Chapter 3

Material and Methods
3 Material and Methods

3.1 Amorphous Silicon flat panel-type detector imager - Elekta iViewGT

The Electronic Portal Imaging Device (EPID) used on this investigation is of type Elekta iViewGT, based on the amorphous silicon type detector panel XRD1640 AL5 and (PerkinElmer Optoelectronics, Fremont, CA, USA). It has a fixed source-detector distance of 160 cm. The radiation sensitive layer has a size of 41 x 41 cm² and consists of 1024 x 1024 detector elements with a sampling aperture (pixel size) of 0.4 x 0.4 mm² (Figure 3.1).

These imagers are indirect detectors; a phosphorous scintillation screen made of terbium doped gadolinium oxysulphide (Gd₂O₂S:Tb) is used to convert incident radiation to optical photons; a copper plate of 1 mm thickness placed on top of the scintillation layer provide build-up and absorbs scattered radiation to enhance image quality. The optical photons are detected by an array of coupled amorphous silicon photodiodes and thin film transistors (TFTs) (Figure 3.2).

![Figure 3.1](image1.png)  
Figure 3.1 Linear accelerator machine coupled with iViewGT a-Si EPID in the retracted a) and extended treatment position b), with and without the top cover (touch guard), respectively.

![Figure 3.2](image2.png)  
Figure 3.2 Schematic illustrations of the elements of iViewGT s-Si EPID. The copper metal plate (a) and the scintillating phosphor acts an x-ray converter layer, which results in optical photons detected by the active matrix array (c) made by a-Si photodiodes and TFTs.
Measurements were made using four of these detectors (based on the same design) mounted on three linear accelerators (LINACs) applying 6 MV photon beams energy, calibrated in isocentric reference conditions: for a field size of 10 x 10 cm², 1 monitor unit (MU) corresponds to a dose of 1 cGy on the central beam axis at the maximum dose depth (Dmax 6 MV = 1.5 cm).

As the present work focuses on the degradation of the image quality during a time period, we used detectors with different clinical use (EPID age since the first irradiation), which were tested for several months (table 3-I).

<table>
<thead>
<tr>
<th>EPID</th>
<th>Clinical Use (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Operational Age</td>
</tr>
<tr>
<td>A</td>
<td>Linac 2</td>
</tr>
<tr>
<td>B</td>
<td>Linac 5</td>
</tr>
<tr>
<td>C</td>
<td>Linac 2</td>
</tr>
<tr>
<td>D</td>
<td>Linac 3</td>
</tr>
</tbody>
</table>

Table 3-I Representation of EPIDs clinical use, research period and lifetime (end-of-life).

After the end of the clinical panel life (EPID A), EPID C (from Linac 3) was mounted in Linac 2. At this point a new detector, EPID D, started being used for clinical applications in Linac 3, due to a new hardware specification unsupported by Linac 2. EPID B remained installed at Linac 5 all research period.

3.1.1 Image acquisition and calibration

For all image acquisitions, Heimann imaging software (HIS) (PerkinElmer) was used to control incoming signal data. The software is capable to demonstrate the functions of the RID (Radiation Image Detector). It detects automatically the size of the sensor and receives images of the detector in a 16 bit digitized data format (65535 steps). The images are displayed on the screen with 8 bit resolution.

The detector is connected to the iViewGT computer, which provides synchronization between the EPID and the Linac. The detector triggering, is controlled by the Detector Control Board (DCB) which uses the gun pulse control board to synchronize the reading of data from the detector, so that image data is read between radiation pulses. When the detector is triggered, a single image data packet is sent directly from the detector panel to the frame grabber in the PC, where appropriate software packages for signal processing, automatically apply a set of corrections to all images, including offset, gain and bad pixel corrections.
The Offset correction image (dark field - DF) is used to take out the specific dark current of the detector (leakage current) or other fixed signals. The Offset image is created and stored when the detector is not exposed to the radiation, and is then used to correct all subsequent images.

