# Radiography Open

# Optimization of Codman® Hakim® adjustable valve radiography

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## ABSTRACT

### Purpose
Cerebrospinal fluid shunt valves are important tools in hydrocephalus treatment. Adjustable valves, sensitive to MRI, are onerous. They need be controlled; in case of re-settings. The vendor give advices for the radiographic procedure; however, hospitals use variations. The purpose was to investigate the different variations.

### Method
Eight images consisting combinations of protocol features, were subjectively and anonymous rated for image quality. The panel consisted of 60 professionals; 50 radiographers and 10 radiologists, from two hospitals doing neurosurgery services. Signal-to-noise ratio compared the level of desired signal to the level of background noise.

### Results
348 scores were distributed onto all eight images, revealing the image quality difference was within acceptance. Options as valve on the head side near to the detector versus far to; differing geometry, use of head bowl versus not use, air-gap versus grids, were favored by both professional groups and at both hospitals in a clear priority image, given 2.5 times scores over average (108/43). Noise, revealed being the strongest indicator for priority of the best image for shunt evaluation.

### Conclusions
It is a potential to improve image optimization in shunt radiography.

## INTRODUCTION

Hydrocephalus is a neurological disorder, in which patients suffer from either high or low intracranial pressure due to obstruction of the cerebrospinal fluid (CSF) flow.[1, 2] People of all ages may develop hydrocephalus. This neurological disorder can either be defined as 'communicating hydrocephalus' or 'non-communicating hydrocephalus'.[1, 2] 'Communicating hydrocephalus' is caused by cerebro-spine fluid (CSF) freely flow from ventricle to ventricle, whereas it is a problem with re-absorbing the CSF. Non-communicating hydrocephalus caused by narrowing of the aqueduct of Sylvius, in which blocks the flow of cerebrospinal fluid (CSF) in the ventricular system. These two neurological disorders, communicating and non-communicating hydrocephalus may further sub-divide into congenital or acquired hydrocephalus. Congenital types are present at birth due to fetal development or genetic abnormalities. While acquired types are due to disease or injuries. Another type of communicating hydrocephalus is "normal pressure hydrocephalus" which develops gradually and hits people whom are middle age and older. Untreated hydrocephalus may cause abnormal cranial growth in infants and severe health problem and/or even death for patients of all ages.[1-3]

The abnormal intracranial pressure is handled (or treated) using a shunt system with an implanted valve, which is either adjustable or non-adjustable.[4, 5] The valve helps drain excess CSF from the cerebral ventricular system to the atrial- (VA shunt) or peritoneal (VP shunt) space through a catheter.[6] Patients are at all ages; however, the majority are rather young.[3]

Non-adjustable valves are pre-set to a fixed setting; that has been replaced to accommodate changes of the intracranial pressure. Contrary, adjustable valves [5,8] (illustrated in figure 1) are re-set non-invasively. Small changes in valve settings may cause health issues and can in worst-case lead to death.[9,10] Some patients have the shunt for years without exchanging it, while other patients need regular check-ups due to shunt malfunctions. Adjustable valves are sensitive to magnetic fields.[4,11] Therefore, radiography is important to control the settings before and after magnetic resonance imaging (MRI).

The Codman® Hakim® valve is common used in Norwegian hospitals. It was realized that hospitals use local shunt protocols that might differ from the vendor's protocol. Another situation to interfere is the use of direct Digital Detectors (dDR), while as the vendor's protocol might be based on imaging on other type of receptors. The research question is; which of the local shunt protocols give the best image quality?
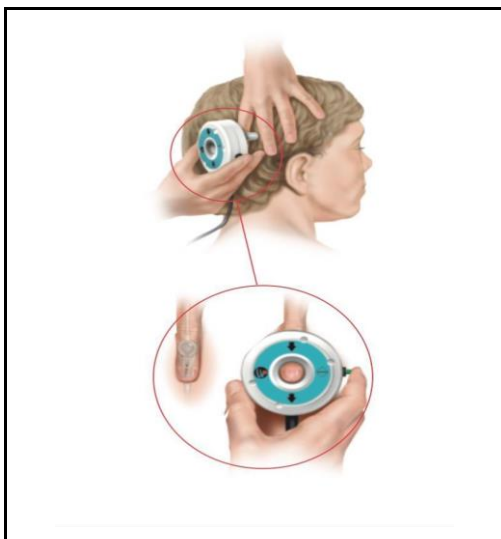


