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Image Quality Control in Digital Radiology

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Abstract Image Quality Control is an important factor that contributes to the improvement of patient care and overall diagnostic accuracy. Our purpose was to elaborate Quality Control Charts and demonstrate the importance of image quality control in a radiology department. A total of 37 random samples, composed of 30 x-ray exams each, were selected and analyzed. Primarily, data about image non-conformities were compiled to make three distinct Quality Control Charts. Secondly, improvement and corrective actions were suggested. Our results allowed us to identify and account for different types of non-conformities found on x-ray images. This illustrates the importance and necessity for the implementation of an adequate Image Quality Control in Digital Radiology.

Keywords Image Quality, Quality Control, Control Chart, Non-conformities

1. Introduction

Nowadays medical imaging is essential and greatly used as an aid to medical diagnoses. Through the evolution of medical imaging equipment there is an increased association with digital technology, the implementation of image quality control becoming essential.

The radiological image must have the quality needed for medical diagnosis. It should be obtained on the first attempt in order to avoid repetition of exams and the consequent exposure of patients to a higher dose of radiation. Technical errors are present when a radiological exam is not performed using the appropriate protocols, or is inappropriately processed[1]. To assess the quality of the radiological images produced it is necessary to monitor the production process. This monitoring can be accomplished through the development of quality control charts previously defined, where nonconformities can be identified.

Through research conducted on quality management and quality aof radiological images, the vast majority of studies performed are concerned with radiological equipment quality control[2][3] to assess their functionality[4].

It is very important for equipment to comply with legal requirements[4], but it is also essential that the quality control of the radiological image encompasses the entire production process and therefore radiographer performance cannot be forgotten. Thus, there is a need to accurately assess whether the images produced, possess enough quality to be used in a clinical diagnosis.

The main objective is to study the quality control of digital radiographic images, through the elaboration of Quality Control Charts. As specific objectives: To assess the quality of digital radiographic images; To plan and suggest corrective and improvement actions; To contribute to the improvement of image quality and medical diagnostic.

1.1. Research Questions

1. Which quality control chart best suits a radiology department?

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2. Will there be a large number of non-conformities?
3. What are the most common types of non-conformities?
4. Which corrective actions should be suggested to improve image quality?

2. Methods

In this section we present the methodology followed in conducting this research. We characterize the type of study, its location, the sample, the instrument, ethical issues and the procedures for collecting, processing and analyzing data.

2.1. Type of Study

This is a case study that employs quantitative methods as we have to quantify the non-conformities existing on digital radiological images.

2.2. Location

All data was collected from the radiology department of one major public hospital.

2.3. Sample

The target population of this study comprises a series of conventional radiology exams. The set of exams concerns the following anatomical structures: Thorax, Abdomen and Foot x-rays. The sample is a stratified random sample. The probabilistic sample is a selection procedure in which each element of the population has the same probability of being selected[5].

The X-ray exams selected were performed to the following anatomical structures: Chest (postero-anterior (PA), anteroposterior (AP) and lateral incidence), abdomen (PA and AP) and Foot (AP and internal oblique).

This study comprises 37 samples of conventional radiology exams composed of 30 elements each. 640 are chest exams, 340 abdomen exams and 130 foot exams.

2.4. Variables

The type of variable used is an attribute variable.

2.5. Instrument

A specific checklist was made for this study. Contained in the header of the instrument sheet there is the following information: date, hour and the number of the exam.

On the instrument there is information about:

- Total number of selected exams;
- Type of exam;
- Anatomical Structure;
- Conform Image;
- Non-conform Image.

In the end of the sheet there is information regarding the total number of conform and non-conform exams in the sample, as well as information about the radiographer´s shift.

The program used for image visualization was the *"Magic Web System"*.

