



a.



b.



c.



d.

Figure 5.22 Feet images with various unsharp mask filters applied:

a. Original image; b. 21x21 filter size; c. 51 x 51 filter size; d. 109x109 filter size



a.



b.



c.



d.

Figure 5.23 Magnified feet images with various unsharp mask filters applied:
a. Original image; b. 21x21 filter size; c. 51 x 51 filter size;
d. 109x109 filter size

Images that have been modified with a 21x21 unsharp mask filter (Figures 5.22b and 5.23b) show increased edge enhancement of fine detail such as the trabecular pattern of the bones. As the filter kernel size increases, enhancement of larger objects can be seen. When the unsharp mask filter with a size of 109x109 was applied, dynamic range compression also occurred. This is seen as an increased ability to visualise all of the anatomy in the image. In Figure 5.22d, both the toes and ankle regions are well visualised compared to the original image.

It was previously discussed that such unsharp mask filters enhance noise. This is not easily seen in the filtered images due to the little or no visible noise in the original image. The previously discussed over-shoot or halo artefact can be seen in Figures 23b & c and to a lesser extent in Figure 5.23d. These artefactual appearances can be seen around the edges of the “L” in the top left of these images.

5.8 Multi-Scale Processing

Multi-scale processing uses the basic concept of unsharp mask filtering. Unsharp mask filtering can be considered as decomposing the image into two frequency bands and individually enhancing these frequency bands. Multi-scale processing decomposes the image into multiple bands that contain information about objects of various sizes within the image. Typically, 12 sub-image bands are decomposed. Each band is then selectively enhanced and the bands are recomposed to form a new enhanced image (Prokop & Schaefer-Prokop, 1997). Figure 5.24 (Prokop & Schaefer-Prokop, 1997) shows an example of the 12 frequencies used in multi-scale processing.

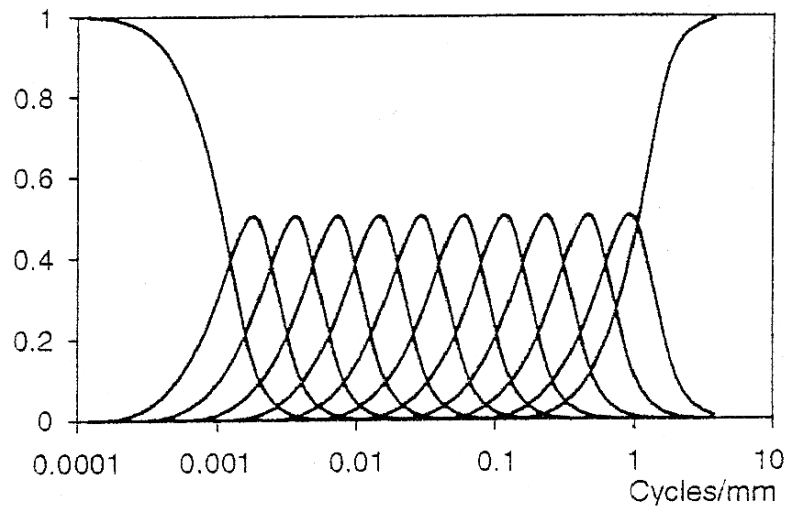


Figure 5.24 Plot of the 12 frequency bands used in multi-scale processing (Prokop & Schaefer-Prokop, 1997, p.S77)

Wavelet transforms, rather than Fourier transforms, have been reported in the use of multi-scale contrast enhancement of mammographic DR images (Chang & Laine, 1999; Clarke *et al*; 1994; Giger & MacMahon, 1996; Laine *et al*; 1994; Mata Campos *et al*, 2000; Sakellaropoulos, Costaridou & Panayiotakis, 2003; te Brake & Karssemeijer, 1999).

Agfa-Gevaert uses a multi-scale approach in its computed radiography systems, based on the so-called Laplacian pyramid transform approach for image decomposition. This is commercially known as multi-scale image contrast amplification (MUSICA). The MUSICA process decomposes a 2,048 row x 2,048 column image into 11 sub-bands. The basis of the process is that the original image is low pass filtered with a 5x5 Gaussian kernel and halved in size. The process is repeated on the newly formed image and continues until a 1x1 image size is reached. Each of these filtered and size-reduced images is then interpolated to the original size of the image and subtracted from the original image to form 11 new sub-bands. Each of the interpolated and subtracted sub-bands is individually enhanced by a non-linear amplification depending upon the size of the image that formed the sub-band. The sub-bands are recomposed to form the new image (Vuylsteke & Schoeters, 1994, 1999).

