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The Effect of Masking on the Evaluation of Clinical Radiographs

A comparison of two methods for evaluation of clinical image quality based on the European Image Criteria

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Abstract

The evaluation of clinical radiographs with the European Image Criteria method has in previous work proven to be an easy and straightforward method. The main drawback with this method is the large inter-observer variation. It has been proposed that the reason for this is that the observers get “distracted” by the surrounding structures in the image and that a sort of “first impression” of the image affects the following evaluation. Masking the images, and thereby removing non-critical structures, can remove the “distractions” leading to a more consistent scoring as a result.
The main aim of this work was to investigate the impact of masking on the evaluation of lumbar spine and chest images based on the European Image Criteria.
The evaluated image material consisted of 25 lumbar spine and 25 chest images produced with different levels of image quality. The images were evaluated by 7 radiologists using the European Image Criteria method. Each radiologist evaluated the 50 images both with and without the masking and the results were compared to each other.

The variance of the Image Criteria Score (ICS) with the masking does not differ significantly from the variance without the masking when all 7 observers are included. When the results of the observers who were experts in the two different regions (spine and chest regions) are grouped together, a decrease in variance is observed when masking the images. This decrease in variance would be highly useful since a more precise scoring could be achieved with a stronger image quality separating power as a result. This decrease is not statistically significant.
The observers gave a lower ICS to the masked images compared to their unmasked counterparts. One of the lumbar spine criterions needs a revision since it was nearly always fulfilled, independent of the image quality.
Statistical issues hamper the variance result of masking and further studies must be carried out to validate the promising result of a decreased ICS variance between experts.

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Introduction

Optimisation, with respect to image quality and patient absorbed dose, in diagnostic radiology requires studies of different radiographic imaging techniques [1-6]. It is relatively easy to measure machine parameters like tube-voltage and focalspot size, but the most significant factor determining the quality of a diagnostic imaging system is the interpretation of the image by the radiologist. The fact that different persons have different diagnostic frames due to different previous experiences complicates the evaluation of imaging systems. A good image quality according to one radiologist may not necessarily be found "good" according to another.

The most frequently used tool for this kind of image evaluation is the ROC (Receiver Operating Characteristics) [7-9].This is more or less the standard method for evaluating and reporting accuracy in two-group classification tasks. The objective of ROC analysis is to observe images containing either one signal (e.g. tumour) or none. The observer has to state the level of confidence of his/her decision on a scale from 1 to 5 ranging from "Definitely or almost definitely negative"(1) to "Definitely or almost definitely positive"(5). However, one of the drawbacks of the ROC method is that it is rather cumbersome to perform.

Another frequently used tool for image evaluation is the VGA (Visual Grading Analysis) method. In this method, the observer grades the quality of images in comparison to a reference image. VGA is a powerful tool for comparison of similar exposure conditions, and small differences between imaging systems can be detected. The VGA method is also rather cumbersome to execute and the results are dependent of the reference image used.

An easier method is the Image Criteria Score method (ICS) [10]. This method uses different criteria based on the visualisation of defined anatomical structures. This method is relatively new (1996) and is therefore not as validated as the ROC and VGA methods.

Earlier work has implied that radiologists form a "first impression" of an image that influences further evaluation of the image [7]. This effect varies between radiologists and must be minimized so that a correct comparison between different radiographic imaging techniques can be achieved. Furthermore, previous discussions with radiologists' revealed that observers tend to view different parts of the image when evaluating it, which leads to an unwanted large inter-observer variation [11]. It is evident that a psychophysical study must be done in order to fully understand the impact of these effects on image evaluation.

One theoretical way of reducing the impact of the "first impression" is by masking the images. This is done by excluding the parts of the image that do not directly hold information about the comparison criteria. The masking achieves this but it also forces the observers to evaluate the same parts of the image. Masked images have been used before, but no thorough evaluation of the effect has been done [11-14].

The main aim of this work was to investigate the functionality of the ICS method and how the use of masked images affects it.

Material and methods

Evaluation of image quality

The evaluation of the images was based on a revised version [15, 16] of the European CEC Quality Criteria for Diagnostic Radiographic Images [10]. These criteria are based on the visualisation of different key anatomic structures in the image. In this study, clinical AP lumbar spine and PA chest images are used.
Since the key anatomic structures differ between the two types of images, there are two different sets of criteria, see table 1 and 2

Table 1. Image criteria for the lumbar spine images, *c.f.* Figure 1.

	Image criteria
1	Visually sharp reproduction of the upper and lower-plate surfaces, represented as lines in the centred beam area
2	Visually sharp reproduction of the pedicles in the centred beam area
3	Visually sharp reproduction of the lateral cortex
4	Reproduction of the intervertebral joints
5	Reproduction of the spinous processes
6	Reproduction of the transverse processes
7	Reproduction of the adjacent soft tissue

Visually sharp reproduction: Anatomical details are clearly defined (details clear).
Reproduction: Details of anatomical structures are visible but not necessarily clearly defined (details emerging).

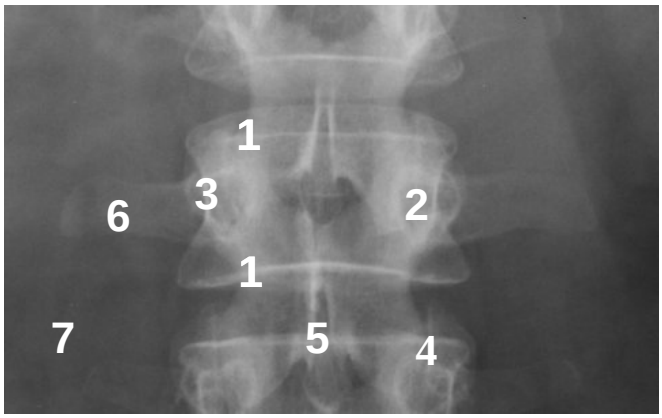

Figure 1. Schematic description of the locations of the image criteria for lumbar spine images as described in Table 1

Table 2. Image criteria for chest images, *c.f* Figure 2.