Sensitivity variations from pixel to pixel are taken into account by the Gain correction image (flood field - FF). The value of each pixel in the offset corrected image is divided by the corresponding pixel value of the normalized Gain to correct also the image dose calibration under different energy conditions. The processed and corrected image \( I(i,j) \) is performed by the application of equation 1, where a raw image \( (I_{raw}(i,j)) \) is acquired by the EPID and subtracted by the dark field image \( (DF(i,j)) \), divided by the normalized Flood Field image \( (FF(i,j)) \). \( FF_{mean} \) is the mean value of the FF\((i,j)\), used for image display.

\[
I(i,j) = \left( \frac{I_{raw}(i,j) - DF(i,j)}{FF(i,j)} \right) FF_{mean} 
\]  

(3.1)

The bad pixel map correction allows the ‘software repair’ of defected or non-responding pixels to enhance image quality. It is used to identify pixels that the response cannot correct for using gain or offset. The corresponding pixel values are set to the mean value of the neighbouring pixels. Before starting the acquisitions, the HIS software should be prepared for radiation tests, see appendix A. The corrections above described are linked to the imaging system software and applied to all images in daily tests acquisitions (Figure 3.3).

Figure 3.3 iViewGT portal image correction images Dark Field image (DF\((i,j)\)) (a), Flood Field image (FF\((i,j)\)) (b), and the bad pixel map (c). The processed image \( (I(i,j)) \) (e) is the result of raw image \( (I_{raw}(i,j)) \) (d) corrected and normalized image by using the equation 3.1.
The performed radiation exposures were made using several beam conditions and EPID acquisition modes. Each test was acquired under specific and controlled parameters described in the table 3-II.

<table>
<thead>
<tr>
<th>Photon Beam Energy</th>
<th>Linac 2</th>
<th>Linac 5</th>
<th>Linac 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 MV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulse Rate Frequency (PRF) (Linac max.) – MU/Min</td>
<td>400 MU/min</td>
<td>570 MU/min</td>
<td>490 MU/min</td>
</tr>
<tr>
<td>Frames per image</td>
<td>5 ; 10 ; 100 frs/img</td>
<td>10 ; 100 frs/img</td>
<td></td>
</tr>
<tr>
<td>Field Size (cm²)</td>
<td>20 x 10 ; 15 x 15 ; 20 x 20</td>
<td>15x15</td>
<td></td>
</tr>
<tr>
<td>Integration Time (EPID max.)</td>
<td>286.104 ms</td>
<td>434.616 ms</td>
<td>434.616 ms</td>
</tr>
<tr>
<td>Attenuation copper (Cu)</td>
<td>2 ; 4 ; 5 ; 7 ; 9 cm</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Input edge attenuation (Cu)</td>
<td>8 cm</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>polystyrene</td>
<td>16 cm</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Table 3-II Summary of general setup conditions and beam acquisition modes.

### 3.1.2 Image: format, Conversion and Analysis

*iViewGT* pixels are digitized in 16 bit resolution (2 byte information) and saved as 16 bit unsigned integer for acquired frames, in .His format which contain a file header of 68 byte and an image header of 32 byte that should be removed for further analysis.

Analysis on MatLab software requires .His to .Tif conversion, which was done by using the *ImageJ* software. The software *ImageJ* 1.29x (Wayne Rasband, National Institutes of Health, USA) have been used for all data conversion. With this program the raw data can be read and the encoded header removed, see conversion procedures in appendix B.

The analyses were performed using MatLab® - the Language of technical Computing Version 7 (R14), Version 7.3 (R2006b); and Version 7.4 (R2007a), Natick, Massachusetts.

### 3.2 Quality Control analysis using the QC-3V phantom

QC-3V phantom (department of physics, Manitoba Cancer Treatment and Research Foundation, Manitoba, Canada) is used to test the image quality from EPIDs. The phantom has progresses through several designs, currently model QC-3V (QC3) is in use (Figure 3.4). The dimensions of 13.5 x 11.3 x 3.6 cm³ incorporate aluminium, lead and PVC each 1.8 cm thick, bonded together.
EPID analysis was performed to assess the system spatial resolution, by differences on relative modulation transfer function (RMTF) from different spatial frequencies of 1 to 5 regions of interest (ROIs), organized as shown in table 3-III. Different resolution line pair gauge bars, generates a square wave modulation transfer function (SWMTF), which is a simple and fast way to measure the RMTF, according to Rajapakshe et al (1996) [95] algorithms (equation 3.2),

$$RMTF(f) = \frac{M(f)}{M(f_1)}$$ (3.2)

where the $M(f)$ is the amplitude modulation response at a spatial resolution bar patterns (ROIs 1 to 4) and $M(f_1)$ is the output modulation for the lowest frequency.

