, for smaller extremities, using standard panels results in no significant differences in image quality (spatial resolution) because, as the table makes visible, the differences in geometrical unsharpness are significantly below the range of these pixel sizes.

Only with larger object thicknesses (e.g. knees, especially when exposed in the bucky) do the changes in resolution caused by the focal spot potentially become perceptible, depending on the SID and pixel pitch of the panel.

Technical image quality: Spatial resolution

To determine the MTF (Modulation Transfer Function)-differences between small and large focal spot sizes, a sharp edge measurement was made in an X-ray-lab using detectors with different pixel pitches, positioned at increasing distances.

Resolution (MTF) tests were performed in an X-ray-lab, using a sharp edge measurement at 2°, with and without RQA5 filter (21 mm Al), with and without diaphragm.

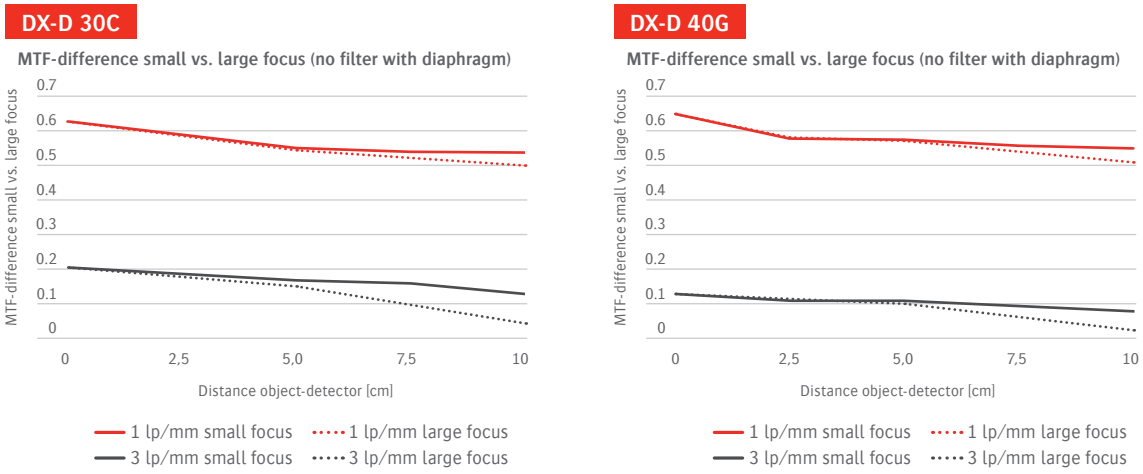
The distance of the object (sharp edge) to the detector was increased from 0 to 10 cm in 2.5 cm increments, in order to simulate and cover the varying thicknesses of different extremities (body parts).

The test was performed with a 125 µm pixel pitch panel (Agfa DX-D 30C) and a 140 µm pixel pitch panel (Agfa DX-D 40G). The 140 µm pixel pitch (GOS) panel was used to reflect the standard pixel size (independent of the scintillator). Exposures were done using both small and large focal spot size.

Test set up (X-ray lab)

- Philips CP80 Super device
- SRO33100 Rot 351 tube (with 2.5 mm Al eq. at 75 kV inherent filtering)
- Small focal spot = 0.6 mm; large focal spot = 1.2 mm
- RQA 5 filter (layered), 99% purity = 21 mm Al)
- SID: ca. 1m

MTF results for small and large focal spot for DX-D 30C (125 µm) and DX-D 40G (140 µm)



The MTF results (MTF at 1 lp/mm and 3 lp/mm) show that with the 140 µm pixel pitch detector, there is no difference in MTF between large and small focal spot sizes for an object-to-detector distance of up to 5 cm (which is the small skeleton range, e.g. for hands, feet, etc.). Differences remain small at 7.5 cm, especially for MTF 1 lp/mm.

With the DX-D 30C detector (125 µm pixel size), the differences in MTF between large and small focal spot are slightly greater, but here as well the results support the study hypothesis, especially for the thinner extremities.

Clinical Image Quality

To determine the extent to which this effect would be perceptible in a clinical situation, or to assess the significance of small and large focal spot size on the appearance of normal anatomy in clinical radiographs (including image processing), a study was carried out using anthropomorphic phantoms.

Anthropomorphic phantom tests & readings

Agfa carried out an internal assessment using hand, foot and knee phantoms. Exposures were made on an Agfa DR 600 modality according to Table 1, which represent the most challenging clinical situations, to investigate the differences in image quality between small and large focal spot. Flat panel detectors (FPDs) with pixel sizes of 125 µm (DX-D 30C) and 150 µm (DR 14e) were used; three dose levels were exposed (i.e. target or reference dose, 62.5% of the reference dose, and 40% of the reference dose). Images were processed with MUSICA3 (skeleton) image processing using the default taste settings. To provide a general reference for this focal spot size investigation, the same exposures were made on analog film/screen (at reference dose only).