	Image criteria
1	Sharp visualisation of the vessels seen 3 cm from the pleural margin
2	Visualisation of the thoracic vertebrae behind the heart
3	Visualisation of the retrocardiac vessels
4	Sharp visualisation of the pleural margin
5	Sharp visualisation of vessels seen en face in the central area
6	Sharp visualisation of the hilar region
7	Visualisation of the carina with main bronchi

Sharp visualisation: Anatomical details are clearly defined (details clear).
Visualisation: Characteristic features are detectable but details are not fully reproduced

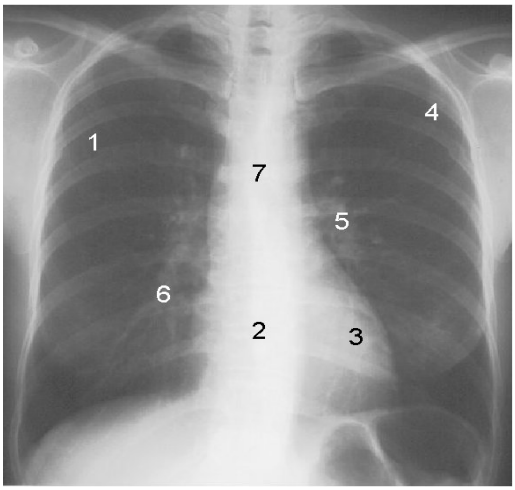

Figure 2. Schematic description of locations of the image criteria for chest images as described in Table 2

For each criterion above, a 'yes' or a 'no' answer is registered and to quantify the results, an Image Criteria Score[1] (ICS) is used. For a group of images taken with the same radiographic technique, the fraction of fulfilled criteria, ICS, is calculated in the following way:

$$\mathrm{ICS}=\frac{\sum_{i=1}^{I}\sum_{c=1}^{C}\sum_{o=1}^{O}F_{i,c,o}}{I\cdot C\cdot O}$$

Where,

$F_{i,c,o}$ = fulfilment of criterion c for image i and observer o. $F_{i,c,o}$ = 1 if criterion c is fulfilled and $F_{i,c,o}$ = 0 if it is not.

I = number of images.
C = number of criteria.
O = number of observers

The result for the individual observer is denoted ICS_0.

In the present study there were 5 images in each image group, 7 criteria for each image, and 7 observers.
The observers (radiologists) were introduced to the study by a radiologist who is experienced in the use of the image criteria.

The observers started with the evaluation of the masked lumbar spine and chest images. A period of at least 24 hours followed before the evaluation of the same images without the masks took place. The observers were not supposed to remember the individual images from the masked reading to the unmasked. The evaluation order and the time interval were decided to minimize the risk of any learning effects concerning the images.

[1] This score is only an evaluating tool and shall not be used as grounds for diagnose. An image that fulfils all clinical requirements, but does not meet all image criteria, must not be rejected.

The observers were instructed to use a “regular” clinical technique when reading the images. The images were evaluated using conventional viewing boxes without restrictions regarding viewing distance or time. Each radiologist masked the viewing box individually with cardboard paper to his or her own liking, and the illumination in the room was dim and kept at a constant level. All identification tags on the films were removed, and the films were assigned a randomly generated code so that each observer evaluated the images without the knowledge of their physical quality. During the evaluation, a list of the criteria definitions (Table 1 and 2) was available.

The observers

The 7 observers were all affiliated to the Malmö University Hospital, Malmö, Sweden and had a large variation of experience in the radiological field (Table 3).

Table 3. The Experience and speciality of radiologists

Observer number	Years in the radiological field	Specialty
1	16	Gastro-intestinal radiology
2	15	Skeletal radiology
3	15	Thorax radiology
4	13	Skeletal radiology
5	11	Thorax radiology
6	9	Chest radiology
7	6	None

Masking of images

The masking of the images was achieved with black cardboard paper, which was “windowed” so that only structures vital for the evaluation could be seen, see Figure 3. This masking should not be confused with the earlier mentioned individual masking of the viewing box by the observers.

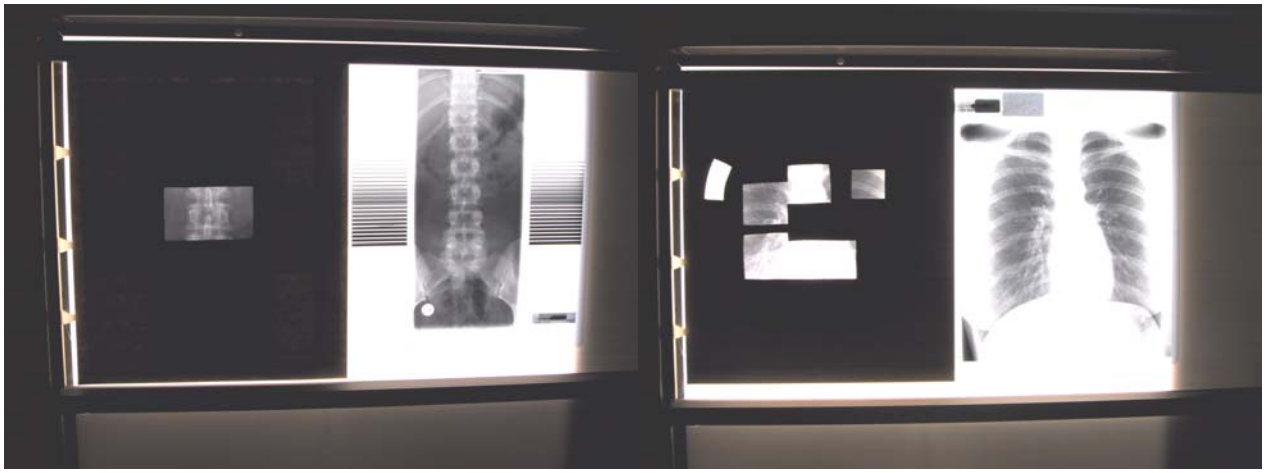

Figure 3 Examples of paired masked and unmasked images. Note that the unmasked images were evaluated with individual masking by the observers so that only the exposed parts of the films were visible. Also note that the masked and unmasked images were not evaluated during the same reading.

