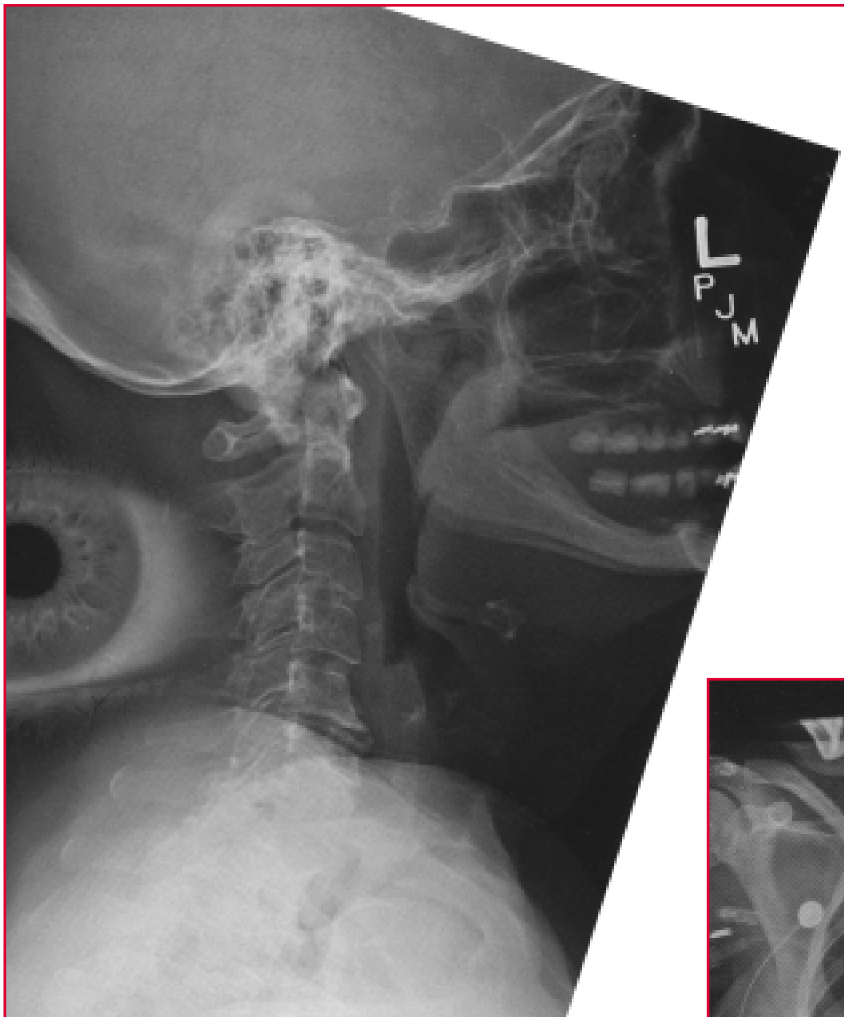
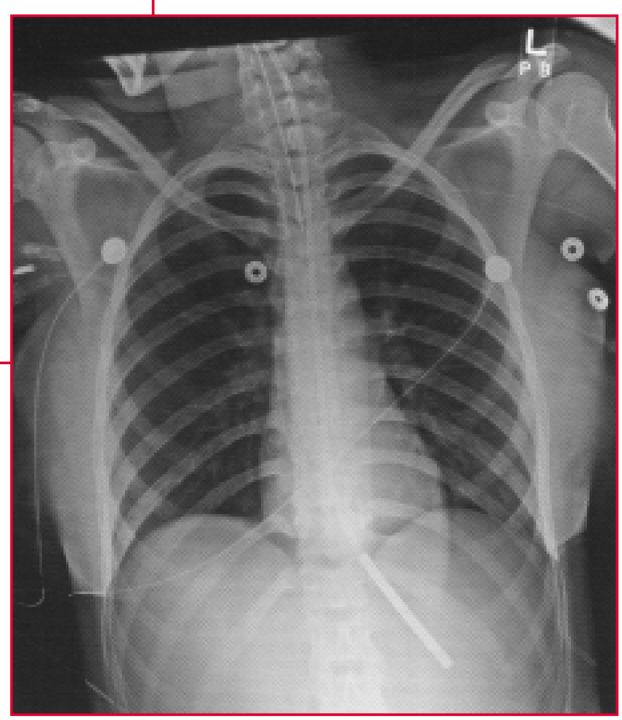
Increased latitude without loss of detail contrast

Introducing – and validating for diagnostic preference – an enhanced visualization image processing software algorithm that exploits the full exposure range of computed radiography image data





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Increased Latitude Without Loss of Detail Contrast

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- **Alexander Michael, MD**
- **Don Siliunas, MD**

The citation for the full diagnostic-preference study summarized in this publication appears below. Reprints of the full study are available by calling Kodak at 1-800-555-8223 and requesting a copy of Kodak publication no. M1–306. This study was also presented as a scientific exhibit at the 1998 annual meeting of the Radiological Society of North America, where it was awarded a certificate of merit.