**Figure 1.** Non-invasive adjustment of the Codman® Hakim® valve with a magnetic programmer. *(Courtesy of DePuy Synthes©*

Image optimization in valve protocols is to our knowledge not previously been investigated following the introduction of digital radiographic techniques. Patient positioning and image optimization are standardized as the most important structures should be positioned being as close as possible to the detector, in this setting; the valve shunt should be positioned at the near side of the head, which means close to the dDR. DePuy Synthes©, the manufacturer of the Codman® Hakim® shunt system, recommends in their procedure the valve to be at the far side of the head when imaged, as shown in figure 2. Image optimization is important to ensure diagnostically reliable evidence in protocols and it is beneficial for the patients´ health to standardize the procedure guide to assure equal diagnostic follow-ups.
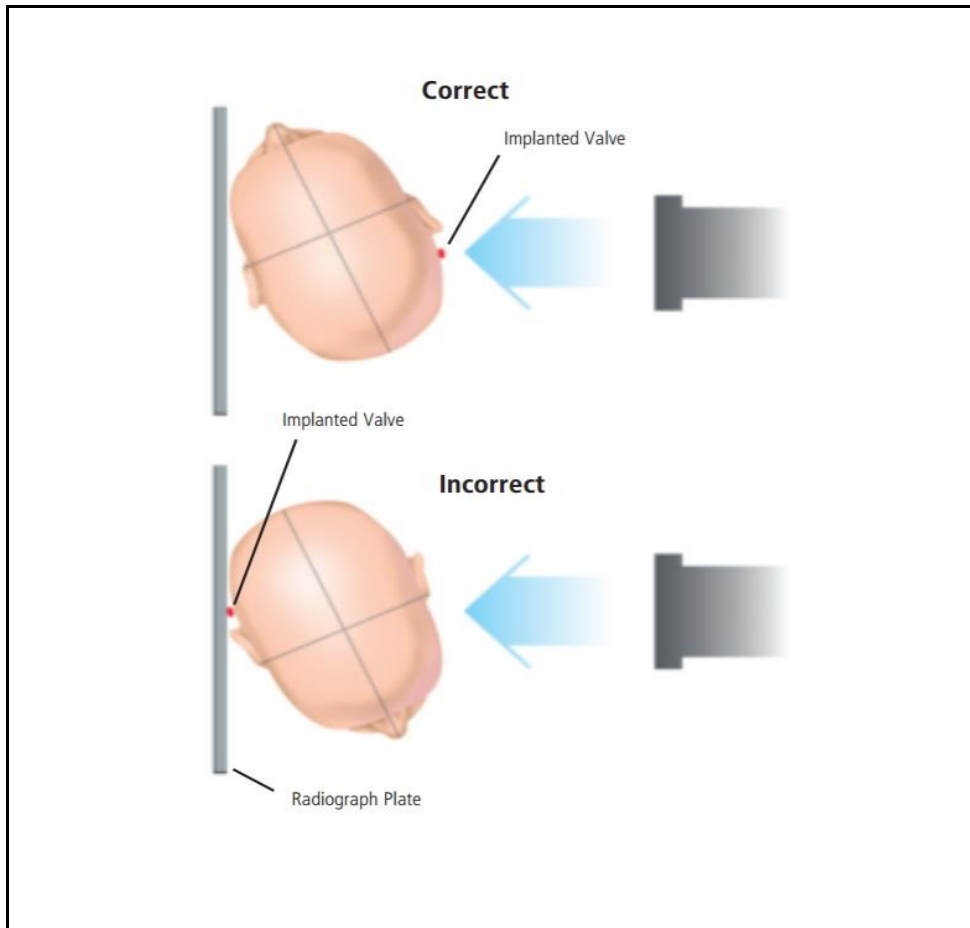