TABLE 2: IMAGE SET AND EXPOSURE PARAMETERS FOR FILM/SCREEN

Single-sided screen-film system (Mammo for extremities)					RP-processing (2' at 34°C)			
Screen: **HD-S**			Nr.: 7YUF5B					
Type FILM: **HT** (Mammoray MR7)			Nr.: 37460007					
Size: **24x30**					Exposure			
Phantom (Body Part)	**kV**	**SID** [cm]	**Focus**	**Position of detector**	mAs	*ms x mA*	Film Density	
							measured	target film density
Hand PA	48	100	large	on table	6.3	*100x63*	1.51	1.45
Hand PA	48	100	small	on table	6.3	*100x63*	1.52	1.45

Double-sided screen-film system					RP-processing (2' at 34°C)			
Screen: **CX-O-Fine**			Nr.: 3YKF5C					
Type FILM: **CP-G-Plus**			Nr.: 79560028					
Size: **24x30**					Exposure			
Phantom (Body Part)	**kV**	**SID** [cm]	**Focus**	**Position of detector**	mAs	*ms x mA*	Film Density	
							measured	target film density
Hand PA	48	93	small	on table	4	*100x40*	1.54	1.45
Hand PA	48	93	large	on table	4	*100x40*	1.42	1.45
Foot AP	55	100	large	on table	2.5	*100x25*	1.33	1.45
Foot AP	55	100	small	on table	2,5	*100x25*	1.54	1.45
Foot LAT	55	100	small	on table	4	*100x40*	1.53	1.45
Foot LAT	55	100	large	on table	4	*100x40*	1.35	1.45
Knee AP	60	100	small	on table	8	*100x80*	1.60	1.5
Knee AP	60	100	large	on table	8	*100x80*	1.51	1.5
Knee AP	60	100	large	in bucky (*)	40	*125x320*	1.52	1.5
Knee AP	60	100	small	in bucky (*)	40	125x320	1.53	1.5

(*) grid 178l/inch R10 FFD 100cm

TABLE 3: IMAGE SET AND EXPOSURE PARAMETERS FOR DR

FPD (CsI):	**DX-D 30C** (100020)		**Pixel size: 125µm**		Exposure			
Phantom (Body Part)	**kV**	**SID** [cm]	**Focus**	**Position of detector**	mAs	*ms x mA*	measured [µGy]	EI
Hand PA	48	92	small	on table	2.5 1.6 1	*16 x 160* *10 x 160* *6 x 160*	50.1 30.4 17.6	540 330 186
Hand PA	48	92	large	on table	2.5 1.6 1	*16 x 160* *10 x 160* *6 x 160*	49.7 30.8 17.4	549 331 187
Foot AP	55	93	small	on table	2 1.3 0.8	*12 x 160* *8 x 160* *5 x 160*	49.8 32.1 19.6	469 219 214
Foot AP	55	93	large	on table	2 1.3 0.8	*12 x 160* *8 x 160* *5 x 160*	49.0 32.2 19.9	465 223 215

FPD (CsI):	**DX-D 30C** (200158)		**Pixel size: 125µm**		Exposure			
Phantom (Body Part)	**kV**	**SID** [cm]	**Focus**	**Position of detector**	mAs	*ms x mA*	measured [µGy]	EI
Knee AP	60	97	small	on table	4 2.5 1.6	*12 x 320* *8 x 320* *5 x 320*	108.0	455 346 208
Knee AP	60	97	large	on table	4 2.5 1.6	*12 x 320* *8 x 320* *5 x 320*	107.7	467 332 206
Knee AP	60	84	small	on table	3.2 2 1.25	*20 x 160* *12 x 160* *8 x 160*	111.3	441 258 175
Knee AP	60	84	large	on table	3.2 2 1.25	*20 x 160* *12 x 160* *8 x 160*	111.4	448 268 178
Knee AP	60	97+7	small	in bucky (*)	16 10 6.3	*50 x 320* *31 x 320* *20 x 320*	115.0	488 392 258
Knee AP	60	97+7	large	in bucky (*)	16 10 6.3	*50 x 320* *31 x 320* *20 x 320*	115.0	516 406 267
Knee AP	60	84+7	small	in bucky (*)	13 8 5	*41 x 320* *25 x 320* *16 x 320*	115.0	524 432 328
Knee AP	60	84+7	large	in bucky (*)	13 8 5	*41 x 320* *25 x 320* *16 x 320*	115.0	530 475 272