- Van Metter R, Foos D. Enhanced latitude for digital projection radiography. *Proc SPIE.* 1999;3658:468-483.

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Summary

Digital capture by computed radiography (CR) makes possible the application of image processing algorithms that exploit the full range of original digital exposure data. Eastman Kodak Company has developed and now makes commercially available a software algorithm for its KODAK DIGITAL SCIENCE Computed Radiography System 400 known as KODAK EVP Software. The EVP (enhanced visualization image processing) algorithm renders the original exposure data to extend the exposure latitude of images while maintaining optimal contrast for diagnostic details.

The improved diagnostic quality of EVP images has been clinically validated. Seventy EVP images were rated against 70 corresponding control images by 10 board-certified radiologists according to a well-established diagnostic-preference protocol. Radiologist preference for diagnostic interpretation was measured in terms of the percentage of images in each rating category. The percentage of images rated "satisfactory" or "optimal" was significantly higher for EVP images than for the control images (92.6% versus 55.6%, $P = 0.05$). EVP images were rated higher than their corresponding control images in 76.1% of the cases studied and two or more diagnostic-preference categories higher in 42.0% of cases.

The EVP algorithm has been shown to overcome the traditional trade-off between exposure latitude and contrast detail and provides an opportunity to improve both diagnostic accuracy and radiologist productivity.

The Well-Known Problem

In traditional screen–film radiography, contrast and latitude are known to be inversely proportional. High-contrast films have narrow *latitude* – defined as the range of exposures over which the x-ray film will produce diagnostically useful optical densities. But they can provide the contrast needed to facilitate recognition of subtle detail and abnormalities. Low-contrast films have wide latitude, enabling the full range of tissue opacities to be displayed in a single image. However, they often produce images that lack sufficient contrast.

The EVP algorithm has been shown to overcome the traditional trade-off between exposure latitude and contrast detail and provides an opportunity to improve both diagnostic accuracy and radiologist productivity.

Because there are obvious diagnostic advantages for images with both high contrast and wide latitude, many efforts have been undertaken to overcome the contrast–latitude trade-off.[1,2] One is the development of commercial exposure equalization products, such as the advanced multiple beam equalization radiography system.[3,4] Another is the introduction of high-resolution, wide-latitude, asymmetric screen–film systems. Yet another is the use of a variety of compensation filters to reduce the range of x-ray transmittance of the body parts imaged in radiographic examinations.[5]

These approaches differ in the methods they use to address this common problem, and each suffers from inherent practical limitations. Consequently, these approaches have found limited clinical application.

Until now, storage phosphor receptors used for CR systems recorded a much wider range of exposures than could be optimally displayed for diagnostic viewing. For normal image processing and display, CR systems generally select a limited range of the potentially available exposures, thus