According to Vuylsteke & Schoeters (1999), this method has several advantages over unsharp mask processes: MUSICA improves the visibility of subtle features of the image; it does not produce the artefactual appearance of unsharp mask processes; and enhancement is also achieved at the edges of the contrast range of the image. MUSICA does, however, enhance any noise that may be present in the image (Vuylsteke & Schoeters).

To illustrate the multi-scale processing technique, a single computed radiographic image of the shoulder region of an x-ray chest phantom (3M Company, St. Paul, USA) was obtained. The image was acquired on an ADC Solo (Agfa-Geveart, Nunawading) computed radiographic unit and the image was processed using the MUSICA functions available through the IPD Viewer Software (Agfa-Geveart, Nunawading). Figures 5.25a, b & c provide comparisons of an enlarged section of the shoulder image using various factors set with the IPD Viewer software. Table 5.1 provides the details of the factors used in Figures 5.25a, b & c. The MUSICA factors used in Figure 5.25b are the preset factors used to display an image of the shoulder using the IPD Viewer Software. Other user selectable factors of edge contrast, noise reduction, extended window left, extended window right and sensitometry curve, also available thorough the IPD Viewer software, were kept the same for the three images.

Table 5.1 MUSICA factors used for processing images in Figures 5.25a, b & c

	Fig. 5.23a	Fig. 5.23b	Fig. 5.23c
MUSI contrast	0.0	3.0	3.0
Latitude reduction	0.0	2.0	6.0
Edge contrast	2.0	2.0	2.0
Noise reduction	0.0	0.0	0.0