Based on Rajapakshe, the contrast-to-noise ratio is determined by the difference of the average gray values of the brightest (ROI\textsubscript{bright} – ROI 6) and darkest (ROI\textsubscript{dark} – ROI 11) homogeneous ROIs, divided by the average of pixel value standard deviations from the 6 uniform regions (ROIs 6-11) (equation 3.3),

$$CNR = \frac{ROI\textsubscript{bright} - ROI\textsubscript{dark}}{\sigma}$$ (3.3)

By using the QC3 standard measurements, physical parameters above described, are only restricted to 25 x 25 pixels ROI’s in the central region of EPID.

1 Pixel = 0.04 x 0.04 cm$^2$ => ROIs = 1.0 x 1.0 cm$^2$

As the QC3 phantom analysis is intended to be used in central beam axis (CAXIS), different tests were carried out to provide global information of system performance, by testing different EPID areas in terms of spatial resolution by RMTF, CNR and system noise.
The QC3 analysis was performed by using the Portal Image Processing System (PIPSpro) software according to procedures enclosed on PIPSpro User’s Guide by Masthead Imaging Corporation (Figure 3.5) described in appendix C. The PIPSpro quality control tests are based on Rajapakshe algorithms above described.

Non standard QC3 conditions were carried out according the following tests:
- Source phantom distance: Isocenter (100 cm);
- Orthogonal phantom rotation (90°);
- Phantom positioning on different EPID matrix areas;
- Source phantom distance from 70 to 157 cm.

Measuring the influence of non standard conditions was made by a combination of source phantom distance (EPID or isocenter) with standard and orthogonal phantom rotation and different matrix locations (Figure 3.6 and 3.7).
As only small EPID regions could be analysed, different areas were tested by moving the panel lateral and longitudinal in respect to the Gantry. By moving the EPID in orthogonal directions, the standard location of the phantom relation to the CAXIS was maintained which was a requisite to use the phantom, since the spatial frequencies bars are perpendicular to the field plane.

These tests were useful to find in which direction can we obtain higher spatial resolution that can be related to the system anisotropy, rather than a decrease in image quality by system degradation. The QC3 was positioned in the following positions at the Isocenter and EPID surface:

- Upper right (UR); UR90°
- Lower right (LR); LR90°
- Center; Center90°
- Upper left (UL); UL90°
- Lower left (LL); LL90°

Figure 3.6 QC3 placed at the Isocenter (100cm) to test the EPID spatial resolution for both the standard a) and orthogonal phantom rotation b). Test blurring effects due to the focal spot size and magnification.

Figure 3.7 QC3 placed at EPID touch guard (157cm). The spatial resolution is tested for different EPID areas, under standard and 90° rotation setup conditions.
EPID and Isocenter Source Phantom Distances (SPD) intend to measure the influence of the magnification and focal spot size on the spatial resolution, contrast and noise. For this purpose were also tested different SPDs, ranged from 70 cm to 157 cm, 20 by 20 cm, including the SPD of 100 cm (figure 3.8).

3.3 Spatial resolution by using an Edge Response technique

The edge response is how the system responds to a sharp straight discontinuity (an edge). The response of the EPID to an input sharp edge could be measured by calculating the distance required to rise from 10% to 90% intensity level across the edge. Edges in images can be easily generated by a discontinuity, based on field attenuation across the beam central axis (CAXIS) (figure 3.10a).

The iViewGT a-Si array is read out using 16 amplifiers chips, eight for each half of the imager. In this way, 16 image segments can be defined, each with an individual pixel response (figure 3.9).

For practical research reasons, we have called these segments “subpanels”. Each subpanel consists of an array of 128 x 512 pixels (51,2 x 204,8 mm) and they can be individualized from the global matrix as shown in Table 3-IV.
The edge response for different EPID subpanels, were obtained in two orthogonal edge orientations (x, y). This way the whole system could be characterized in terms of spatial resolution in the spatial domain.