Basic image set

The images in this study have previously been used in other studies [7, 13, 14] and have been found to comply with good radiographic technique according to the European Guidelines [10].

Lumbar spine and chest images

In the lumbar spine case 15 patient images were used, produced with clinical standard settings (Kodak Lanex regular screen (speed class 400), Kodak T-Mat L film, 70 kV tube voltage, grid) [17].

15 chest images from healthy volunteers were taken with a standard technique used for chest radiography in Sweden (Kodak Lanex screen (speed class 320), Kodak T-Mat L film, 141 kV tube voltage, air gap) [18].

Simulation of new screen-film combinations

The manipulation and adaptation of the images was not a part of this work and had previously been carried out by Dr. Francis Verdun and his co-workers at the Department of Applied Radiation Physics, Lausanne, Switzerland.

The basic image set was digitised so that different exposure conditions and screen-film combinations could be computer simulated without the need of additional patient exposure. Two different high-resolution film scanners were used to digitise the basic image set: The lumbar spine images were digitised with a flat bed scanner (ULTRASCAN 5000,Vexcel imaging, Graaz, Austria) and a drum scanner was used to digitise the chest images (TANGO, Heidelberg Druckmaschinen, Heidelberg, Germany). The scanners were calibrated in terms of optical density and they were both used with a spatial resolution of 40 μm. The contrast resolution was 16 bit linear to transmission. The digitised images were manipulated in terms of noise, MTF (Modular Transfer Function) and image contrast. These parameters are closely linked to the quality of the images and are important factors for the absorbed dose to the patient [5, 19].

For image display a high-resolution imager was used (Scopix LR5200, Agfa-Gevaert, Munich, Germany). The nominal spatial resolution of the laser imager was 40 μm and its dynamic resolution was eight bits. The knowledge of scanner and printer characteristics is fundamental for the image manipulations. These instruments must be closely monitored so that no unwanted image quality variation appears. The characteristics for the printer and scanner used in this particular work are presented elsewhere [20].

The digitised basic image set was manipulated so that four new screen-film combinations were achieved. Two new speed classes were simulated by varying the noise and MTF of the original images, and two new film types were simulated by varying the characteristic curve of the film. The following screen-film combinations were achieved:

Table 4. Data on the different image combinations

Combination	Filmtype	Speed class
A	Latitude (L)	400 for lumbar spine images 320 for chest images
B	Latitude (L)	600-800
C	Latitude (L)	>1000
D	Infra-Latitude (IL)	400 for lumbar spine images 320 for chest images
E	Gradient (G)	400 for lumbar spine images 320 for chest images

Combination A represents the images produced with the original and clinically used screen film combination.

The L-film is the regular latitude film. The G-film (Gradient) is a high contrast film with a steep H/D curve. The IL-film is not commercially available and was constructed with a flatter H/D curve than the L-film, making it a low contrast film.

To simulate the different image qualities the characteristic curves (H/D curve), MTF and Wiener spectrums of the different films had to be known. These parameters were measured by the Institute of Applied Radiation Physics of the University Hospital of Lusanne and were performed according to ISO 9236-1 [21].

The noise and MTF were altered to simulate screen-film combination B and C. The noise in the images was increased to the desired level by adding a randomly generated noise array with zero mean and a spectral distribution mimicking the characteristics of combinations B and C. [22]. Before adding the noise to the images, the MTF of the original screen-film combination was applied to the noise array. For manipulation of the spatial resolution, the scanned films were filtered with an appropriate filter simulating the decreased MTF of screen-film combinations B and C respectively, in the frequency domain.

The application of the different film characteristics on the digitised basic image set was performed with a lookup table that contained the H/D curves from the original and desired film, and the calibration curves of the laser imager and film digitiser.

From the 30 original images a set of 25 images (5 in each combination) were constructed in both the lumbar spine and chest case. This means that some of the original images are used in more then one of the combinations.

Computerised data collection

To simplify the data collection a computerised evaluation form was created, which allowed the radiologists to input the data directly into a database. The form was connected to a Microsoft Access database.

The sets of criteria were implemented with ‘yes’ and ‘no’ checkboxes, see Figure 4. To minimise the human errors when inserting the data, a visual basic routine was used to check that all seven criteria for each image were evaluated, and that a film ID number was entered. A post for comments was also included. All results were finally extracted to, and evaluated in, Microsoft Excel 2000.