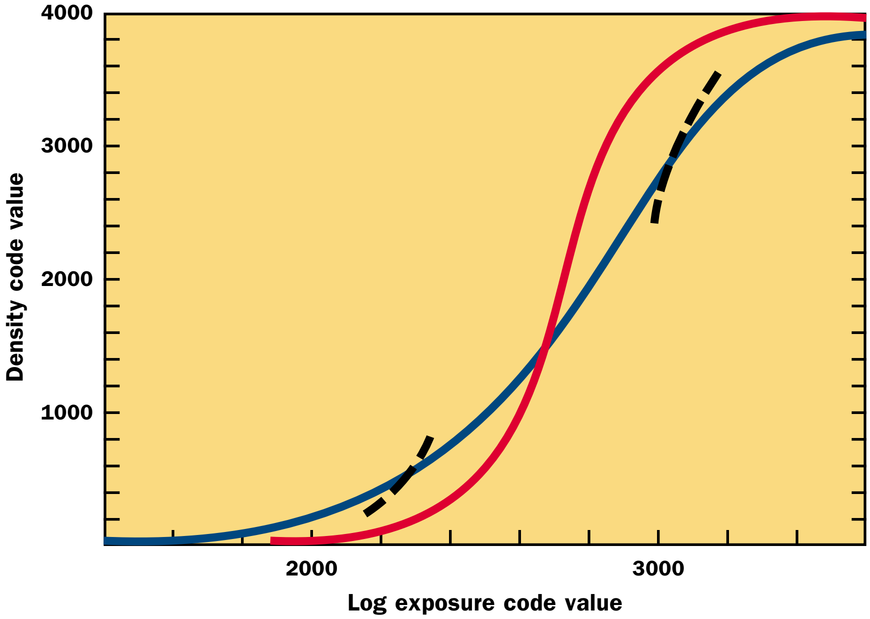

Figure 1. The effect of EVP (enhanced visualization image processing) on image tone scale, which is defined as the relationship between optical density of the displayed image and log x-ray exposure. The red line is the tone scale curve of the Kodak baseline image processing software. EVP (blue line) lowers the overall or global contrast of the image, but the contrast of image detail is preserved at each density (dashed line segments).

introducing the contrast–latitude trade-off that is not inherent in the original CR image data. Image-processing software that can exploit the full exposure range of CR image data should be able to increase the exposure latitude of images without reducing the contrast of digitally important detail.

The EVP software algorithm was developed by Eastman Kodak Company to accomplish just this. Developed for the KODAK DIGITAL SCIENCE Computed Radiography System 400, EVP is the first commercially available processing algorithm to enhance latitude by utilizing the full exposure range of CR image data. This results in images of superior diagnostic quality.

Enhanced Visualization Processing as a Solution

The state-of-the-art image processing used by the KODAK DIGITAL SCIENCE Computed Radiography System 400 to display radiographic images involves a sophisticated chain of image analysis and rendering. Image analysis can be subdivided into a series of steps including: (1) background detection, (2) foreground detection, (3) image segmentation to define a region of anatomical interest, and (4) histogram analysis. Image rendering includes: (1) developing a perceptually optimized tone scale for display, (2) edge enhancement of the image data, and (3) application of the optimized tone scale to the exposure image data. Kodak's state-of-the-art image processing provides a solid basis for further image manipulation.

The EVP software algorithm is applied to a radiographic image after edge enhancement and tone-scale analysis but before the application of the tone scale to the image data. The EVP algorithm divides an image into low- and high-frequency component images. The contrast of the low-frequency image is reduced, thus increasing the range of exposures visible in the image, and the contrast of the high-frequency image is enhanced, thereby preserving the visual contrast of the image detail. The low- and high-frequency images are then recombined by the EVP algorithm and the tone scale is applied.

Figure 1 illustrates how the EVP software algorithm affects the image tone scale. The figure shows the relationship between density of the displayed image and log x-ray exposure. The tone-scale curve resulting from current image processing is shown in red. The EVP algorithm (blue curve) lowers the global contrast of the image while preserving the contrast of image detail at each density, as shown by the dashed line segments.

Three parameters control the appearance of images produced by the EVP software algorithm. Default values – which can be adjusted by the user if desired – are specified for each body part and projection. EVP gain is the most important parameter. This is the factor by which latitude is increased. An EVP gain of 2.0 will double the latitude of an image. Typical gain values range from 1.5 to 2.5. A second parameter is EVP density – that is, the large-area image density that remains invariant when EVP is applied. Typical density values range from 1.0 to 2.0. The third parameter is kernel size (specified in millimeters), which determines the cut-off frequency for enhancement. Typical kernel-size values range from 10 to 20 mm.

The advantages of adding the EVP software algorithm to the default processing software of the KODAK DIGITAL SCIENCE Computed Radiography System 400 are multifold. The new processing software not only eliminates the loss of detail in dense bone and other underpenetrated areas but also provides better anatomical context. **Figure 2** compares the effects of EVP and current image processing on a radiographic image of a knee. The three panels show the traditional trade-off between contrast (panel A) and latitude (panel B) resolved in an EVP image (panel C).