**Figure 2.** Correct valve positioning by DePuy Synthes© with the shunt on the far side of the head when positioned towards the detector. *(Courtesy of DePuy Synthes©)*

## MATERIAL AND METHOD

A pre-study in eight major hospitals in Norway was conducted for information about which protocol settings were used for the Codman® Hakim® valve radiography. Six hospitals answered the request (table 1); among them, three hospitals performed neurosurgical services. The pre-study property's combination, were combined into eight experimental images, by use of different imaging techniques such as geometry and sources for noise amount variation (table 2).

| Hospitals | Valve positioning (**/***) | Head support |
|---|---|---|
| Hospital 1 (*) | Near | |
| Hospital 2 (*) | Near | |
| Hospital 3 (*) | Near | X |
| Hospital 4 | Far | |
| Hospital 5 | Near | X |
| Hospital 6 | Far | |
| DePuy Synthes© | Far | |

**Table 1:** Pre-study results among six hospitals, compared to
Codman© Hakim© valve protocol for valve positioning and
use of head support.

\* Hospitals with neurosurgical services.
\*\* "Near" means that the valve is on the near side of the head when positioned towards the detector.
\*\*\* "Far" means that the valve is on the far side of the head when positioned towards the detector.

## Image acquisition

Test images acquired at Oslo University Hospital, Ullevaal, using Siemens AXIOM Artis Zee dMP fluoroscopic unit (Siemens, Munich, Germany),[14] were produced at 70 kVp, AEC mid-chamber and maximum zoom according to the local protocol. A Codman® Hakim® adjustable valve was mounted on the Phantom Patient™ adult head phantom[16] according to vendors procedure guide.[8] The valve was placed perpendicularly to the detector, either on the near or the far side of the head.

Use of head support [17] and variations of air-gap versus grid, may increase image noise, which often deteriorates the overall image quality and decreases the image accuracy of the ROI considerably. Source-image distance (SID), and object-image-distance (OID) were verified. Source-image distance (SOD) is the difference between SID and OID. Images were transferred on a CD, DICOM format[18], for visual grading analysis in two hospitals.

All eight images illustrated the valve cross and valve settings, radiopaque marker and central marker (figure 3-4). ROI were measured in all images, and signal to noise ratio (SNR) calculated. The images were used in a visual grading test, at two different hospitals.

| IMAGE | GEOMETRY | | | | NOISE | | |
|---|---|---|---|---|---|---|---|
| | VALVE POSITION (*/**) | SID (†) | OID (‡) | SOD (§) | HEAD SUPPORT | AIR-GAP | GRID |
| **A** | Near | 110 cm | 01 cm | | | | X |
| **B** | Far | 110 cm | 15 cm | | | | X |
| **C** | Near | 110 cm | 01 cm | | X | | X |
| **D** | Far | 110 cm | 13 cm | | X | | X |
| **E** | Near | 115 cm | 21 cm | 94 cm | | X | |
| **F** | Far | 115 cm | 31 cm | 84 cm | | X | |
| **G** | Far | 115 cm | 31 cm | 84 cm | | X | X |
| **H** | Near | 115 cm | 21 cm | 91 cm | | X | X |

**Table 2**. Imaging techniques and corresponding settings used in the image acquisition.

 \* "Near" means valve on the near side of the head when positioned towards the detector.
 \*\* "Far" means valve on the far side of the head when positioned towards the detector.

† SID: Source image receptor distance.

‡ OID: Object image receptor distance.

§ SOD: Source to object distance.

Image D has a shorter OID due to the head support. Image E and H has a longer OID and shorter SOD than image F and G due to the positioning and head support.

When the shunt is "far" the OID will increase and the SOD will decrease.