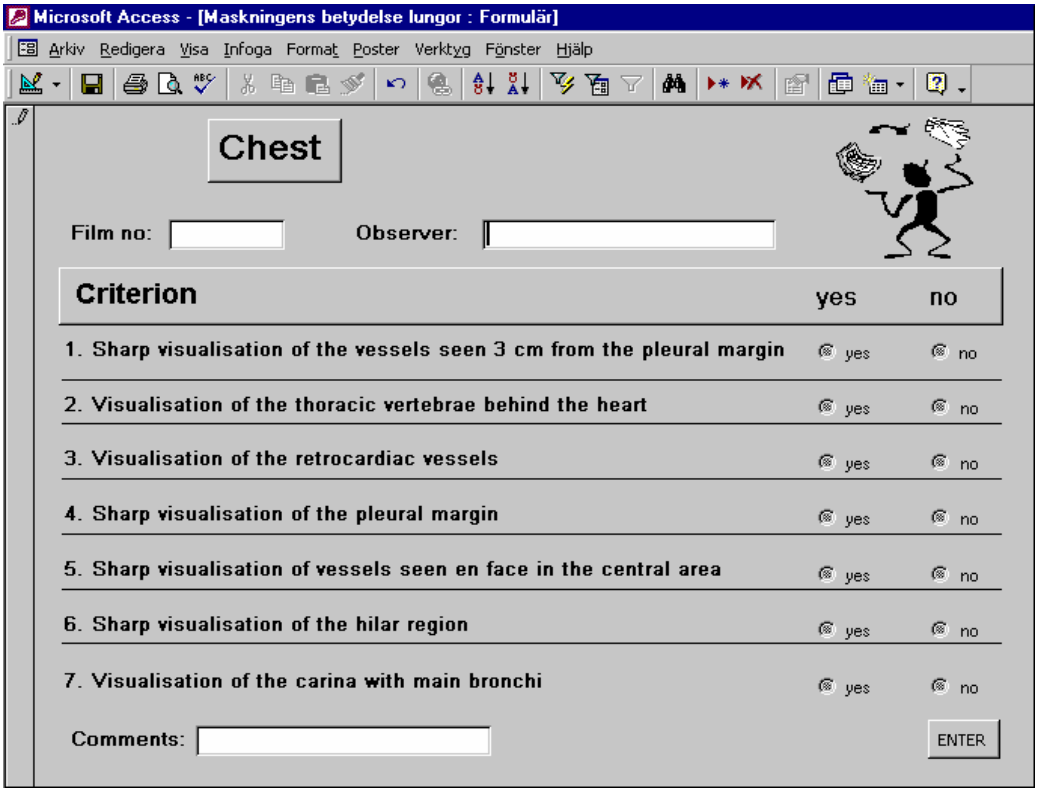

Figure 4. The form for evaluating chest images. A corresponding form was used when evaluating the lumbar spine images.

Data evaluation

For every observer, an ICS_0 was calculated for each of the 5 screen-film combinations (5 images in each combination). With the 7 ICS_0 scores from the observers a global ICS score for each screen-film combination was calculated with the corresponding variance. This was done for both the masked and unmasked images.

A comparison between ICS for the masked and unmasked images with the corresponding variances was performed to evaluate the effect of masking on image evaluation.

Each individual criterion was also evaluated to control its relevance for image evaluation studies.

Statistics

The statistical validity of changes in the ICS was monitored with a T-test and any possible significant change in variance was monitored with an F-test (ANOVA).All p-values are presented here so that the reader can judge the results from their own opinion of statistical significance.

Results

Lumbar spine images

The results of the lumbar spine image evaluation showed that masked images scored lower than their unmasked counterparts (Figure 5) except for combination C. The drop in ICS for combination A was the only one with a reasonable statistical difference of p=0.056. The other combinations had very weak statistical significance ranging from p=0.46 (combination B) to p=0.88 (combination C).

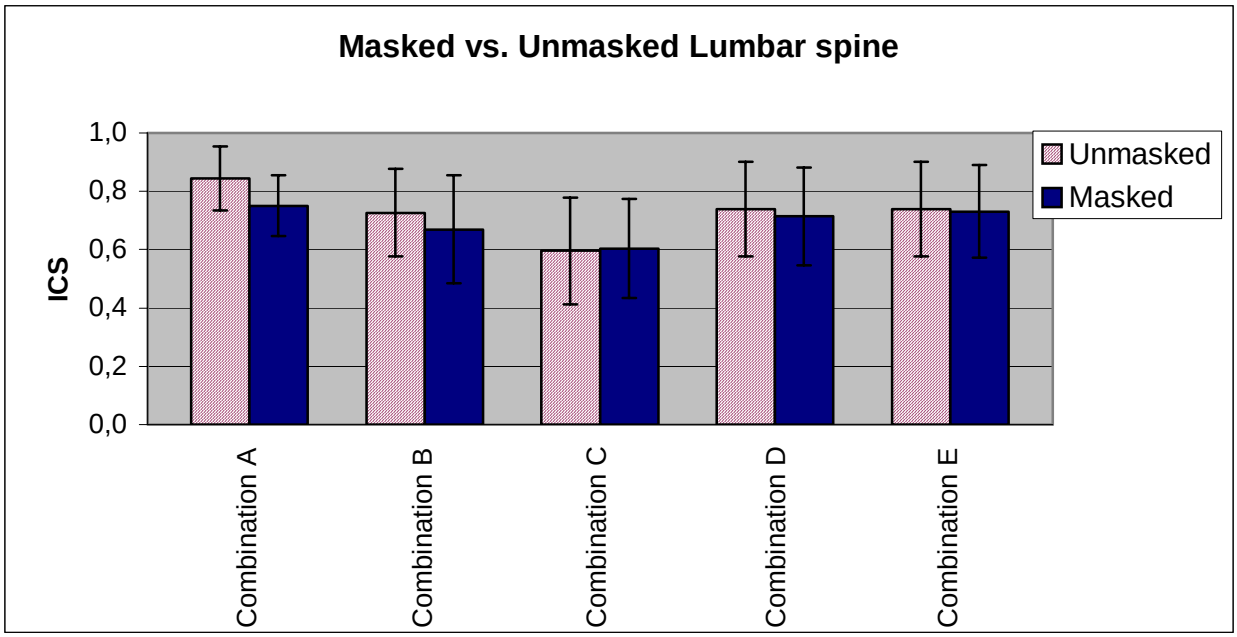

Figure 5. The ICS for the lumbar spine images with standard deviation bars.

The gradually decreased scores from combinations A to C follow the decrease in image quality as expected. The two simulated film types, combinations D and E, received scores equal to each other and are very close to the standard image technique, combination A, when evaluated masked.

To evaluate how much the observers agree on their scoring the ICS variance was calculated. In Figure 6 the variance as a percentage of the ICS is presented for masked and unmasked lumbar spine images. This form of variance presentation is necessary for a correct interpretation of the results because of the different ICS of the images. In two cases the variance for the masked images are lower than for their unmasked counterparts. There is a weak statistical significance between the differences in variances of the masked and unmasked images. All combinations had a p-value equal to or greater than 0.62.