For this analysis were built analysis tools, to measure the edge response of 3 horizontal and 7 vertical edges. For each Horizontal edge it was possible to analyse half of detector subpanels. By moving the EPID laterally (related to the gantry), it is possible to cover the entire subpanel matrix (16 subpanels) Horizontal red lines in the figure 3.9.

As the subpanels are aligned 2-by-2 in the vertical direction, the maximum coverage of subpanels for each vertical edge are only two. As the EPID arm support cannot move completely out in relation to the CAXIS, the maximum achievable edges were 7 (3 right side + CAXIS + 3 left side) which means that only 12 of 16 subpanels could be evaluated in (x) direction (2-7 and 10-15).

Different edges were generated by using large copper slabs that cover an approximate 35cm of the 41cm length of entire panel, in which were it was possible to investigate the edge response of ~85% of the full matrix area.

<table>
<thead>
<tr>
<th>Upper EPID subpanels</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. (1:512, 1:128)</td>
</tr>
<tr>
<td>2. (1:512, 129:256)</td>
</tr>
<tr>
<td>3. (1:512, 257:384)</td>
</tr>
<tr>
<td>4. (1:512, 385:512)</td>
</tr>
<tr>
<td>5. (1:512, 513:640)</td>
</tr>
<tr>
<td>6. (1:512, 641:768)</td>
</tr>
<tr>
<td>7. (1:512, 769:896)</td>
</tr>
<tr>
<td>8. (1:512, 897:1024)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Lower EPID subpanels</td>
</tr>
<tr>
<td>9. (513:1024, 1:128)</td>
</tr>
<tr>
<td>10. (513:1024, 129:256)</td>
</tr>
<tr>
<td>11. (513:1024, 257:384)</td>
</tr>
<tr>
<td>12. (513:1024, 385:512)</td>
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<tr>
<td>13. (513:1024, 513:640)</td>
</tr>
<tr>
<td>14. (513:1024, 641:768)</td>
</tr>
<tr>
<td>15. (513:1024, 769:896)</td>
</tr>
<tr>
<td>16. (513:1024, 897:1024)</td>
</tr>
</tbody>
</table>

Table 3-IV Subpanels in the 1024 x 1024 matrix
To perform the Edge response analysis in larger EPID areas, the following materials and settings were introduced:

- $23 \times 10 \times 8 \text{ cm}^3$ copper slab aligned to field CAXIS (4 copper slabs aligned at the isocenter each of $23 \times 10 \times 2 \text{ cm}^3$), see Figure 3.10a and 3.10b):
  - 8 cm Cu thickness – reduce the influence of random noise
  - CAXIS alignment – follow the field divergence
  - Source table distance (STD) = 100 cm

- Field size: 20 x 10 (edge mid-length of width)

- 1D Analysis: horizontal and vertical edges by applying a $90^\circ$ rotation generate orthogonal edges for each subpanel.

- Moving EPID in (x,y) directions – measurement in different subpanels (Figure 3.10c)

- Frames per image: 10 and 100frs/img

Figure 3.9 EPID matrix (1024x1024), showing the individual subpanels ranged from 1 to 16 (8+8). The red lines represent the 3 horizontal and 7 vertical edges used for one-dimensional edge response analysis. Lateral and longitudinal EPID movements are done in respect to the Gantry head.
3.3.1 MatLab® Edge response analysis

The measurements of the step function were performed by applying different algorithms, each one for distinct edge positions related to the EPID matrix.

MatLab routines for Edge selection and verification (see Appendix A.I):

- “Subpanel selection”
- “Vertical Edge”
- “Horizontal Edge”

By selecting a predefined edge image, the algorithms above mentioned, allows a discrimination of the edge surface to be analysed. When selected a specific perpendicular line to the edge spread function (ESF), the software generates the automatic normalization, to transform the pixel min-to-max intensities, into 0-to-1 values. The analysis was then performed based on the spatial difference from 10% to 90% of the normalized Edge Spread Function.