## Noise measurements

To compare the noise indication within images, region of interest (ROI) were calculated by use of the ImageJ program.[19] ROI had equal diameter of 7mm. The ROI were measured manually in identical homogeneous areas, the top left corner (figure 3). ROI count pixel values within the circle, which further were used to calculate the Signal-Noise-Ratio (SNR) for each image.
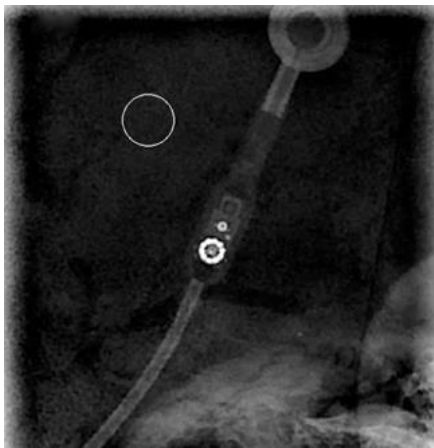


**Figure 3**. Region of interest placement illustration.

The coefficient of variation formula used to calculate the SNR, as shown:

$$\text{SNR} = \frac{\mu}{\sigma}$$

The symbol μ stands for the median value and the symbol σ stands for the standard deviation value. The calculated SNR values are shown in table 5.

## Visual grading

199 radiographers and radiologists were invited to visually grade the images. Two participants became excluded due to incorrectly completing the form. An allocation of 60 professionals, 50 radiographers and 10 radiologists, participated in the study; 28 from hospital A and 32 from hospital B.

The evaluation was conducted two days in a row for each hospital. Instructions were given both orally and in written form, to judge the quality of significant objects such as the central marker, the radiopaque marker, the valve cross, and the position indicator (figure 4). Each participant was instructed to evaluate all eight images and the four properties of each. They were asked to prioritize the three images which in their opinion, displayed the best image quality and grade them as follows: 1-best image quality, 2- second best image quality, and 3-third best image quality.
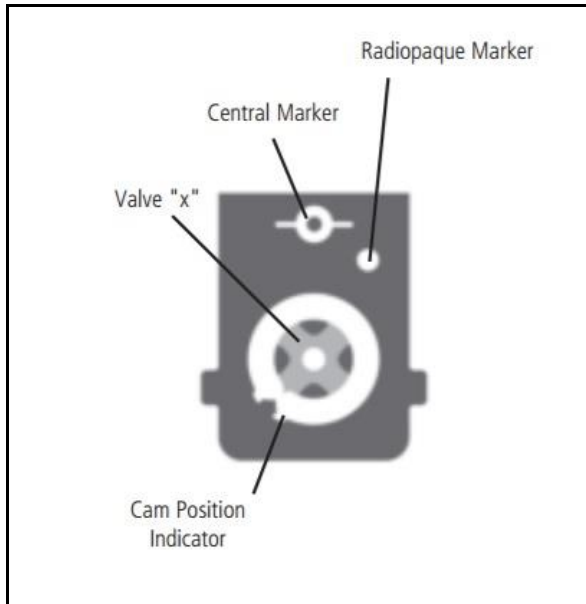
**Figure 4**. Valve head illustrating the four properties each respondent evaluated. Courtesy of DePuy Synthes©

The eight images were graded individually and anonymously and the participants had no restrictions regarding the use of post-processing options; window width/level, pan, or zoom.[20] The participants from each hospital viewed the images under the following conditions: same room, monitor, and light settings. Viewing settings were re-set between each reader. At hospital A the images were shown in SECTRA picture archiving and communication system (PACS)[21], and at hospital B in Syngo.Via, which is Siemens´ advanced visualization software [22]. The results were translated into quantitative data and integrated into a point system in this manner; grade 1 translated into 3 points, grade 2 translated into 2 points, and grade 3 translated into 1 point.[23]

### Ethics
This was a phantom study. Ethical considerations were not needed as participants participated freely and scored anonymously. The use of DePuy Synthes© images was confirmed.