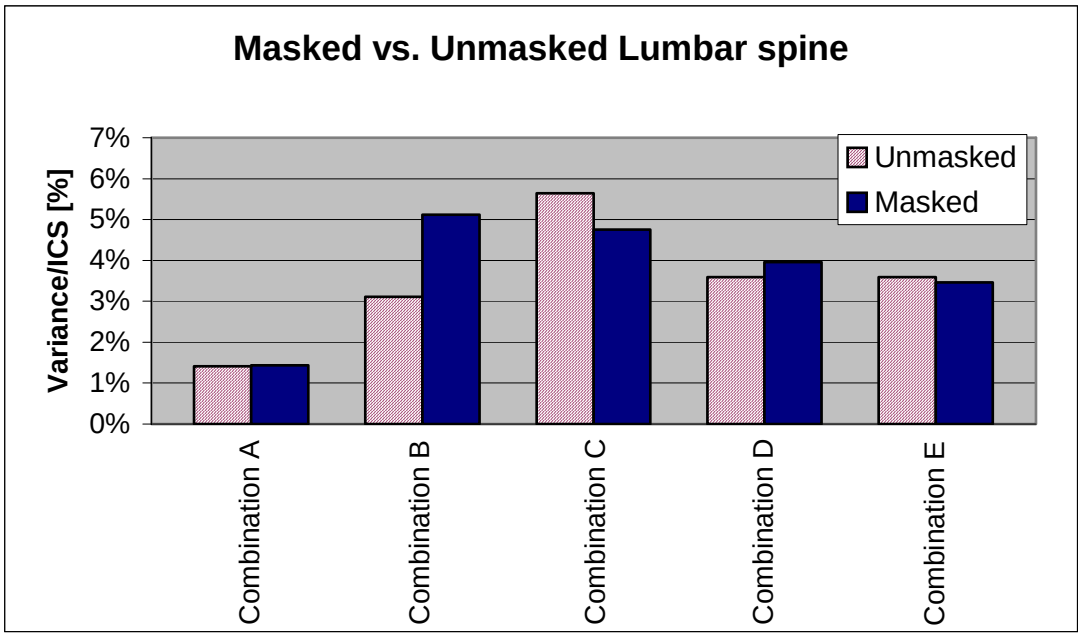

Figure 6. Variance of ICS as a percentage of ICS for lumbar spine images.

In Figure 7 the variance between observers 1, 2 and 4, who are the most experienced in lumbar spine radiology, is presented. It is expected that these observers agree more on their scoring of the images. There is a weak statistical significance between the differences in variance of masked and unmasked images. All combinations had a p-value equal to or greater than 0.42.

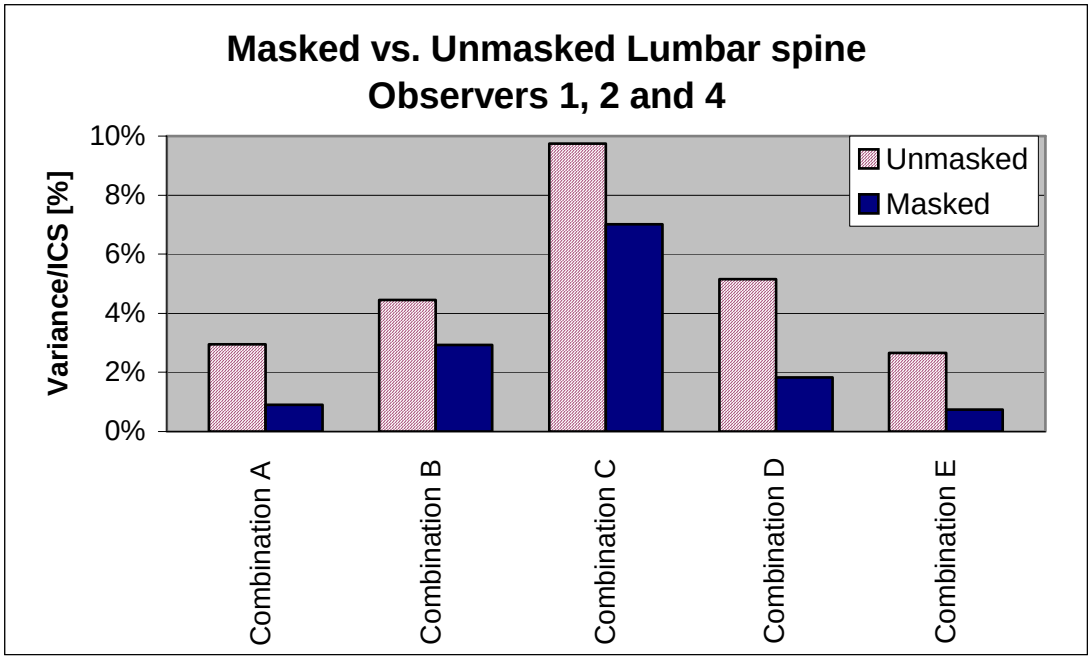

Figure 7. Variance of ICS as a percentage of ICS for lumbar spine images for observers 1,2 and 4

Chest images

The results of the chest image evaluation showed that masked images scored lower than their unmasked counterparts (Figure 8). The drop in ICS for combination A and D was rather big with a statistical difference of p=0.022 and p=0.012 respectively. The statistical difference between masked and unmasked ICS for combination B and E were p=0.165 and p=0.137 respectively. Combination C had the weakest statistical difference, p=0.253.