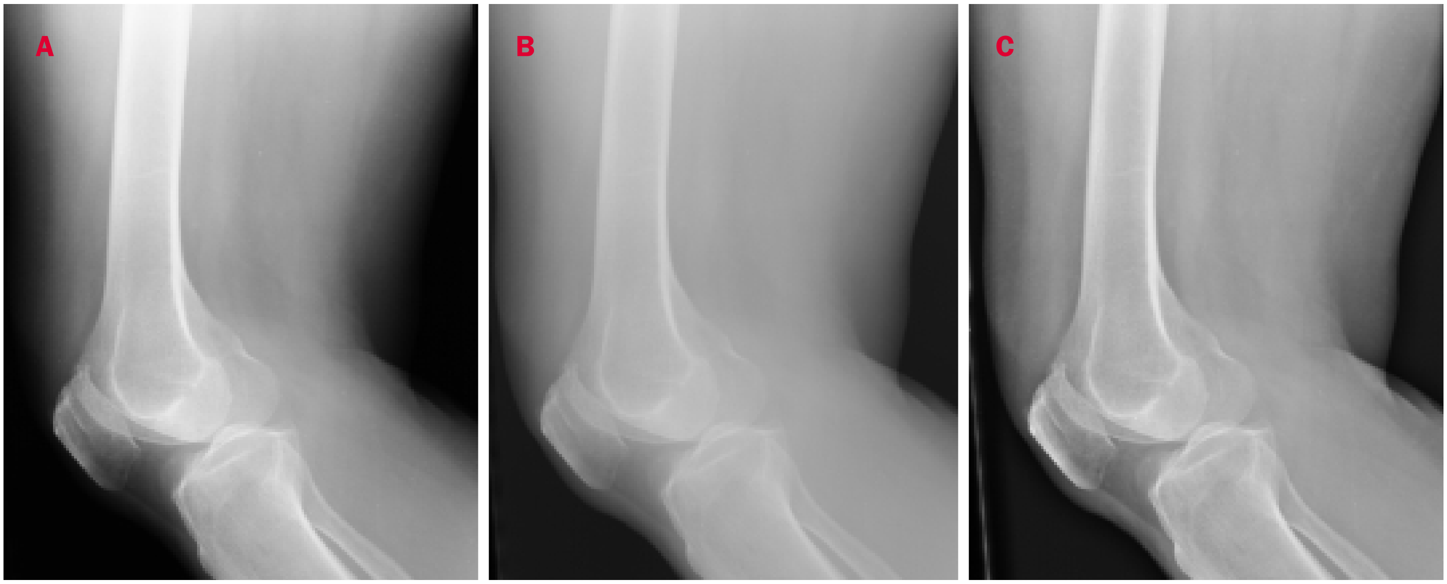

Figure 2. The resolution of the contrast–latitude trade-off with EVP (enhanced visualization image processing) software. In a radiographic image of the knee, panel A shows adequate contrast with good bone detail, but the soft tissue is overpenetrated because of limited latitude. Panel B shows the same image with adequate latitude and improved rendering of the soft tissue, but bone and soft-tissue detail are limited by low contrast. Panel C shows the same image after application of the EVP software algorithm. Here (panel C) there are both the fine-detail visibility of the adequate-contrast image (panel A) and the full range of exposures available in the adequate-latitude image (panel B).

Clinical Evaluation of EVP: A Diagnostic-Preference Study

The Protocol

In a controlled clinical study, 70 representative radiographic images processed with and without the EVP algorithm were independently rated by 10 board-certified radiologists.[2]

Representative images were selected from a database of more than 2300 images acquired as part of routine care by means of a KODAK DIGITAL SCIENCE Computed Radiography System 400 at Lutheran General Hospital (Park Ridge, Illinois). Five sample images of each of 14 different examination types were chosen (**Table 1**).

The experimental control for the study was a set of images processed with the edge-enhancement and tone-scale processing software that is part of the KODAK DIGITAL SCIENCE Computed Radiography System 400. Because Lutheran General Hospital radiologists had earlier taken part in an evaluation of the control processing software, these images had already been optimized to reflect the preferences of this group of radiologists.[6]

The EVP algorithm was applied to the experimental control images. As described in the preceding section, the EVP algorithm requires specification of three parameters – gain, density, and kernel size. In this study, gain was determined for each image in a preliminary experiment by a radiologist not otherwise involved in the study. The gain values used varied from 1.5 to 2.5. Density was 2.0 for chest images and 1.2 for other examination types. Kernel size was 17.5 mm for all examination types.

For each of the 70 original clinical CR images, both the EVP and control images were printed onto 14- by 17-inch KODAK DIGITAL SCIENCE HN Medical Film by a KODAK EKTASCAN 2180 Laser Printer. The full set of 140 film images was

Table 1. The 14 types from which representative images were drawn for this study.