### RESULTS

Totally, 348 scores, were given by fifty radiographers and ten radiologists, representing staffs at two main hospitals for neurosurgery services. Scores were distributed onto all eight images, revealing the image quality of all images were within acceptance. However, both professional groups, at both hospitals, favored image C as representing the very best image quality, given 2,5 times scores over average (108/43), while image F and D were given lowest scores with 7% (table 3-4). For image C, the shunt valve was at the near side of head to the detector. Objectively measured SNR as an indication of noise, 2.22/ 2.23, was the strongest indicator for scoring as a clear number one. Image A and C had the lowest noise among all settings, almost 60% below average. All the images acquired with the valve positioned near the detector have a SNR < 3 while all the images acquired with the valve positioned far from the detector have a SNR >3 (table 5).

64% of the total scores were given to imaging techniques with the valve on the near side of the head when positioned towards the detector. This supports our theory that image readers prefer the valve to be nearest the detector when imaged.

SNR distribution are lowest with 2.2 for image A, 2.23 for image C, and increasingly E 2.6, H with 2.89. Image G got 3.29, F 3.93, B 5.24 and image D in last with 7.98. Lowest count is the least noisy image. (table 5)

On the second place in the visual grading, was image B, given 30% scores below image C. The further grading was as follows; image C, B, H and A, all counted for a noise average of 3,14, while the others; image E, G, D and F had significant higher noise average of 4.45. Noise therefore seem be the strongest indicator for the visualization of the central marker, the radiopaque marker, the valve cross, and the position indicator's quality. Among the best-group images, three (respectively C, A, and H) all had the shunt against the dDR's side. Image B were also a high rated image and within the best-group, this image had the shunt at the rear side of the phantom head, it might indicate that the placement of the shunt on near or rear side, do not significant count for a favor of placement. Use of air-gap versus grid differ, may not be a significant importance, for favoring.

Visual scores totally are shown in table 3. Counting divided for each hospital, are shown in table 4.
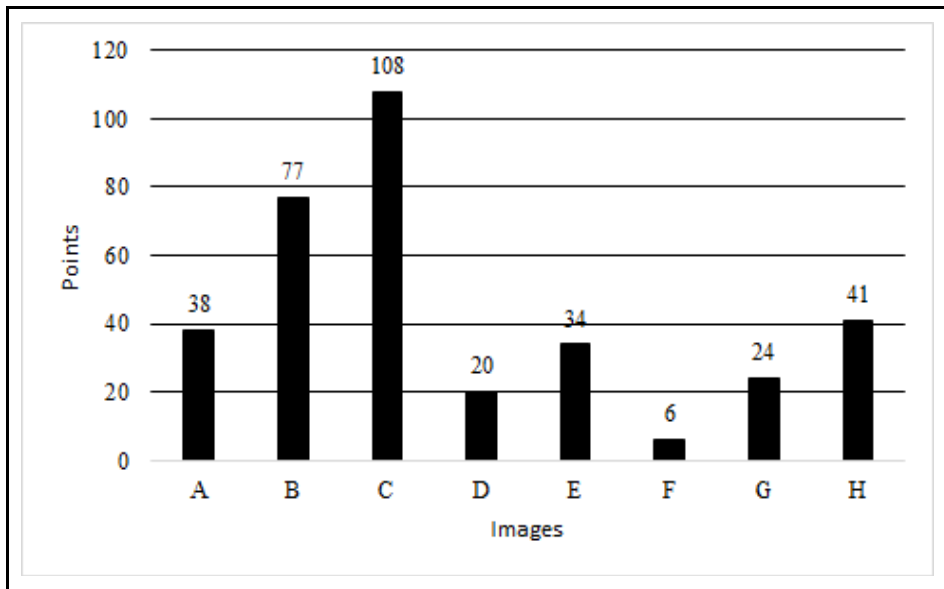