The criteria to classify an exam as Conform (C) or Non-conform (NC) were made using guidelines on how to perform and classify radiology exams[6][7]. We considered conform when they are present in the study, in other words, requirements were obtained (quality criteria), previously established, as listed below:

- Image processing: Radiographer ID, Side identification, Adequate Contrast;
- Correct Patient Positioning: no overlapped structures, complete view from the study area;
- Image artefacts: absence of metallic artefacts, clean Image Plate (IP), no movement artefacts.

2.6. Ethical Issues

In accordance to institutional guidelines, the approval of this study was obtained from the review board and the data of the patients selected were kept confidential.

2.7. Data Processing and Analysis

The collected data was introduced in *Microsoft Excel Office 2007*, to calculate the control limits and construct the Control Charts by type *p*, *np* and *c* (Table 1). These charts classify a product as Conform or Non-conform and assess the overall image quality.

Taking into account the sample size Type *p* Control Charts were chosen to determine the average percentage of non-conform exams and Type *c* Control Charts to identify the total number of Non-conform exams on each sample [8][9].

Table 1. Formulas for calculating the Control Charts Limits by type *p*, *np* and *c*

Type of Chart	Central Limit	Superior Central Limit	Inferior Central Limit
p	$\bar{p} = \frac{\sum pi}{n}$	$\bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$	$\bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$
np	$\overline{np} = \frac{\sum xi}{n}$	$n\bar{p} + z\sqrt{n\bar{p}(1-\bar{p})}$	$n\bar{p} - z\sqrt{n\bar{p}(1-\bar{p})}$
c	$\bar{c} = \frac{\sum c}{n}$	$\bar{c} + 3\sqrt{\bar{c}}$	$\bar{c} + 3\sqrt{\bar{c}}$

We also made determine the Warning Control Limits for the standard deviation (δ) – inferior and superior to the central limit (Table 2).

Table 2. Formulas used for calculating the Warning Control Limits

Type of Chart	Central Limit	Sup. Central Limit	Inf. Central Limit
p	$\sigma p = \sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$	$\bar{p} + 1.\sigma p$	$\bar{p} - 1.\sigma p$
		$\bar{p} + 2.\sigma p$	$\bar{p} - 2.\sigma p$
np	$\sigma np = \sqrt{n\bar{p}(1-\bar{p})}$	$n\bar{p} + 1.\sigma np$	$n\bar{p} - 1.\sigma np$
		$n\bar{p} + 2.\sigma np$	$n\bar{p} - 2.\sigma np$
c	$\sigma c = \sqrt{\bar{c}}$	$\bar{c} + 1.\sigma c$	$\bar{c} - 1.\sigma c$
		$\bar{c} + 2.\sigma c$	$\bar{c} - 2.\sigma c$

For the analysis of the sample distribution trend, 4 of 8 rules states by ISO 8258:1991 were selected. The quality process is out of statistical control when at least one of the following rules occurs:

1. Rule nº1: One dot/point above the control limits;
2. Rule nº2: 9 consecutive points on the same side of the Central Line;
3. Rule nº3: 6 consecutive points upward or downward;
4. Rule nº4: 14 point upwards or downwards alternately;

3. Results

In this section we present the results of our research. Firstly, the data used to determine the Control Limits of the three control charts (Control Charts *p*, *np* and *c*). Secondly, we demonstrate the respective Control Graphics. Thirdly, the data related with the number of Non-conformity exams and the type of Non-conformities found.