(*) grid 215l/inch R10 FFD 100cm

FPD (CsI):	**DR 14e** (QE20001)		**Pixel size: 150µm**		Exposure			
Phantom (Body Part)	**kV**	**SID** [cm]	**Focus**	**Position of detector**	mAs	*ms x mA*	measured [µGy]	EI
Knee AP	60	97	small	on table	4 2.5 1.6	*12 x 320* *8 x 320* *5 x 320*	108.0	399 279 186
Knee AP	60	97	large	on table	4 2.5 1.6	*12 x 320* *8 x 320* *5 x 320*	107.7	400 277 183
Knee AP	60	84	small	on table	3.2 2 1.25	*20 x 160* *12 x 160* *8 x 160*	111.3	372 236 153
Knee AP	60	84	large	on table	3.2 2 1.25	*20 x 160* *12 x 160* *8 x 160*	111.4	395 233 152
Knee AP	60	97+7	small	in bucky (*)	16 10 6.3	*50 x 320* *31 x 320* *20 x 320*	115.0	496 313 217
Knee AP	60	97+7	large	in bucky (*)	16 10 6.3	*50 x 320* *31 x 320* *20 x 320*	115.0	524 341 214
Knee AP	60	84+7	small	in bucky (*)	13 8 5	*41 x 320* *25 x 320* *16 x 320*	115.0	526 327 277
Knee AP	60	84+7	large	in bucky (*)	13 8 5	*41 x 320* *25 x 320* *16 x 320*	115.0	762 482 294

(*) grid 215l/inch R10 FFD 100cm

As an additional evidence, a focal spot measurement was performed on the DR 600's X-ray tube, which confirmed the size of the small focal spot (0.6 mm) and the large focal spot (1.2 mm).

The assessment of the anthropomorphic phantom image set was carried out by five experienced internal readers: two from the film/screen department and three from the digital radiography group (one of the latter also had past experience with film/screen).

In this evaluation, the impact of focal spot size on the image quality was assessed by comparing phantom image pairs made with the same exposure settings and dose; thus the only difference was the focal spot size.

The images were displayed on high-quality diagnostic monitors (for digital images) and appropriate light boxes (for analog images) for viewing of general radiology images, in a properly dimmed and quiet environment. Image quality differences were evaluated via a blind reading.

The reader could choose to compare the digital images next to each other on the two 3 MP diagnostic monitors, and/or toggle between them. Zooming was allowed. For the analog images, readers were provided with an 8x magnifying glass for the evaluation on the light box. For each image comparison, the reader was asked to identify his preferred image, and to give a score for overall image quality (i.e. general visibility of detail and sharpness of structure outline).

The following scoring scale (relative scoring) was used:

Blind reading:

- Overall image quality perception (including sharpness)
- 2-by-2 comparison per subtest image (small vs. large focus)
- Relative rating, on a scale of -2 to +2, to reference:
  - +2: significantly superior
  - +1: slightly different, but preferable
  - 0: equivalent
  - -1: slightly/aesthetically different, but still adequate
  - -2: significantly worse
    (possibly impacting diagnosis, in case of scoring by a doctor/radiographer)

What is what?