**Table 3**. The total score of 348 points divided per image. Total scores for the best image C, 108 points, got highest scores at both hospitals, given 2.5 times scores over average (108/43).
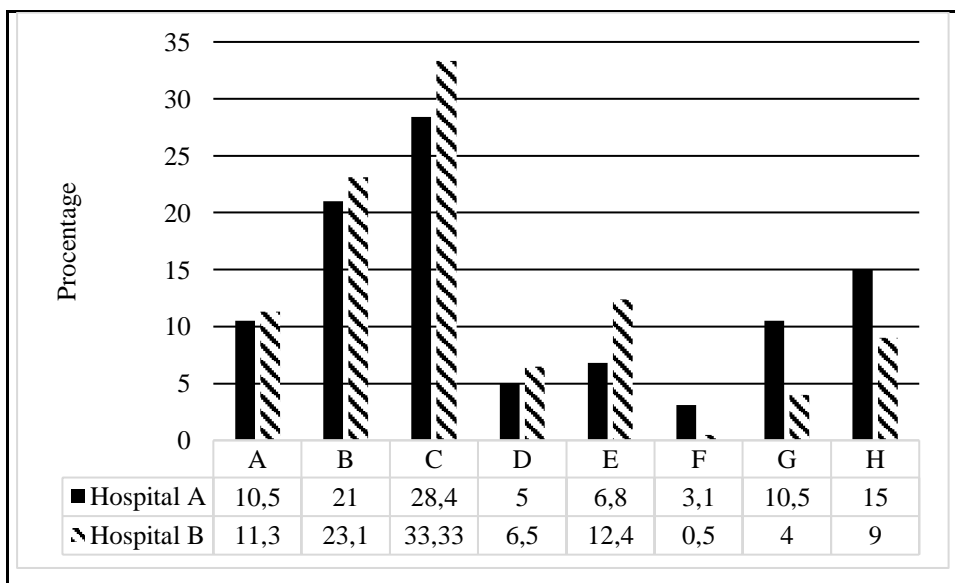


| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| ■ Hospital A | 10,5 | 21 | 28,4 | 5 | 6,8 | 3,1 | 10,5 | 15 |
| ◪ Hospital B | 11,3 | 23,1 | 33,33 | 6,5 | 12,4 | 0,5 | 4 | 9 |

**Table 4**. Distribution of total scores between the two hospitals, in percentages. Image C was chosen as the best, in both hospitals and by both radiographers and radiologists.
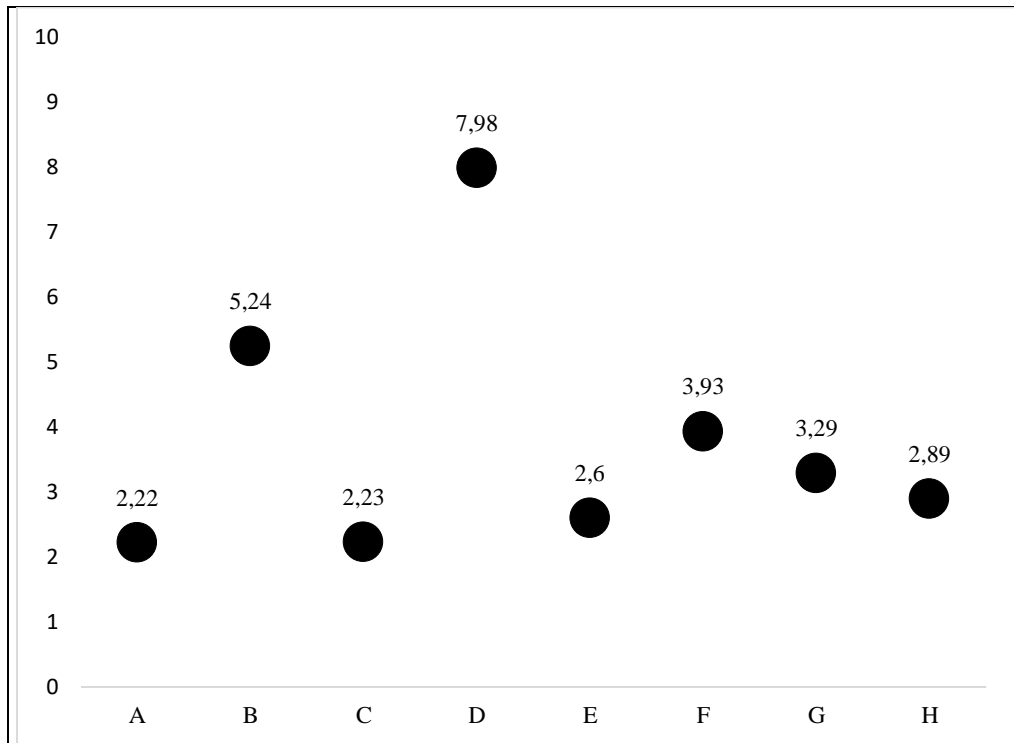
**Table 5**. Signal-to-noise ratio (0-10) for images A-H. Low SNR-images was the highest preferred.

