Initial Experience With Soft-Copy Display of Computed Radiography Images on Three Picture Archive and Communication Systems

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We recently installed picture archive and communication systems (PACS) from three different vendors on our campus for evaluation. A major part of this evaluation involved assessing the capabilities of these systems for displaying computed radiography (CR) images for primary interpretation. The three PACS provided different functionality for CR image display in terms of availability of the proprietary Fuji CR image processing algorithms, availability of user-specified contrast look-up tables, and application of the processing at the time of CR image capture or image display. We found that the Fuji processing algorithms were important for printing film, but were not necessary for acceptable soft-copy display. Non-linear contrast processing produced superior results compared to simple linear processing (via standard window width and level controls). Display processing was best applied immediately prior to the display operation, as opposed to at the image capture time. This allows the display to be adjusted to demonstrate the full 10-bit range of the CR image, and also allows raw CR data (i.e. not optimized for any particular display device) to be stored in the long-term archive.

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IN 1995, Mayo Clinic-Rochester began three projects aimed at evaluating computed radiography (CR) and picture archive and communication systems (PACS) from different vendors in different areas of our campus. A Lockheed-Martin Vantage PACS (Lockheed-Martin Medical Imaging Systems, Hoffman Estates, IL) was installed for use in our community medicine practice. General Electric PACS equipment (General Electric Medical Systems, Milwaukee, WI) was used to manage portable chest images acquired primarily in the pediatric and neonatal intensive care units (ICUs) at St. Marys Hospital. A SIENET PACS (Siemens Medical Systems Inc, Iselin, NJ) was used to manage musculoskeletal images for four orthopedic surgeons in the clinic practice. Fuji CR equipment (model FCR 9000, 9501 or AC3 CR readers, Fuji Medical Systems USA Inc, Stamford, CT) was used in each of the three projects.

Our initial experience with display of CR images involves printing images that have been processed using the Fuji-supplied algorithms to a laser film printer directly attached to the CR reader. After acquisition and printing of the CR images for an examination, a quality control (QC) technologist reviews the images and evaluates the image appearance. Acceptable images are made available to a radiologist for interpretation, and unacceptable images are reprocessed and reprinted. Substantial time and effort were invested to optimize the Fuji processing algorithm for each type of radiology examination, such that, for most images, a single, autprinted rendering of each image was sufficient for diagnosis. Currently, only about 5% of the CR images acquired in the community medicine practice must be refilmed.

A major goal for each of the PACS projects was to optimize automatically the initial soft-copy display quality presented to the QC technologist and the radiologist, so as to minimize the time spent manually adjusting the image display. On all three PACS, the three main functional elements affecting soft-copy CR image display were (1) nonlinear contrast processing (possibly combined with spatial filtering), (2) window width and level (W/L) control, and (3) a video card and cathode ray tube (CRT) combination. We found that the capabilities of these display elements and the specific implementation of the display chain varied from vendor to vendor, and significantly affected our ability to optimize successfully the soft-copy display. This article reviews our initial practical experiences in optimizing soft-copy display of CR images on each of the three PAC systems.

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LOCKHEED-MARTIN PROJECT

The Lockheed-Martin Vantage PACS was the first of the three PACS to be installed. When the system was installed initially, nearly all of the CR images were adjusted using window W/L by a QC technologist prior to radiologist interpretation. This process was extremely time-consuming. Even with these W/L adjustments, the image quality was judged to be inferior to the image presentation on film (the existing standard).

The Vantage system did not allow processing of CR images using the Fuji algorithms, but a look-up table (LUT) was available on each display workstation. Different LUT display functions could be specified for each type of CR image (as specified by the Fuji CR organ code). The LUT was implemented on the PACS workstation so as to interact with the window W/L controls. If no LUT function was specified for a particular organ code, the W/L control defined a range of 10-bit pixel values that was mapped linearly to an 8-bit image that was displayed on the CRT. If an LUT function was present, the pixel range specified by W/L was not mapped linearly, but rather was mapped according to the (typically nonlinear) LUT function. This allowed W/L controls to be used to view the full range of 10-bit raw CR pixel values (although with the nonlinear mapping defined by the LUT). Changes to W/L settings were displayed at video rates whether or not a LUT function was present. Also, the LUT processing occurs in memory when the image is displayed, and the processed image is never stored. The raw CR data from the CR reader are stored on the PACS server and in the long-term archive.