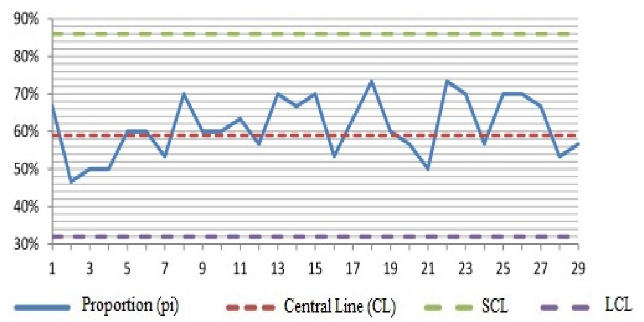
3.1. Control Charts Preparation

By grouping all data, we built several Control Charts:

- **Type p Control Chart**

A Type *p* Control Chart was made based on the proportion of Non-conformity exams of the samples. To ensure the quality and statistical control of our samples, an adjusted Type *p* Control Chart was made in order to eliminate outliers. The values of the Central Limit (CL), Superior Central Limit (SCL) and Lower Central Limit (LCL) were set to 59%, 86% and 32% respectively (Graphic 1).

The adjusted Type *p* Control Chart does not present any sample outside the Control Limits, indicating that the quality of our samples is under statistic control. These values will be used as the standard Quality Control referential for Type *p* Control Charts.

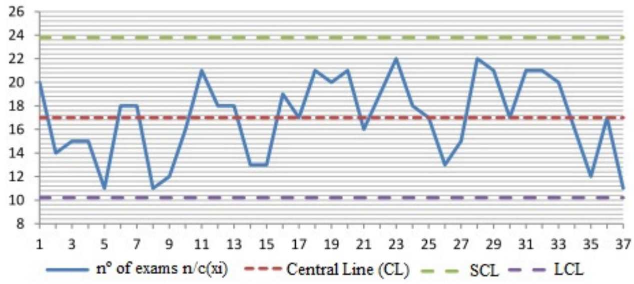


Graphic 1. Adjusted Type *p* Chart composed of 29 Samples

- Type *np* Control Charts

A Type *np* Control Chart was made based on the total number of non-conformity exams of each sample. The values for the Central Line (CL), Superior Central Limit (SCL) and the Lower Central Limit were 17, 23.79 and 10.21 respectively (Graphic 2).

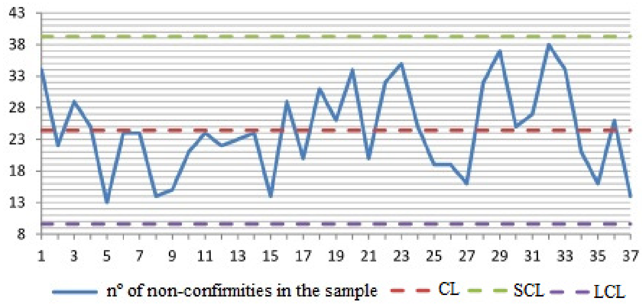
There are no samples outside the control limits (Graphic 2), therefore it can be used as the standard Quality Control referential for Type *np* Control Charts.



Graphic 2. Type np Control Charts

- Type c Control Charts

A Type *c* Control Chart was made based on the total number of Non-conformities of each sample. The values for the Central Line (CL), Superior Central Limit (SCL) and the Lower Central Limit were 24.43, 39.26 and 9.60 respectively (Graphic 3).



Graphic 3. Type c Control Chart

There are no samples outside the control limits (Graphic 3), therefore it can be used as the standard Quality Control referential for Type *c* Control Charts.

3.2. Analysis of x-ray Exams Collected

Of all 1110 x-ray exams observed (37 samples, composed of 30 elements each) of the chest, abdomen and foot, there is a larger number of Non-conform exams than Conform exams with 57% and 43% respectively (Table 3).

Of the 640 chest x-rays analysed, 40% were were Conform and 60% were Non-conform. Of the 340 abdomen x-rays analysed, 46% are Conform and 54% are Non-conform. Relatively to foot x-rays, 51% are Conform and 49% are Non-conform (Table 3).

Table 3. Conform and Non-conform exams according to anatomical structure

Anatomical Structure	Conform Exams		Non-conformity Exams	
	Total	Percentage	Total	Percentage
Chest	259	40%	381	60%
Abdomen	156	46%	184	54%
Feet	66	51%	64	49%
Total	481	43%	629	57%

As for the observed anatomical structures, the larger number of Non-conform exams correspond to chest x-rays (60%), followed by abdomen x-rays with 54% and foot x-rays with 49% (Table 3).