## DISCUSSION

The study combines subjectively and objectively measured data representing different settings used in shunt radiography. The aim of this study is to investigate different imaging techniques to identify which gives the best image optimization. The pre-study results in table 2 tell us that a study to find the most optimal protocol is needed. Small changes in valve settings may cause health issues,[9, 10] and image optimization is important to ensure diagnostically reliable evidence in protocols. A known low sensitivity in detection of shunt failure (24) also argues in favor of the optimization in image quality and resolution. The difference in protocols investigated in the pre-study might be a result of old and outdated protocols, where use of geometric zoom might be helpful. Radiographic images are digital in Norway. Post- processing is a normal part of radiography. It may help in a subjective visualization experiment since image readers use this tool on daily basis.[20] Post-processing functions like inverting, electric zooming and changing window width/level, enhance image interpretation, and makes the geometric zoom technique redundant. DePuy Synthes© procedure guide was established before 2011[8] and recommends a long object-detector-distance, which might be to accommodate both analogue and digital x-ray technique. The decreasing image quality effect by geometric zoom was already known in 1996[25] and a short object-detector-distance was recommended to avoid this.[26, 27] Three different mammographic articles state that electric magnification can be used for an existing condition (screening) because of its sufficient image quality,[28-30] while geometric zoom produces better quality to see overall structures, and are by that more accurate in diagnostics. One can speculate on if the features are of importance; the focus of mammography is tiny spots and the focus of shunt radiography is moreover lines; according to Vyborny[12] these are two out of three different features (spot/ line/ area), that also might favor different types of image processing. Use of geometric zoom might be better to see tiny details in mammographic radiographs. Radiographers and radiologists normally use zoom and windowing when looking at specific features; as Krupinski[20] also state should be a part of daily practice.

Image C is the highest scoring technique with 31% of the total score, image B had the second highest scoring image with 22%, and image H is the third highest scoring image with 12% of the total score. Image F in last place got 2% of the total score. This means that at least one image reader chose that particular image to be amongst the three most optimal images. Radiologists and

radiographers both chose image C as their preferred image and this makes for a stronger result. Further discussion about radiologists and radiographers as image readers are out of scope for this article. Imaging technique C was produced using grid, head support, and with the shunt on the near side of the head when positioned towards the detector. The earlier pre-study investigation reveals that only two hospitals out of six use head support (table 2). Using head support makes the valve easily placed perpendicularly to the detector and avoids blurring caused by movement, as are factors that affect image quality.[26] This image (image C) had the second lowest SNR value, even with the use of head support.

Image B was acquired using the manufacturer's recommended technique and scores second highest on the visual score. It uses grid and has the valve on the far side of the head when positioned towards the detector. This imaging technique is the single one with far valve positioning which got a high total score. A long object detector distance produces a natural geometric zoom caused by the valve falling on a greater number of sensor pixels.[26] This imaging technique has the second highest SNR value, which indicates a less optimal image contrast. The SNR measurement objectively argues that the DePuy Synthes© procedure guide is suboptimal. The total score given subjectively by the image readers argues that the manufacturer still is not completely wrong in recommending this option.