• Abdomen	• Chest	• Cervical-spine
• Elbow	• Fibula	• Foot
• Hand	• Knee	• Lumbar-spine
• Shoulder	• Pediatric skull	• Pediatric abdomen
• Wrist	• Pediatric chest	

Table 2. The diagnostic-preference rating scale. Each of the 10 participating radiologists applied a score from the rating scale to each of the 70 EVP and 70 control images.

Score	Diagnostic-preference quality	Explanation
9	Very satisfied	Optimal for evaluating the appropriate category of information
8		
7	Satisfied	Acceptable for interpretation; no loss of information
6		
5	Neither satisfied nor dissatisfied	Suboptimal image; bordering on loss of information; subtle abnormalities could be overlooked
4		
3	Dissatisfied	Poor image that impairs interpretation; important information could be lost; the interpreter would consider reprocessing
2		
1	Very dissatisfied	Inadequate for diagnosis; definite loss of information; the image should be reprocessed

then loaded onto a film alternator for quick and convenient side-by-side viewing. The images were presented in a single-blind protocol and were read independently by the 10 participating radiologists.

The radiologists were instructed that they were rating two *new* image-processing techniques. In this way, the EVP images and the control images could be independently rated on a 9-point scale. Viewing time was unrestricted and in practice varied from 30 minutes to 1 hour. An observer recorded the rating for each image as well as comments concerning factors related to the diagnostic quality of the images.

The 9-point ordered-category scale (**Table 2**) was an augmentation of the 5-point scale used by Slone and colleagues to evaluate the effect of exposure variation on the clinical utility of chest radiographs.[1] The same scale had also been used by the participating radiologists in a prior study evaluating the control processing software.[6] The scale measures a radiologist's satisfaction with the diagnostic quality of an image and thus indicates a radiologist's diagnostic preference for the image.

The Results

A rating of 7, 8, or 9 on the 9-point scale indicates that a participating radiologist considers an image "acceptable for interpretation" with "no loss of information" or "optimal" for clinical evaluation. Our ultimate goal is for all images to fall in these categories. The percentage of EVP images scoring 7 or higher was 92.6%; the percentage of control images scoring 7 or higher was 55.6% (**Figure 3**). The difference between the EVP and control images was statistically significant at $P = 0.05$.

A rating of 1, 2, or 3 on the 9-point scale indicates that a participating radiologist considers an image so "poor" that it "impairs interpretation" and that "important information could be lost." The percentage of EVP images scoring 3 or lower was 0.6%; the percentage of control images scoring 3 or lower was 4.0%. This difference was also statistically significant at $P = 0.05$.

The percentages of EVP images scoring 7 or higher for each of the 14 different examination types were found to be higher than the control images in all cases. The differences were statistically significant in all cases except the abdomen and elbow (**Figure 3**). The largest improvement was found for the lumbar-spine examination (100% versus 42%). The EVP image quality improvements for chest, pediatric skull, foot, and cervical-spine examination types were also very large.

Overall, for 76.1% of the 70 comparison-image pairs, the participating radiologists rated the EVP images superior to the corresponding control images (**Figure 4**). In 42% of the comparison-image pairs, the participating radiologists rated the EVP images two or more categories higher than corresponding control images. Some images improved by as much as six categories. Eighteen percent of the image pairs were rated equal in diagnostic quality, while in only 6% of the comparison-image pairs were the control images preferred.

Generally consistent results were obtained across all examination types studied. The percentage of image ratings for which EVP images were rated superior varied from 48% for elbows to 90% for lumbar-spine examinations.