3.3. Analysis of the Type of Non-conformities Identified

An x-ray exam was considered Non-conform when at least one or more images, that constitute the radiographic study, did not meet the quality criteria set for this study (Table 4).

Non-conformities were grouped into 3 groups:

1. *Incomplete/incorrect image process;*
2. *Incorrect Positioning;*
3. *Artefacts;*

Image processing is divided into 2 subgroups – Non-conformities that do not affect image interpretation (i.e. "*right*" or "*left*" side marking and radiographer´s identification) and Non-conformities that affect image quality (i.e. inadequate contrast). For *Incorrect Positioning* the following Non-conformities were identified: *overlapped anatomical structures, missing anatomical structures and patient rotation*. The Artefacts group had the following Non-conformities: *metallic artefacts, Image Plate (IP) dirt/grains and movement artefacts*.

Table 4. Classification of Non-conformities

Types of Non-conformities	Designation
Incomplete or incorrect processing	Image was not archived properly. Collimation, contrast, side identification and radiographers id missing
Radiographer ID missing	Image does not have identification
No side identification	Right or Left sign missing
Inadequate Contrast	Image is overexposed or underexposed compromising diagnosis
Incorrect Patient Positioning	At least on criteria for image evaluation related to anatomical structures is missing (i.e. overlapped structures, missing or incomplete)
Artefacts	Unwanted image or external structure
Metallic Artefacts	Unexpected metallic artefacts
Dirt on Image Plate (IP)	Image presents unwanted dirt (i.e. white dots)
Movement Artefacts	Image shows signs of patient movement or incorrect definition of anatomical structures (i.e. blurred image)

A total of 904 Non-conformities were identified: 64.16% are related with *incorrect or incomplete image processing*, 27.10% to *incorrect positioning* and 8.74% to a*rtefacts* (Table 5).

Incorrect or incomplete image processing, are responsible for more than half of Non-conformities in the sample. Taking into account the group subdivision into Non-conformities that affect and Non-conformities that do not affect image quality and interpretation, 61.84% of Non-conformities identified correspond to criteria that do not affect image quality and interpretation. Table 6 represents the analysis of the number of non-conformities identified for different anatomical structures (Chest, abdomen and foot x-rays).

Table 5. Non-conformities identified

Non-conformity Group	Type of Non-conformity	nº n/c	Frequency
Incomplete/ Incorrect Processing	No side ID	289	64.84%
	No Radiographer ID	262	
	Inadequate Contrast	21	2.32%
Incorrect Positioning	Overlapped Structures	26	27.10%
	Incomplete/Missing Structures	141	
	Patient Rotation	78	
Artefacts	Metallic	5	8.74%
	Dirt on IP	73	
	Movement	1	

Table 6. Non-conformities by anatomical structure

N/C Group	Type of N/C	Chest	Abdomen	Foot
Incomplete or incorrect processing	No side	212	67	18
	identification			41
	No Radiographer ID	141	80	
	Inadequate Contrast	15	4	2
Incorrect Patient Positioning	Overlapped Structures	25	0	1
	Missing Structures	74	60	7
	Patient Rotation	48	27	3
Artefacts	Metallic	1	4	0
	IP Dirt	48	22	3
	Movement	1	0	0
Total		565	264	75

Chest x-rays correspond to the greater number of Non-conformities of the sample (63%), followed by abdomen x-rays (29%) and foot x-rays (8%). For all exams analysed, regarding *incomplete or incorrect processing*, there is a large number of Non-conformities in images with *no side* and no *Radiographer's identification* (Chest – 353; Abdomen – 147; Foot – 59).

The second group with more Non-conformities are images with *missing anatomical structures*, followed by images showing *patient rotation*.