The measurements were done for all acquired edges as following described (Figure 3.9c):

- 7 Vertical edges - 10-by-10 mm (perpendicular analysis along the edge);
- 3 Horizontal edges - 5-by-5 mm (perpendicular analysis along the edge).

Figure 3.10 Setup positioning of 8 cm copper edge a) built with four copper slabs (23 x 10 x 2 cm³) aligned at CAXIS b) and the respective measured markers for edges (horizontal and vertical) localization at the EPID surface c).
Input horizontal edges intent to measure vertical edge responses (y direction), and in an opposite way, vertical edges are used for horizontal edge response measurements (x direction), see Figure 3.11.

The Edge response was extracted by using the following MatLab algorithm (see Appendix D.1):

- **“Slope”** analysis (10% to 90% response)

By applying this function the software detects the edge slope in terms of percentage of variation and automatically finds the index sample numbers surrounding the 10% and the 90% from the ESF. This function calculates the exact distance between two interpolated indexed positions. The subtraction of the two spatial positions, allows the edge discrimination in terms of pixel index number position. By knowing the pixel size (0.4 mm) and magnification at the isocenter distance (1.6) the edge response can be converted in distance (mm) (Figure 3.12).

Figure 3.12 The system output response to the input physical edge (8 cm copper) represents the Edge Spread Function, where the Edge Response is the spatial distance (index pixel) from the index 90% to index 10% of respective percentage response.
3.4 System Noise by using a Subpanel Image Noise technique

The noise characteristics into x-ray imaging system process means that the system is no longer deterministic and that its performance must be analysed using statistical methods. The simplest measure of output noise is given by the standard deviation of the intensity over the image of a uniform field, with or without a homogeneous attenuator.

When measuring the SNR the standard deviation represents noise and other interferences. In these cases, the standard deviation is not important by itself, but only in comparison to the mean pixel values, which rise to the term: signal-to-noise-ratio (SNR), measured in a simple way by the mean value of means of each line of each subpanel, divided by the mean of the standard deviations for the same subpanel (digital signal processing). The combination of all subpanels SNRs by the SNR calculation can give a measure of random and structural noise (fixed noise pattern) for all tested area.

Different attenuation levels and averaged image frames were applied to set the optimal conditions for a precise measurement of the damage in the subpanels, by reducing the quantum noise influence. The influence of a different source attenuator distances was also tested, i.e. shadow tray and table (isocenter).

As the random noise present in the images varies with different beam and imaging system setups, statistical fluctuation in the number of x-rays quanta absorbed will always be unpredictable but not significant for a reduction in the image quality. A reduction in image quality is always accompanied by a structural noise (fixed pattern) mixed by a random noise.

As the noise in the images becomes more visible in time due to defected and less responding pixels (isolated, in-line or clustered), the measurements of these parameters can demonstrate the system intra-variability.

To perform the subpanel image noise analysis, the following materials and settings were introduced:

- **Field size:**
  - 15 x 15 (isocenter – 100 cm) = 24 x 24 (EPID 160 cm) = 600 x 600 (pixels)
  - 20 x 20 (isocenter) = 32 x 32 (EPID) = 800 x 800 (pixels)
- **Frames per image:** 5, 10 and 100 frs/img
- **Copper attenuation – 15 x 15 (Figure 3.12a)**
  - 5 and 9 cm (shadow tray – Source Tray Distance = 67 cm)
- **Copper attenuation – 20 x 20 (Figure 3.12b)**
  - 4 cm (shadow tray and isocenter distance)
    - (2x) - 2 copper slabs (23 x 10 x 2 cm$^3$) on top of each other.
- **Polystyrene – 20 x 20 (Figure 3.12c)**
  - 16 cm (isocenter at half-thickness (92 cm))
The measurements of Subpanels Image Noise were performed by applying different algorithms that can generate automatic numbers of means and standard deviation for each subpanel.

MatLab routines for Subpanels array selection and analysis (see Appendix D.II):

- “Analysis SIN 15 x 15”
- “Analysis SIN 20 x 20”
- “Function_std_mean”

These algorithms provide a fast and accurate selection of each subpanel within the 1024 x 1024 matrix. By inputting an image, the program decomposes the 2D matrix into 16 subpanels which are introduced in a 3D matrix as multidimensional array of 512 by 128 by 16 (figure 3.13).