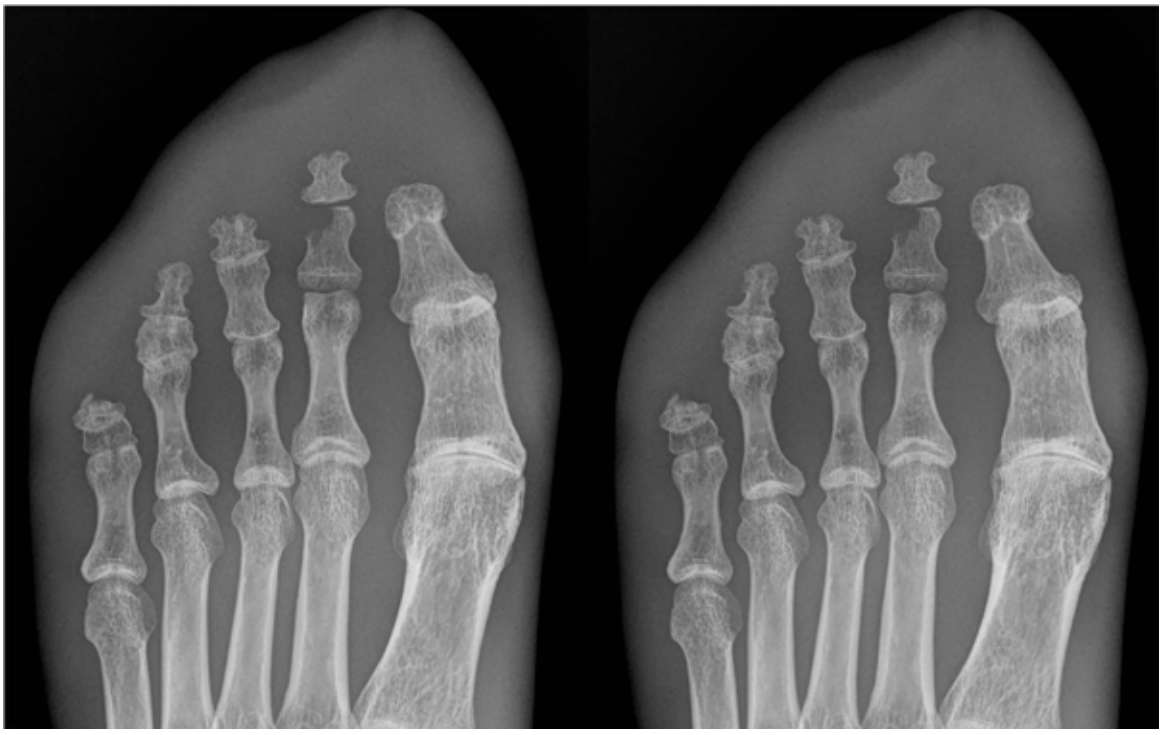


Image 1: Small focal spot

Image 2: Large focal spot

Analysis of reading results (t-test based)

Tables 4 and 5 (below) show the average ratings for all readers. As this was a blind reading, the references during the reading were not always the same focal spot size (so as not to bias the readers).

A Student's t-test was performed on the overall image quality scores of the five readers, as a measure of the inter-reader variability or consistency of the scores, i.e. to determine whether the individual ratings were likely to have the same mean as the reference (0-values). When the probability (P-value) was less than 5%, the average rating is considered as significantly different from the reference, and the respective P-values in the table are marked in color: red when the result for the large focal spot differs in a negative way to the small focal spot result, green for the inverse.

For the DR images, the t-test was performed on the scores for three dose levels separately, and then on all the scores for the total of the three dose levels (for more accurate statistics).

TABLE 4: AVERAGE RATINGS FOR FILM/SCREEN

Single-sided screen-film system (Mammo for extremities)

Screen: **HD-S**

Type Film: **HT** (Mammoray MR7)

Phantom (Body Part)	SID [cm]	Focal spot TEST	Focal spot REF	Position of detector	Image quality rating	
					AVG	P-value
Hand PA	100	**small**	large	**on table**	0.70	0.004636

Double-sided screen-film system

Screen: **CX-O-Fine**

Type Film: **CP-G-Plus**

Phantom (Body Part)	SID [cm]	Focal spot TEST	Focal spot REF	Position of detector	Image quality rating	
					AVG	P-value
Hand PA	93	**large**	small	**on table**	-0.50	0.034109
Foot AP	100	**small**	large	**on table**	0.65	0.040642
Foot LAT	100	**large**	small	**on table**	-0.90	0.000844
Knee PA	100	**large**	small	**on table**	-0.80	0.002838
Knee PA	100	**small**	large	**in bucky**	1.30	0.000446