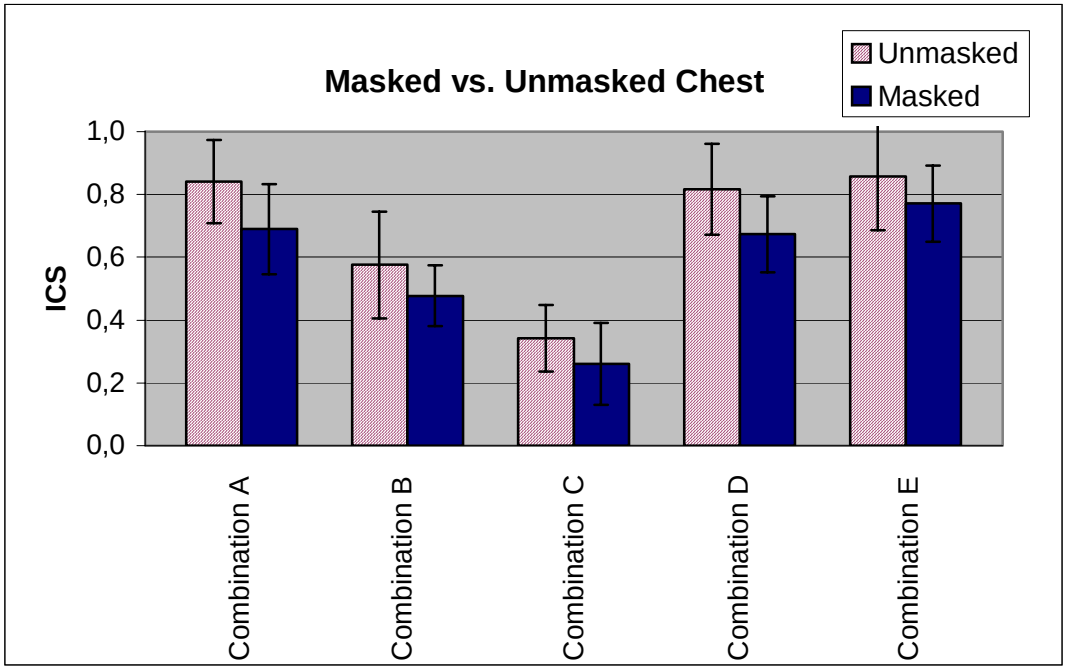

Figure 8. The ICS for the Chest images with standard deviation bars.

The gradually decreased score from combination A to C follows the decrease in image quality, as expected. The two simulated films, combinations D and E, receive scores that are approximately equal to the standard image technique, combination A, in both the masked and unmasked case.

In Figure 9 the variance as a percentage of the ICS are presented for masked and unmasked chest images. In three cases the variance for the masked images are lower than for their unmasked counterparts. These results are statistically very weak. Combination B is closest to statistical significance (p=0.19) and the rest of the combinations has a p>0.42.

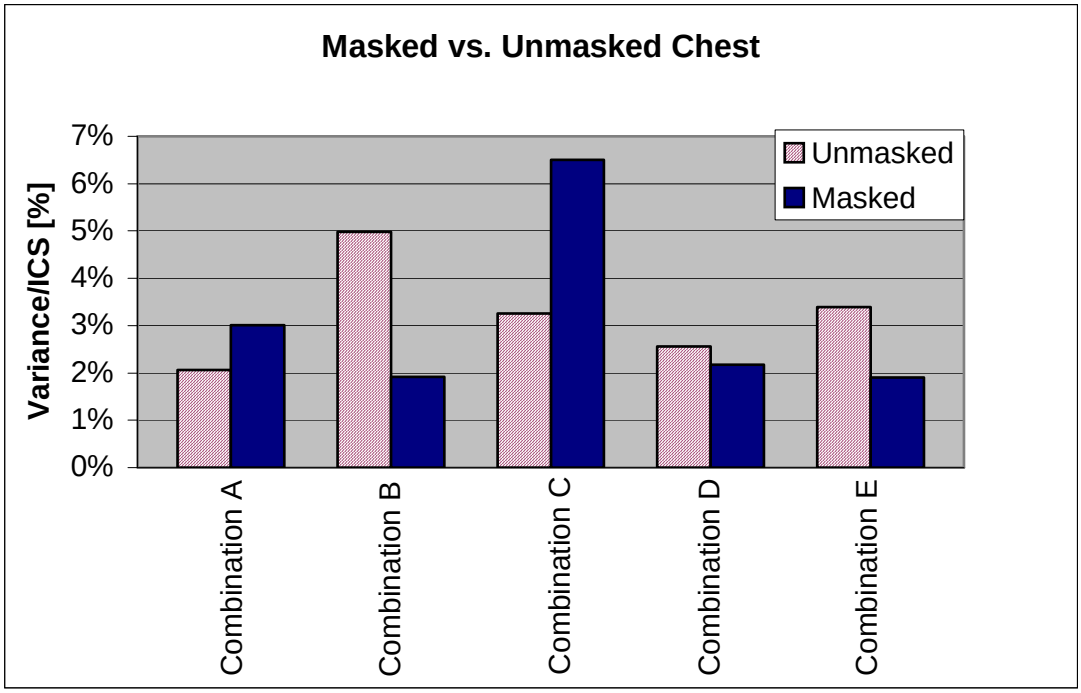

Figure 9. Variance of ICS as a percentage of ICS for Chest images.

In Figure 10 is the variance between observers 3, 5 and 6, who are the most experienced in chest radiology, is presented. It is expected that these observers agree more on their scoring of the images. There is a weak statistical significance between the variances of the masked and unmasked images. All combinations had a p-value greater than 0.40.

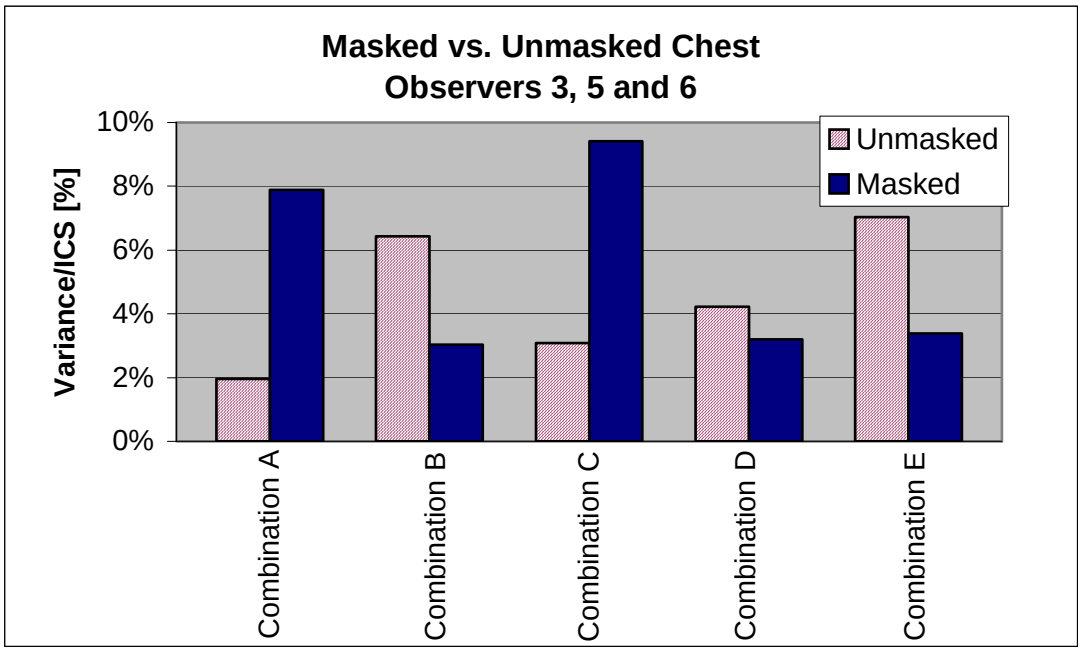

Figure 10. Variance of ICS as a percentage of ICS for chest images for observers 3, 5 and 6.

