Contrast improvement using color-coded radiographs of anatomic specimens

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Summary. Radiographs are used in a wide variety of musculoskeletal examinations. Special procedures are required to improve image quality. We report a new radiologic technique that uses monochromatic molybdenum Kα radiation together with secondary digital color-coding to produce well contrasted images of supporting tissue. In order to investigate the diagnostic capability of this approach we studied specimens of the intervertebral disc, harvested from cadavers undergoing chemonucleolysis following an injection of chymopapain. Radiographs of the specimen taken using a Mo X-ray tube with a zirconium filter were scanned into a computerised image-processing system and color-coded. This method improves resolution and contrast in the images and allows the differentiation of morphologic changes.

Key words: Radiographs — Color-coding — Monochromatic Mo Kα radiation — Intervertebral disc — Chemonucleolysis

Material and methods

A lumbar vertebral column was dissected from a cadaver (female, 32 years) four hours post mortem. Nucleolysis was induced by the injection of 2000 U chymopapain (Chymodiactin®, Kanoldt, Hochstäd, Germany) [13]. Lysis was stopped after 45 min by denaturing the enzyme with alcohol. One intervertebral disc was not lysed and served as a control specimen.
Parallel sagittal sections (3 mm) were then produced using a diamond wire saw (Well, Mannheim, Germany).

Radiographs of the specimens were produced using a molybdenum X-ray tube (21 kV, 1 mA) with a zirconium filter. The resultant Mo $K_\alpha$-radiation was nearly monochromatic ($\lambda = 71.1$ pm) and in combination with a fine grained material testing film (Cronex NTD 55 NIF 100 DIN 54111:G2, Dupont, Bad Homburg, Germany) enabled high-contrast, high-resolution radiography [10, 11, 13].

The radiographs were scanned into an image processing system and color-coded images were generated using three different methods: 1) a linear rainbow color scale was defined between the minimum and maximum possible radiologic densities, assigning blue to the lowest density and red to the highest. 2) The color scale was modified to restrict it to the intensity range within the object under investigation. 3) Intensity ranges were determined separately for the osseous and disc tissue and for the lysis zone, and differently color-coded. Bone was colored in shades of red, disc tissue in green and yellow, and the nucleolysis zones in blue.

Results

Figure 1 shows a positive print of the original radiographs. The compacta and spongosia of the adjacent lumbar vertebrae, the anterior and posterior longitudinal ligaments as well as the disc tissue can be differentiated. The disc tissue displays a range of density depending on water content and collagen fiber dispersion.

Figure 2 shows color images of the original radiogram (Fig. 1) generated using the three methods described above. Figure 2a, using the first method, does not display any improvement in contrast or resolution. The presentation of the different radiologic densities tends to be worse than in the black and white images due to limited color range. In contrast, the second method delivers an improved delineation of the disc tissue, and there is a better separation of the different density zones. This is clear in both the control specimen (Fig. 2b) and the lysed disc, (Fig. 2c). The anterior longitudinal ligament (Fig. 2b), the posterior ligament (Fig. 2c) and the lysis zone (Fig. 2c) are very well delineated. The osseous structures in the adjacent vertebrae are poorly depicted, and the extreme color differences from dark-green to yellow exaggerate the radiologic density differences. The third technique (Fig. 2d) produces a much improved morphologic representation with rich contrast between the various radiologic densities. Osseous structures are represented in a satisfactory fashion and in contrast to previous techniques the anterior and posterior ligaments can be clearly recognised. The extent of the lysis zone can be determined exactly from the blue coding. An important feature of the third method is that there are no extreme color changes within a single anatomic structure unlike the two other methods.

Discussion

The various methods for obtaining color radiographs found in the literature differ in the way the images are produced and in the interpretation of the delivered results [2, 3, 7, 8, 9, 12, 14]. Previous methods of color-coding black and white radiographs are based on a variety of photographic development procedures [1, 5]. These techniques are based on the rehalogenisation of a radiograph followed by color development. Another approach is the photographic method of Konermann [6] in which a number of different color films representing the various intensities in the original radiograph are overlaid to produce a color image. Finally, colored images can be produced using a monitor chain so that contrast enrichment is achieved [4].

The advantages seen by the authors in the various procedures range from contrast enhancement [4] to improved representation of isodense zones in a radiograph [6]. These methods all entail so much processing that their routine use is impracticable. Furthermore, the quality of these techniques with regard to resolution and color-coding is best described as poor. We have introduced a technique of coloring radiographs, generated with low energy Mo $K_\alpha$-radiation, using a digital image-processing system. It enables a colored image to be produced in about 5 min with optimal contrast obtained by adjusting the color reference table to