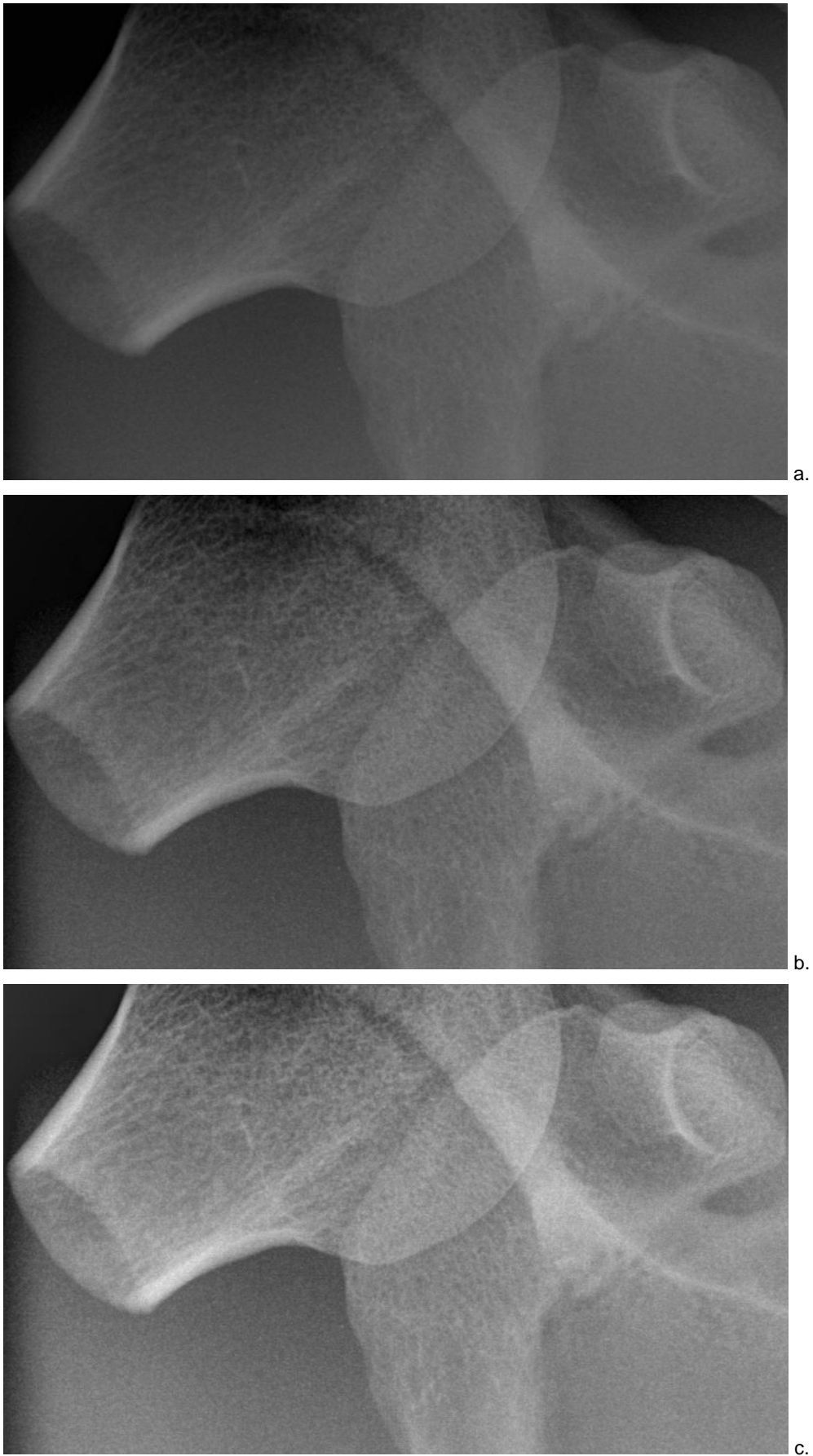


Figure 5.25 Enlarged images of a shoulder phantom with various MUSICA factors:

- a. MUSI contrast = 0, latitude reduction = 0;
- b. MUSI contrast = 3, latitude reduction = 2;
- c. MUSI contrast = 3, latitude reduction = 6.

According to the IPD Viewer Software Reference Manual (2002), MUSICA parameters can be adjusted using the six factors and slider adjustments seen in Figure 5.26 (IPD Viewer Software Reference Manual, 2002). The factors of extended window left, extended window right and sensitometry curve affect only the LUT and as such do not affect the MUSICA process. Details provided in the reference manual state that the MUSI contrast slider fine-tunes the contrast of all features; edge contrast fine-tunes the contrast of short-range features and latitude reduction fine-tunes the contrast of long-range features. The minimum and maximum values of MUSI contrast, edge contrast and latitude reduction are 0 and 6 respectively.

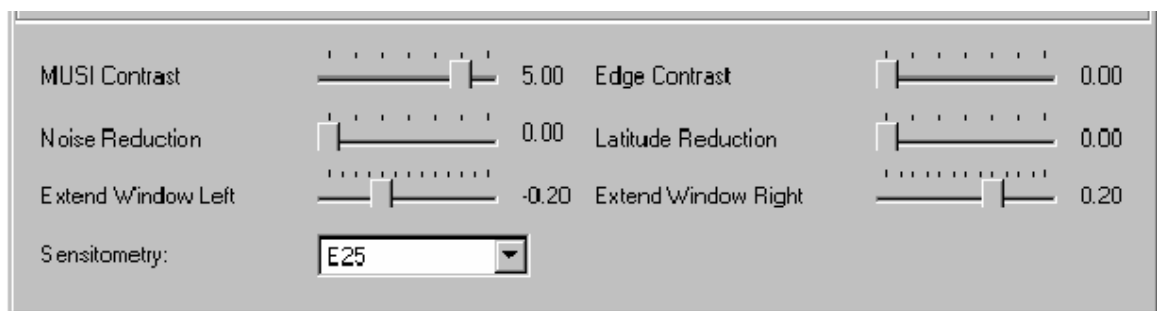


Figure 5.26 MUSICA parameter adjustment window for the IPD viewer software (IPD Viewer Software Reference Manual, 2002)

The image in Figure 5.25a, the unprocessed image, has had no MUSI or latitude reduction applied. Bone trabecular patterns increased in visibility and increased contrast differences are also visible in the scapula in Figure 5.25b. Maximising the latitude reduction parameter in Figure 5.25c improved contrast across the entire image. Figures 5.25b & c exhibit an increase in noise compared to the original image, Figure 5.25 a.

5.9 Radiographic Contrast-Enhancement Mask Approach

In the adjustment of contrast and brightness, both point operations and frequency based enhancement methods have limitations. Both these methods are applied globally to the image. The process may have undesired effects in a section of the

image. Frequency based approaches can enhance noise within the image and can produce artefactual appearances in the image.

To overcome the limitations of global point operations and global frequency based enhancement methods, an alternative method was devised. The method developed herein for DR images simulates the effects of physical tissue compensation filters (TCFs) in general radiography. The equivalent of a digital TCF, which is referred to as an anatomically based RCM, was devised, implemented and evaluated.

The RCM approach is a locally based contrast enhancement method. The RCM algorithm can alter the image relatively in different areas within the image while still maintaining image detail. The viewer of the image is able to locate the digital RCM over the desired area of the image to alter the displayed contrast in that area. This method is not a globally based approach and as such does not have the disadvantages of global methods. As the digital RCM method utilises contrast enhancement methods, the undesired effects of frequency based methods are not present in the altered image.

The development and basis of the RCM method are described in Chapter 6. Applications of RCMs in digital radiography and comparison of methods are detailed in Chapter 7. Evaluation of images modified using the RCM method compared to other current methods of dynamic range control is conducted in Chapter 8. Medical images in everyday use are subjectively evaluated. Chapters 9 and 10 describe a survey comparison of the effects of the RCM method on DR images.