Figure 11 is the same as Figure 10, except that the result of observer 3 is excluded. This Figure is interesting because observer 3, who is the most experienced of the three observers, has a radically different evaluation score for the different images. There is weak statistical significance between the variances of masked and unmasked images. Combination D has a p-value of 0.15. The rest of the combination has a p-value equal to or greater than 0.40. Observers 5 and 6 gave the masked combination A an identical score which explains its absence in the diagram.

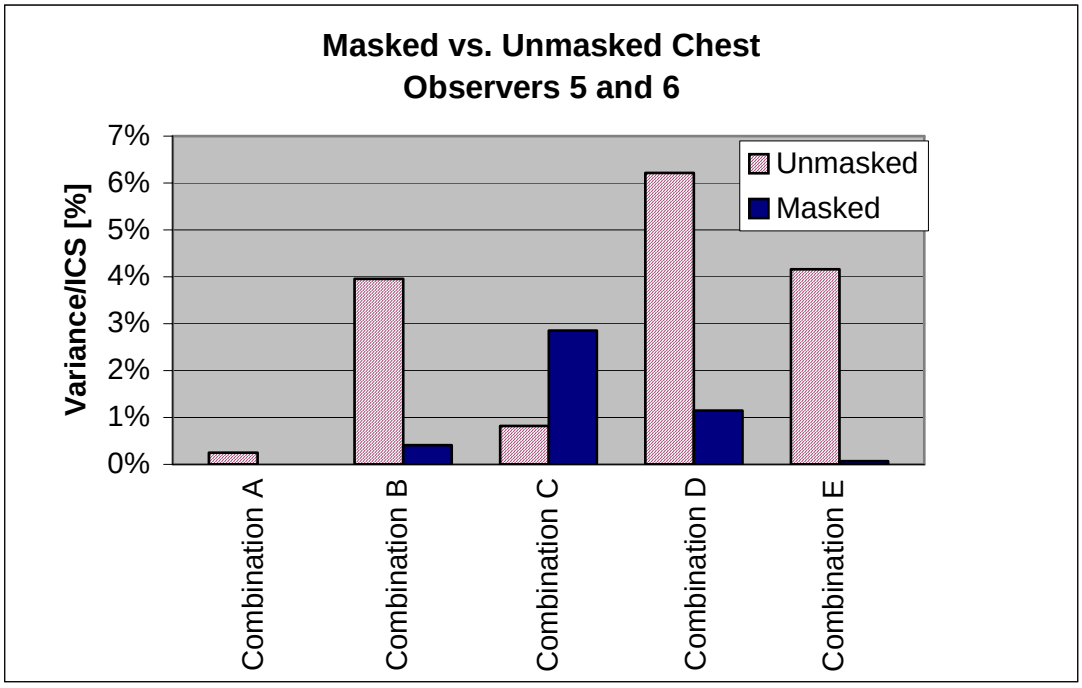

Figure 11. Variance of ICS as a percentage of ICS for chest images for observers 5 and 6.

The individual criteria

A more detailed study of the effect masking has on the separate criterion is presented in Figure 12 (lumbar spine images), and Figure 13 (chest images).

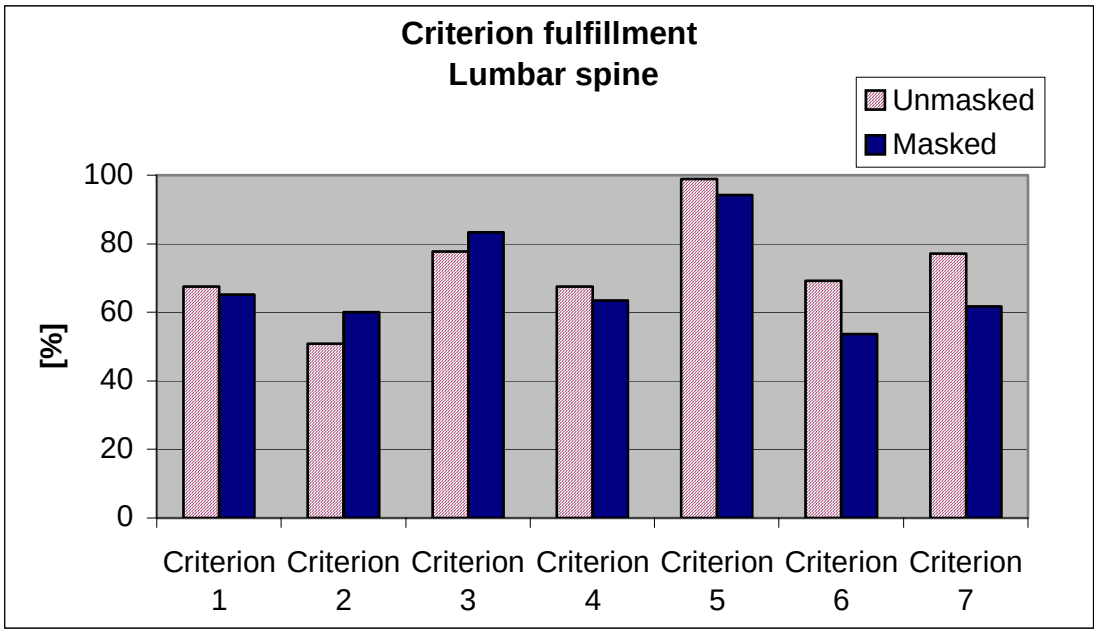

Figure 12. The percentage of fulfilled criteria for the lumbar spine images.