The Selection of the field size to be analysed depends on the field coverage attenuated area, due to the (x,y) dimensions of the attenuator material. A field size of 15x15 and 20x20 at the isocenter, corresponds to a 24x24cm$^2$ (600x600 pixels) and 32x32cm$^2$ (800x800 pixels) at the EPID surface, respectively.

In practice, the area for analysis should take into account the radiation penumbra from the beam edges which could influence the statistical measurements for each subpanel. From processed images were taken out ~1.5cm (0.75cm for each field edge), which corresponds to an analysis of ~23.3 x 23.3 cm$^2$ and ~31.3 x 31.3 cm$^2$. This approach was useful for more accurate analyses without the influence of different image gradients (at the field borders) (Figure 3.14).

As a multidimensional matrix is composed, the system can read each row or column of each subpanel at the same time. The purpose of this test is to analyse the noise present on each subpanel in the readout direction (x). Therefore it is possible to evaluate 8192 (16subpanels x 512 rows) means and standard deviation for all subpanels at the same time.
For each subpanel in analysis within a specified field size (above described) were calculated row-by-row (x-direction), the mean and the standard deviation. The results were then evaluated in a global way by taking the mean of means (µ) and the mean of standard deviations (ρ). The Subpanel Image Noise by the SNR was calculated for each subpanel by equation 3.4:

\[ S_{NIR} = \frac{\mu}{\rho} \]  

(3.4)
3.5 System sensitivity by Non Average Pixel response

EPID Pixel response to high radiation beams used in radiotherapy is always influenced by different kind of variables, like Linac output, intrinsic detector/electronics characteristics and signal A/D conversion. External variables as different objects densities and thicknesses have always an important role on the input to output transfer (figure 3.15). As the system responds to different beam parameters and imaging system setup conditions, this experiment should be able to detect the matrix Non Average Pixel (NAP) response for different attenuation levels and frame/dose per image, see section 3.5.1.

Figure 3.15  Schematic representation of an attenuated field 15x15cm² a), which irradiates an approximated matrix area of 24x24cm² at 160cm from the focus. The image frame integration is displayed in the imaging system as shown in b).

The material and methods used for this test are the same of previously described in the section 3.4. The analysis consists in the acquisition of open and attenuated fields with 6 MV photon beams and different number of frames per image. A pair of images (open and attenuated fields) acquired with the same frames are then processed using homebuilt MatLab® algorithms, which can automatically generate numbers and graphs of variability of pixel response.

3.5.1 MatLab NAPs analysis

The NAPs were performed in a time trend evaluation for checking the influence of the ageing effects on the pixel response in the presence of different attenuation levels and frames per image.

Developed MatLab® routines for NAPs detection and analysis (see Appendix D.III):
- "badPixelcounter"
- "correctForFlatteningFilter"
The combination of the mentioned routines allows the creation of a sub matrix set, due to the size of processed attenuated fields, which can be matched pixel-by-pixel with open fields. The ratio between the open \( I_0 \) and attenuated fields \( I_{\text{att.}} \) is firstly corrected for beam angle divergence \( I_{\text{dCorr}} \) in the attenuation material as also for the flattening filter and gain effects (polynomial fit for each matrix line) (Figure 3.16).

\[
\frac{I_0}{I_{\text{att.}}} = \frac{I_{(\text{log})}}{I_{\text{dCorr}}}
\]

Figure 3.16 Image correction procedures for the non average pixel response analysis. The image \( I_{(\text{log})} \) represent the \( \mu x \) (linear attenuation coefficient x distance) relationship between open field \( I_0 \) and the attenuated fields \( I_{\text{att.}} \). the angle correction image \( I_{\text{dCorr}} \) correct for the small differences on the path length throughout the copper slab attenuator. The best resultant polynomial fit from each \( I_{\text{dCorr}} \) raw (ii) is then divided pixel-by-pixel to correct the circular flattening filter effect.