TABLE 5: AVERAGE RATINGS FOR DR

FPD (CsI): **DX-D 30C**			**Pixel size 125µm**		Image quality rating			
Phantom (Body Part)	**SID [cm]**	**Focal spot TEST**	**Focal spot REF**	**Position of detector**	**AVG per dose level**	**P-value**	**AVG all 3 dose levels**	**P-value**
Hand PA	92	**large**	small	**on table**	**0.00** **0.00** **-0.20**	- - 0.177808	**-0.07**	0.164318
Foot AP	93	**large**	small	**on table**	**0.00** **0.20** **0.00**	- 0.177808 -	**0.07**	0.164318
FPD (CsI): **DX-D 30C**			**Pixel size 125µm**		Image quality rating			
Phantom (Body Part)	**SID [cm]**	**Focal spot TEST**	**Focal spot REF**	**Position of detector**	**AVG per dose level**	**P-value**	**AVG all 3 dose levels**	**P-value**
Knee AP	97	**large**	small	**on table**	**-0.50** **-0.45** **-0.35**	0.034109 0.000844 0.134702	**-0.43**	0.000080
Knee AP	84	**small**	large	**on table**	**0.15** **0.40** **0.45**	0.467605 0.034920 0.021312	**0.33**	0.001807
Knee AP	97+7	**large**	small	**in bucky**	**-0.50** **-0.42** **-0.35**	0.003198 0.006297 0.024896	**-0.42**	0.000001
Knee AP	84+7	**small**	large	**in bucky**	**0.45** **0.50** **0.25**	0.000844 0.003198 0.298015	**0.40**	0.000126
FPD (CsI): **DR 14e**			**Pixel size 150µm**		Image quality rating			
Phantom (Body Part)	**SID [cm]**	**Focal spot TEST**	**Focal spot REF**	**Position of detector**	**AVG per dose level**	**P-value**	**AVG all 3 dose levels**	**P-value**
Knee AP	97	**large**	small	**on table**	**-0.10** **-0.30** **-0.40**	0.621308 0.323941 0.195138	**-0.27**	0.063696
Knee AP	84	**small**	large	**on table**	**0.25** **0.40** **0.10**	0.266265 0.016130 0.688457	**0.25**	0.029981
Knee AP	97+7	**large**	small	**in bucky**	**-0.47** **-0.47** **-0.42**	0.010808 0.010808 0.006297	**-0.45**	0.000001
Knee AP	84+7	**small**	large	**in bucky**	**0.45** **0.25** **0.40**	0.021312 0.326164 0.016130	**0.37**	0.000908

Anthropomorphic phantom study: results

- The **screen**/**film** reference images show a statistically significant difference (P-value <0.05) in image quality between small and large focal spot images for all three extremity phantoms (hand, foot and knee). The average difference in favor of the small focal spot is >0.5 on a +/-2 standard scale. The smallest average score difference is found for the hand, and the largest for the knee in the bucky. This is in line with the calculated penumbras in table 1 (hypothesis).

  Moreover, the single-sided film/screen system (hand) shows a more pronounced advantage for the small focal spot as compared to the double-sided system. These findings confirm the expected results for screen/film.

- For the **DR images** at SID <1 m, the results for **smaller extremities** (hand and foot) do not show significant difference between the 0.6 mm and 1.2 mm focal spot size, even with this smaller (125 µm) pixel size detector, for any of the three dose levels.

  Average score differences are only present for the lower dose levels and are very ('insignificantly') small: max. 0.2 on a +/-2 standard scale). In the case of the foot, the difference is even in favor of the large focal spot.

- For the **DR knee images**, a slight difference in favor of the small focal spot is seen (<0.5 on +/-2 standard scale). These small differences prove to be statistically relevant for the detector with smaller pixel size (DX-D 30C – 125 µm) at a SID of ±1 m (both exposed on the table and in the bucky).

  For the detector with standard pixel size (DR 14e – 150 µm), the average difference between small and large focal spot is small (<0.3 on +/-2 standard scale), when the detector is exposed on the table. Differences prove to be insignificant when the SID >1 m, but become significant when the SID is <1 m (note: usual SID range for extremities is 1 m to 1.2 m).

  In addition, with this standard pixel size, average differences between small and large focal spot become significant when the detector is in the bucky at SID ±1 m.

Conclusion

This study demonstrates that there is no significant difference in clinical image quality between large and small focal spot for several types of X-ray extremity radiographs at standard exposure conditions. For on-table exposures of extremities at standard SID using DR detectors with standard pixel pitch, the small focal spot has no added value and hence can be omitted.

- Small extremity exams can be equally well-exposed with large as with small focal spot size using DR detectors with pixel sizes ranging from 125 µm to 150 µm, without statistically significant differences in image quality. Therefore, for these exams the small focal spot can be omitted.
- For larger extremities exposed on the table, the small focal spot has no added value when detectors with standard pixel size (±150 µm) are used at a standard SID for extremities.
- If larger extremities are exposed with smaller pixel size detectors, or in a bucky (with grid), a slight difference in favor of the small focal spot will become perceptible.

Daily Practice & Advantages

In daily clinical practice, using only the large focal spot has many potential advantages: simplifying workflow, but also – indirectly – having a positive impact on image quality and financial aspects.

- The use of a single focal spot size simplifies exposure technique.
- The use of a large focal spot reduces exposure times, and thus motion unsharpness (contributing to better image quality).
- Excessive use of the small focus has an impact on the tube lifecycle. Using the large focal spot reduces stress on the X-ray tube, resulting in a longer lifecycle of the tube.
- Omitting the small focal spot opens up possibilities to use – and thus manufacture – (cost-effective) mono-track X-ray tubes.

About the authors

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