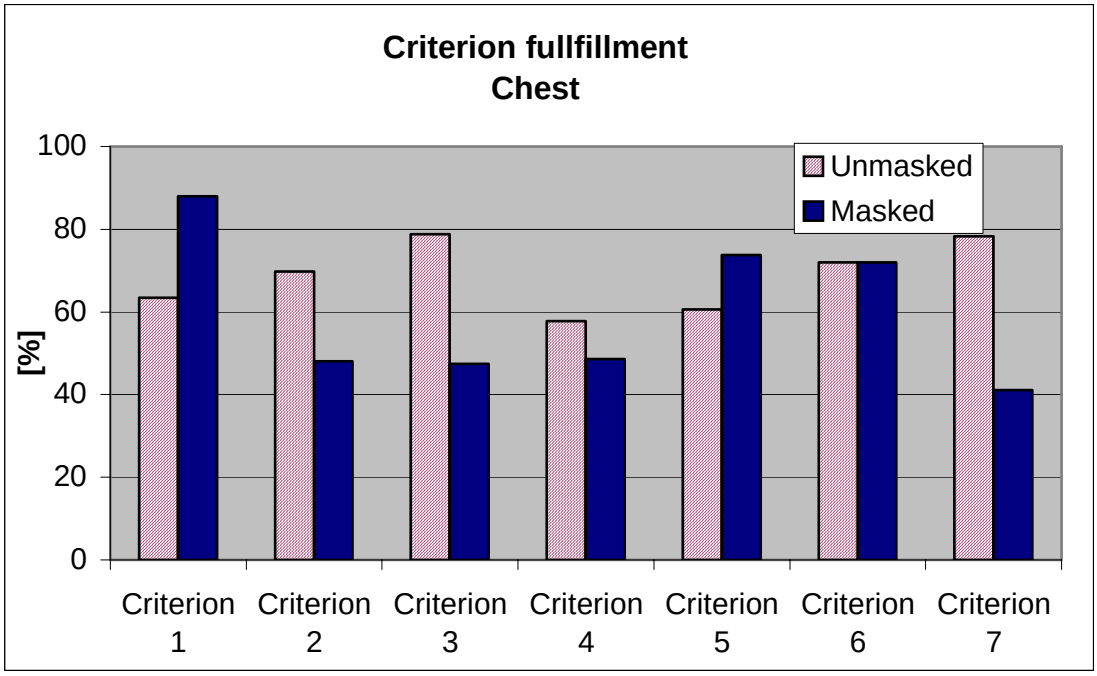

Figure 13. The percentage of fulfilled criteria for the chest images.

Discussion and conclusions

The results show that ICS, with or without masking, is a powerful tool for evaluating image quality in quality radiographs. This is manifested for both the lumbar spine and chest images by the decreasing ICS for an increased speed of the screen-film system.

The most obvious effect of the masking of the chest and lumbar spine images is that the ICS is lowered when the images are examined with the masks. Only one combination (combination C, chest images, see Table 4) has a contradicting result.
Even if this result only is statistically supported ($p<0.06$) in three cases (combination A and D for the lumbar spine images and combination A for the chest images, see Table 4), the general trend supports this conclusion.

For chest images, combination E (the G-film, see Table 4) is preferred to combination A, the standard technique (Figure 8). This result is expected because of the higher contrast supplied by the G-film. However, in a clinical situation, the use of a G-film would probably result in a large number of over- and underexposed chest images due to the steep characteristic curve of the G-film. Even if the G-film receives a higher ICS than the regular L-film it would be unpractical, for the reasons mentioned above, to switch films in clinical practise.

A few interesting results appeared when the individual criteria were studied.
A noticeable difference when masking the chest images was the evaluation of criterion 7, “Visualisation of the carina with main bronchi”, and criterion 3, “Visualisation of the retrocardiac vessels” (Figure 13). When unmasked, criterion 7 was fulfilled in 78% of the cases but this figure dropped to 41% when masked. The explanation for this radical change (almost a drop to half of the unmasked value) is probably that the radiologists use the surrounding structures as a mean for localizing this particular structure.
This explanation cannot be valid for the drop in evaluation score of criterion 3(from 79% unmasked to 47% masked). The retrocardiac vessels are easy to locate and the evaluation should not depend on the surrounding structures. The effect masking has on criterion 3 surprises radiologists spoken to and further studies are needed to explain this.

The chest criteria 1 and 5 showed a distinct increase (over 16%) when the images were masked (Figure 13). The evaluation of these criteria clearly benefits from masking. In order to explain this effect further studies has to be carried out.
The inclusion of criterion 5 in the lumbar spine case, “Reproduction of the spinous processes”, in its present form has to be reconsidered. This criterion is fulfilled in almost all cases and is poorly suited to separate images with different image quality (Figure 12).

The variance analysis gives no significant statistical base of conclusions. However, in the lumbar spine case, it seems like experts in this area (observer 1, 2 and 4) generally agree more on their scoring when masking is introduced (Figure 7). This result would be highly useful in future trials since a more precise scoring would be achieved.

In the chest case (Figure 10), the variance shown by the experts (observers 3,5 and 6) are worse than the variance calculated from the whole group. The result for this group is heavily dependent on observer 3 and without observer 3 the results are totally different (Figure 11). As in the lumbar spine case a reduced variance would improve the separation power of the method. It is not possible to draw any solid conclusions from these data.

It is clear that further studies, concerning the promising effect of radiological specialisation on the ICS variance, must be done.

The use of ICS as an analytical instrument for separating different radiographic imaging techniques has proven to be simple and powerful. A few refinements of the method, like a revision of the criteria in the lumbar spine case, and an even more thorough investigation of the masking effect on the observer variance could improve an already powerful method. ICS, ROC and VGA are different tools to achieve the same goal, image evaluation, and give us the opportunity to choose the method best suited for the given situation.

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