Look-up table functions for each CR image type involved in the community medicine practice were derived to mimic the presentation of the processed images on the Fuji HI-C 654 workstation (see Appendix for details). The 654-workstation display had been calibrated to match closely the image

printed on the film, so this was taken as the gold-standard for soft-copy display. The LUT functions were reviewed, optimized, and finalized through the consensus of a panel of radiologists.

No spatial filtering capabilities were present on the Vantage system. The characteristics of the CRT displays used by the QC technologists and radiologists are summarized in Table 1.

Lockheed-Martin Project Results

Use of the LUTs significantly improved the soft-copy image quality, and also reduced the requirement of the QC technologists to manually adjust the image presentation (W/L) before approving the examination for interpretation. Currently, only approximately 2% to 3% of the CR images are adjusted manually prior to primary interpretation by the radiologist. This number is even lower than the 5% of films that are reprinted. This difference is due to the routine use of W/L by the radiologist (typically for more than 50% of the images) to optimize the display for different areas of the image (e.g., bone and soft tissue). A survey of 30 radiologists indicated that the soft-copy image quality was equal to or better than that of film (86% of respondents). All respondents judged the image quality as acceptable for primary interpretation.

GENERAL ELECTRIC PROJECT

The General Electric (GE) system was the second to be installed. Fuji processing algorithms were optimized for printing the portable pediatric and neonatal images to film. The GE system allowed application of the Fuji CR image processing algorithms (contrast and spatial filtering) for soft-copy display. The processing was applied when the raw image was transferred from the CR reader, and the processed image was stored. Unless the raw image is stored in addition to the processed image, it is lost as it cannot be recovered from the processed data set. The same processing parameters used for

Table 1. Workstation Display Specifications*

Vendor	Pixel Matrix	Orientation	Maximum Luminance (ft-L)
Lockheed-Martin	1536 × 2048	Portrait	80
	1280 × 1024	Landscape	60
General Electric	1536 × 2048	Portrait	60
	1280 × 1024	Landscape	60
Siemens	1280 × 1024	Landscape	60
	1280 × 1024	Landscape	60

*For each vendor, the top specifications apply to the radiologist (primary interpretation) workstation and the lower specifications apply to the QC technologist workstation. Maximum luminance is measured in foot-Lamberts (ft-L).

the film were applied for soft-copy display, and were judged to be acceptable for primary interpretation. Window W/L of the processed image may be adjusted on the display workstations. Table 1 summarizes the specifications of the workstation CRT displays.

General Electric Project Results

Only about 1% of the CR films required reprocessing and reprinting. Also, only about 1% of the CR images were adjusted by the QC technologists prior to primary soft-copy interpretation by a radiologist. Nine of the ten radiologist survey respondents judged the soft-copy display to be acceptable for primary interpretation (although only two felt the display was as good as or superior to film).

SIEMENS PROJECT

The third system to be installed was a SIENET PACS from Siemens, which was used to manage musculoskeletal images. Similar to the GE System, this system provided Fuji contrast and spatial frequency processing for soft-copy display. The window W/L of the processed image could be adjusted; but again, unless the raw CR data were explicitly stored, they could not be recovered.