On chest x-rays there is a large number of images with *missing anatomical structures* (74 Non-conformities), mainly the pulmonary apexes and the costo-phrenic angles. As regards the 60 Non-conform abdomen x-rays, there are coexisting images in which the spine is not on the centre of the image. On foot x-rays there are 7 images with *anatomical structures missing*, or *not completely visualized*. Most *missing anatomical structures* are due to *incorrect patient positioning* in relation to the equipment or central x-ray beam.

On chest x-rays there are 48 Non-conformities related to *patient rotation*, represented by the lack of equidistance between the external extremities of the clavicles and the central line of the column. On abdomen x-rays (27 Non-conformities) *patient rotation* causes *incomplete anatomical structures*, such as the iliac bone.

On foot x-rays there are 3 Non-conformities caused by *patient rotation*.

The most important artefact present on x-rays are *dirt artefacts* on the Image Plate (IP) (Chest – 48; Abdomen – 22; Foot – 3);

There are a large number of Non-conformities on chest x-ray, however, these are the most common type of exam performed (Graphic 4).

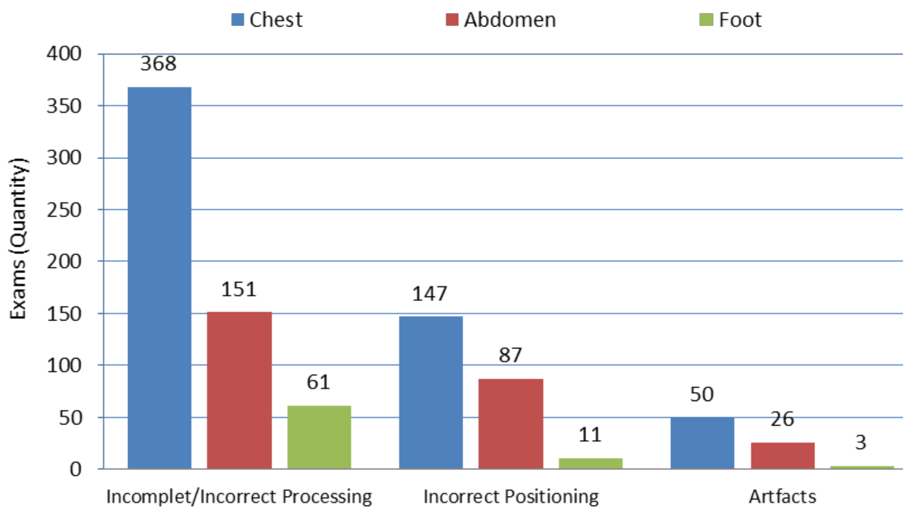
Radiographer´s Work Schedule

All exams were selected according to radiographer´s work schedule and shifts. The morning shift is from 8h00 a.m. to 2h00 p.m., the afternoon shift is from 2h00 p.m. to 8h00 p.m. and night shift is from 8h00 p.m. to 8h00 a.m. Each shift corresponds to a total of 10 exams. On graphic 5 conformities and non-conformities are grouped by shifts.

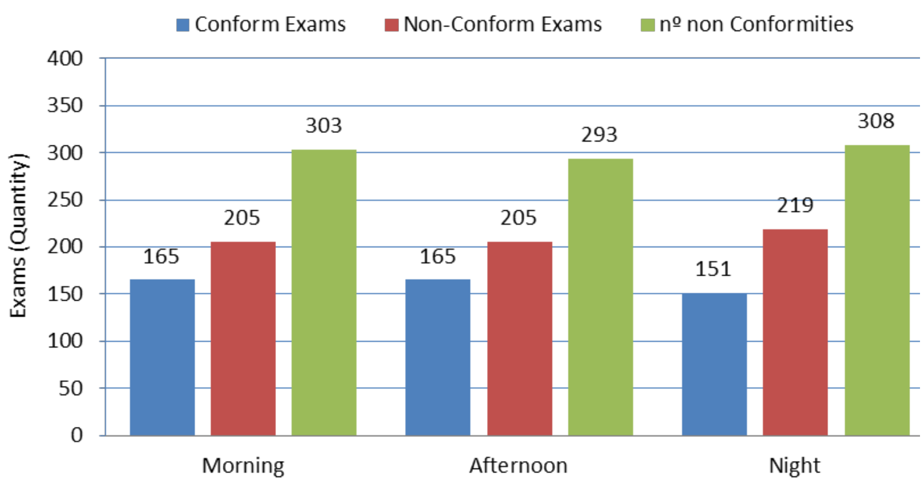
There are more Non-conform exams on every shift than Conformity exams (Graphic 5). The night shift represents the larger number of Non Conform exams, as well as the larger number of Non-conformities.