Image H, representing the third highest scoring imaging technique, was designed to observe whether air-gap or grid technique could improve image quality. Both G and H images were produced testing the artificial combination of two different scatter reduction techniques, air-gap and grid. Image G has the valve on the far side of the head when positioned towards the detector, while image H has the valve on the near side of the head. The fluoroscopic C-bow used in this study had a limitation towards possible air-gap. The air-gap used is similar to an 8:1 grid, and a larger SID would be preferable to reduce scattered radiation.[26] Both air-gap and grid will increase the radiation dose towards the patient. It enhances image quality, which might make it possible to detect even small changes in valve settings.[12, 31] This would be beneficial to the patients´ health even with the increased radiation dose.[24]

The three highest scoring imaging techniques are C, B, and H, counting for a 65% of the total scores (table 3). The similarities amongst these images are the use of grid, which reduces the scattered radiation.[26] Scattered radiation increases noise, and produces a grainy and less optimal image.

Two out of six hospitals in the pre-study do not follow this imaging technique as displayed in table 2. The two hospitals are not wrong in using DePuy Synthes© recommended technique since this got the second highest score in the subjective visual grading test. The objective result argues however that they will get a more optimal image quality by changing their protocol. To be visualized good enough for clinical diagnostics; the quality of significant objects is based on radiographic factors like sharpness, noise and contrast,[12] in which the contrast is easily changed by post-processing,[32] leaving the two main features sharpness and noise as the important features for a radiographer to control. A large irregular distribution of photons received by the detector will cause a grainy appearance, also called noise.[33, 34] Image noise is measured as SNR by calculating ROI values gathered from the images in question. The ROI measurement was placed manually, but with precision, on the left top side of the significant object used in the grading. This may have caused a small, but non-significant difference in placement accuracy. The ROI measurement is converted to SNR by using the coefficient of variation formula as earlier mentioned. According to table 5 did image A, C, E and H receive a SNR < 3. These images are all acquired with the valve on the near side of the head when positioned towards the detector. The low SNR value indicates lesser noise in the image, due to a good distribution between the pixel values. The head support used in this study is radiolucent[17] and should not interfere with image quality. This is reflected in the SNR values since there is little difference between images with and without head support, but this data is not enough to conclude interference by using the head support. The SNR-data cannot alone conclude optimization, but is used as a supplement to indicate image quality. The study design used in this article does not equally exclude variables since images are produced in two different ways with different image techniques. However, even

with these flaws in the study design did we get significant objective and subjective results, which also concludes with each other.

All images were produced with an under-table fluoroscopic unit by the same hospital, modality, and radiographer. The fluoroscopic unit has a flat detector panel which yields good image quality due to that the geometric factors are equal for the whole image.[35] According to the protocol used in this study, maximum fluoroscopic zoom was set. The head phantom was moved between every image to simulate a new patient. By moving the head phantom there might be an inaccuracy in the phantom positioning. This may result in a difference in image quality compared to if we had acquired all the "near side"-images first, then all the" far side"-images. The Phantom Patient™ adult head phantom is andromorph and made of Rando® radiation-equivalent material which yields human-like radiographs.[16, 36] This gives the study a realistic approach together with the valve being mounted on the head phantom according to DePuy Synthes© procedure guide. The images were stored in Digital Imaging and Communications in Medicine (DICOM) format, and evaluated in SECTRA PACS in hospital A, and in Syngo.Via in hospital B. The DICOM format contains pixel data and metadata that will produce the same image quality in any DICOM image reading program.[18] The monitors in both hospitals were produced to display diagnostic x-ray images, but were made by different manufacturers. Since the two hospitals came to the same result (table 4), one can assume that the use of different monitors did not make a significant difference in interpreting the images.

## CONCLUSION

All images were within image quality acceptance. Both radiographers and radiologists, and at both hospitals, favored the same image, representing the very best quality with 2.5 scores over average and at low noise, almost 60% below the average. Noise was the strongest indicator for scoring. Still, it is a potential for optimizing shunt radiography.

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