Figure 3.17 Non Average Pixel calculation by setting 2.5 standard deviation limits. The pixels intensities on the image corrected for the flattening filter effect \( I_{\text{Flat}} \) are quantified and selected according statistical limits by the standard deviation. Only clustered (>2) pixels quantified in a 5 x 5 matrix outside the limits can be assumed and counted as NAPs.
The NAPs identification is made by statistical variation around the polynomial fit, which represents an optimal approximation of the average pixels. The NAPs are the result of statistical differences of pixels intensities around the mean, measured by presetting a superior and inferior statistical limit based on standard deviation from the pixel sample matrix. Only the clustered NAPs were counted (> 2 pixels in a 5 x 5 pixel matrix) and inserted in their spatial matrix relative position for graphical display (Figure 3.17).

When using a 4 cm copper slabs for 20x20 cm² analysis, done by two copper slabs placed together face to face, it is necessary to correct for the mid-line artefact by replacing intensity pixels in this region, for the matrix mean pixel value normalized to “1”.

3.6 Subjective Clinical Evaluation

Clinical portal images (PI) for treatment setup localization and verification, is nowadays a request for the quality assurance of a Radiotherapy treatment delivery. Routine checks of planned fields and isocenter localization must be done prior the treatment and during the treatment. According the institution protocols PI should be taken in the first treatment fractions, weekly and when isocenter position or field setup change. Errors or uncertainties in set-up positioning during the treatment should be detected by using the verification obtained by EPIDs.

As image registration, reporting and documentation become an issue for treatment quality assurance, EPIDs take an important role in all clinical situations, which confer more reliable, fast and accurate treatment field setup verification by a human decision maker.

The quality of clinical portal images may influence the prescribed dose to predefined planning target volumes and organs at risk, thus it may be of great importance for treatment outcomes.

The EPID damage and consequent image quality occurs with ageing by the radiation history (absorbed dose in the lifetime).

Quantification of image degradation by measuring EPIDs physical parameters should be correlated with clinical examination of portal images that can result in a prediction of the EPID damage in time, by knowing which numbers, rates, ratios, etc. are related to an increase on negative subjective evaluation (clinical examination of portal images).

Image degradation in time, can be subjectively evaluated by the clinical users. As portal image artefacts become more visible in certain regions, the variability of clinical usability varies from observer to observer, which means that this evaluation is dependent on individual subjectivity.

The quantification of subjective evaluation of clinical portal images has been performed by the EPID users committee (five radiotherapy technologists) (table 3-V) using a structured questionnaire. The aim of this questionnaire is to access the expertise of clinical portal imaging
users by using a Likert scale that range between “1” (strongly disagree) and “5” (strongly agree), for the less and more clear images respectively (see Appendix E-I and E-II).

<table>
<thead>
<tr>
<th>Anterior/Lateral fields</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1. The bony structures can be easily recognized</td>
</tr>
<tr>
<td>1.2. The bony structures edge can be easily delineated</td>
</tr>
<tr>
<td>1.3. The markers can be easily identified and matched</td>
</tr>
<tr>
<td>1.4. Artefacts/noise are masking the bony structures intensity</td>
</tr>
<tr>
<td>1.5. The overall image quality is enough for a precise verification</td>
</tr>
</tbody>
</table>

Table 3-V Clinical test for subjective portal image evaluation by clinical user’s

The variations rated from 1 to 5, intent to measure different degrees of perception of radiographic image quality. For practical samples evaluation, the score from overall image quality and the ability for recognize and delineate anatomical structures were summed for analysis (Questions 1.1, 1.2 and 1.5). Since they are meant to be related to each other an increase in sample size results in an increased power.

The questions related to detectability of fiducial markers inside the body (Q.1.3) and artefacts detection in the images (Q.1.4) were analysed individually. The questionnaire was applied during the research period (about 11 months) for the four tested EPIDs (A, B, C and D) and for both the pelvis and thorax anatomical locations, which represents a 45 treatment isocenter localizations plus 2 (AP and lateral views) for a clinical examination. Therefore, 90 images were analysed by 5 individual user’s which means that 450 observations were performed during this research period. Anterior and lateral images were taken for the same patients in different EPIDs to reduce the influence of inter patient variability (figure 3.18).

![Figure 3.18](image)

Figure 3.18 Portal images for (a) antero-posterior (AP) and (b) lateral pelvic fields, and thorax AP (c) and lateral (d) fields.