Considerable effort was expended in an attempt to identify optimal image processing parameters for the soft-copy display of each image type acquired in the musculoskeletal practice. (The parameters optimized for film printing were found to be unacceptable.) Parameters were found in some cases that produced an acceptable initial image display. Width and level adjustment, however, often was required during image interpretation, and this operation exposed the absence of image data in the extreme bright and dark areas of the image (caused by the contrast processing operation). It was not found to be possible to produce, for any image type, a processed image that required no W/L adjustment outside of the pixel value range present in the processed image. This is inconsistent with our findings for the GE project. We believe that the source of this disagreement is the very different patient populations imaged for the two projects. The adult bone images displayed by the SIENET system often exhibited a wide dynamic range between the bony structures and the soft tissues, whereas the dynamic ranges observed in

the pediatric and neonatal images displayed on the GE workstations were considerably lower.

To address the lack of dynamic range in the SIENET image display, we chose to disable the Fuji processing and simply optimize window W/L as much as possible. To minimize time spent by the QC technologists, we attempted to derive default W/L values for each CR image type. Default values were obtained by fitting a straight line (by eye) to the nonlinear LUT functions used with the Vantage PACS project (described previously), and computing the corresponding W/L value. The radiologist could adjust the W/L away from this initial value and see all the information in the original raw CR image. A panel of radiologists attempted to optimize and finalize these default W/L values, with marginal success. We were not able to find default W/L values for all image types that consistently produced initial image displays acceptable to the panel. This approach to optimizing CR image display, however, was more successful in our hands than using Fuji processing, and the W/L approach was used for the remainder of the SIENET PACS project. The workstation display CRT specifications are summarized in Table 1.

Siemens Project Results

Only about 6% of the CR films required reprocessing and reprinting, whereas about 25% of the CR images were adjusted by the QC technologists prior to primary soft-copy interpretation by a radiologist. All 14 of the radiologist survey respondents judged the soft-copy display quality to be acceptable for primary interpretation (although only three felt the display was as good as film).

CONCLUSIONS

Our initial experiences with soft-copy display of CR on three different PACS lead us to the following conclusions:

1. Soft-copy display flexibility is rigidly set by the hardware and software design of the PACS, and capabilities may be quite different on different systems.
2. Fuji contrast processing and spatial frequency enhancement are most important for printing film, where a single image display "look" is all that is typically available.
3. When displaying soft-copy CR images, nonlinear contrast processing, which was imple-

Fig 1. Sample luminance response curves for the CR and PACS workstations (showing both the individual luminance measurements and the interpolated curves). Also shown are the four logical steps taken to build the display LUT, which allows the PACS workstation to simulate the CR workstation image display.

mented to allow access to the full 10-bit raw CR image data set, provided the most acceptable image quality for primary diagnosis.

4. Even when nonlinear contrast processing for soft-copy display is applied, adjustment of window W/L during interpretation is done routinely (underscoring the importance of maintaining access to the original raw data set).
5. When interpreting CR images using soft-copy displays, spatial frequency processing was not found to be required. Zoom and roam tools, however, were used routinely during interpretation.

APPENDIX: CALCULATION OF VANTAGE PACS DISPLAY LUT FUNCTIONS

The display LUTs were designed to allow the PACS workstation to display the CR images as they are displayed on the CR workstation (whose contrast display characteristics have been optimized).

Calculation of the LUT for a particular image type begins with the measurement of the luminance response curves of the CR workstation and the PACS workstation. This is accomplished by displaying any test pattern that provides 10 or more areas

of known, uniform pixel value, ranging from the minimum to the maximum value. The luminance corresponding to each of these pixel values is measured using a photometer. The pattern is displayed on the CR workstation, with the desired contrast processing in place (the spatial processing should be disabled). The CR workstation measurements include the effects of the contrast processing and the intrinsic CRT response, whereas the PACS workstation measurement is affected only by the CRT response. The measurements of each response function then are interpolated to provide function values for all possible pixel values. Examples of these two luminance response curves are shown in Fig 1.

Building the LUT occurs by stepping sequentially through all possible CR image pixel values that correspond to the LUT input value. For each of these input values, the two luminance response curves are used to determine which PACS workstation display pixel value is required to produce the luminance observed on the CR workstation. This logical operation is shown in Fig 1. The PACS workstation display pixel value corresponding to the CR image pixel value is taken as the LUT output.