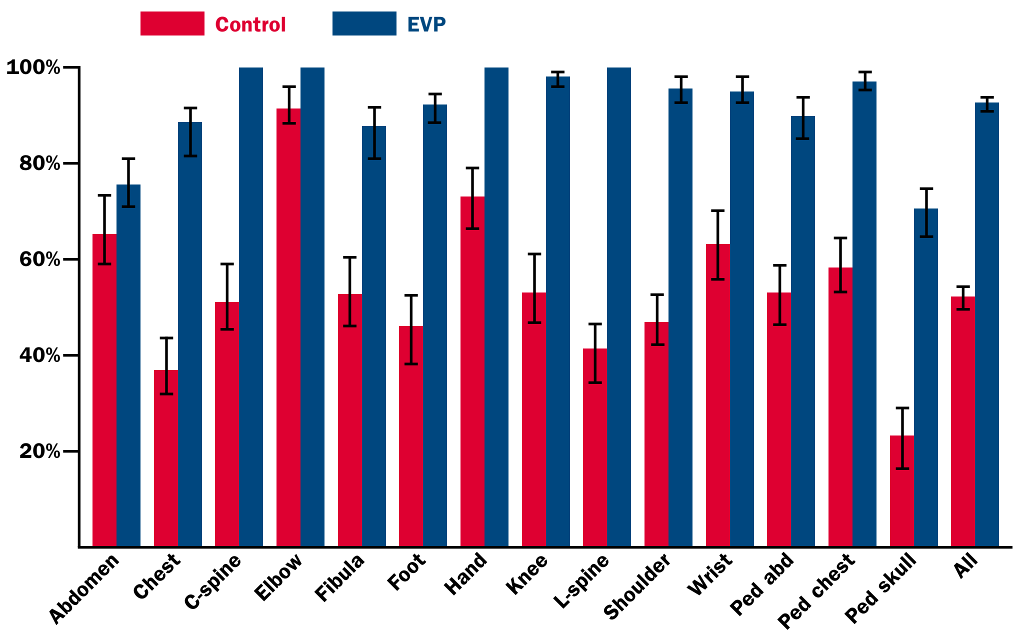

Figure 3. Percentage of EVP (enhanced visualization image processing) and control images rated 7 or better in terms of diagnostic preference for interpretation (a rating of 7 represented "satisfaction"). Overall, the percentage of EVP images scoring 7 or higher was 92.6%; the percentage of control images scoring 7 or higher was 55.6%, a statistically significant difference ($P = 0.05$). The superiority of the EVP images was statistically significant for all examination types except abdomen and elbow. The error bars represent 95% confidence intervals.

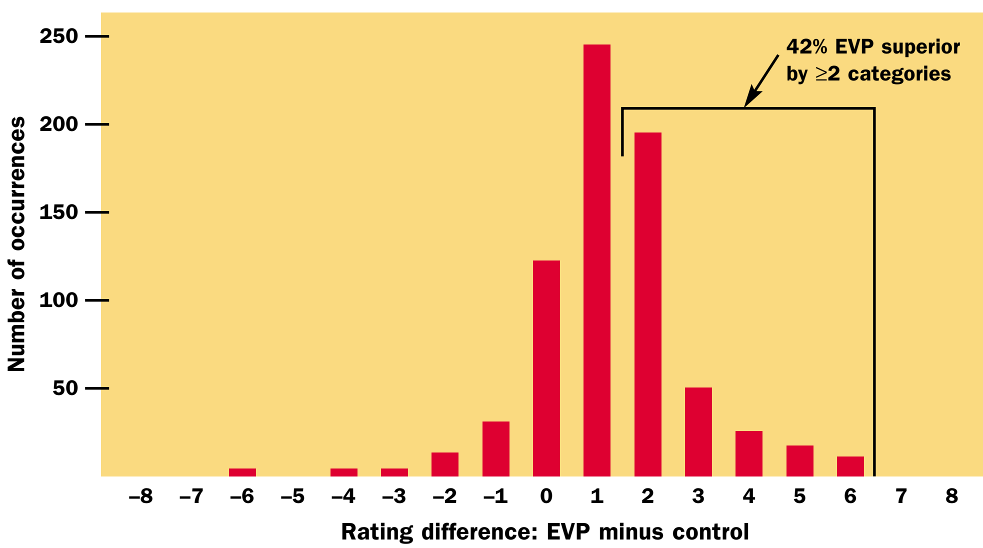

Figure 4. Paired rating comparison between EVP (enhanced visualization image processing) and control for all 700 image ratings. In 42.0% of the comparison-image pairs, the EVP images were rated two or more categories higher than the control-processed images.

Conclusions

Ten board-certified radiologists rated images processed by the EVP software algorithm clearly superior in terms of diagnostic-preference quality to images processed by a current state-of-the-art algorithm. The results were largely independent of examination type, with the greatest improvements observed in examinations expected to benefit from increased exposure latitude.

While demonstrating the diagnostic-preference quality of EVP images is not equivalent to demonstrating that EVP images improve diagnostic accuracy or radiologist productivity, these preliminary results strongly suggest the likelihood of these desired outcomes.

In summary, the development and commercial availability of the EVP software algorithm represents a significant step toward optimally exploiting the full range of exposure data captured by the KODAK DIGITAL SCIENCE Computed Radiography System 400. As radiology enters its second hundred years, a well-established principle – the inverse proportionality of latitude and contrast – no longer stands as a practical barrier to obtaining images of superior diagnostic quality.

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