4. Discussion

A study on the evaluation of mammography in Australia, used two different benchmarks for evaluating mammography exams: the PGMI and the EAR (10). The first classified images as Perfect, Good, Moderate and Inadequate and the latter as Excellent, Acceptable and Repeat. In spite of the great subjectivity of these two benchmarks, the importance of radiological image quality in the detection and identification of breast tumors was clearly shown. Another study assessed technical errors in intraoral peri-apical radiographs[11] where 82.74% presented technical errors, but 50,51% were acceptable. This results shows us the importance of image quality improvement, because even if some images are acceptable for medical diagnosis, its interpretation becomes much more difficult.



Graphic 4. Non-conformities identified by anatomical structure (Chest, abdomen and Foot x-rays)



Graphic 5. Distribution of Conform Exams, Non-conform exams and number of Non-Conformities

In our research the Control Chart that better suits the Image Quality Control of a Radiology Department is the Type *p* Control Chart, based on the proportion of Conform and Con-conform exams with 70% for the Central Limit, 95% for the Superior Control Limit and 45% for the Inferior Control Limit. However, due to an abnormal variation new Control limits were set as well as Warning Limits according to ISO 8259 (8) with 59% for the Central Limit, 86% for the Superior Control Limit and 32% for the Inferior Control Limit. To identify outliers, the types of Non-conformities outside control were identified. A total of 76 Non-conformities related with images absent side or Radiographers identification, followed by the incorrect positioning group with 40 Non-conformities were identified. The Type *p* Control Chart presents an extremely high value, allowing for a high “error tolerance”. In other words, it is acceptable that in a sample of 30 exams, an 86% of Non-conform exams is considered acceptable. It is also worthy to note that despite this value, 61.84% of Non-conformities identified correspond to criteria that do not affect image interpretation and diagnosis (Table 5). According to the labour instructions set by the radiology department, where the study was performed, all exams must have the Radiographers Identification as well as a mark labelling the “right” or “left” side of the anatomical structure.

In the other groups, 27.10% correspond to incorrect patient positioning and 8.74% to artefacts. Chest x-rays represent the exams with more Non-conformities (63%), followed by abdomen exams (29%) and foot exams (8%). These results may be explained by the fact that chest x-rays are the most common type of exam.

Other studies have a much lower “error tolerance” but they also present a higher number of Non-conformities related with *incorrect positioning, image processing and inadequate image contrast*[12].

As recommend when is used this type of instruments[13], a fishbone diagram also called Cause–and–Effect Diagram was constructed to help identify the probable causes that led to incorrect positioning. The main causes were bedridden patients and children who could not cooperate with the radiographer.

Although the Quality Control of Radiographic is not present in many radiology departments, taking recently its first steps, the existence of adequate Digital Image Quality Control is crucial.

In the only study of this type carried out in a Public Portuguese Hospital, the implementation of an image quality control program allowed for a reduction of Non-conform exams of 39.78%[12].

5. Conclusions

The existence of adequate quality control carried out on radiological images, allows greater uniformity of the final product and decreases the variability of exam execution, regardless of the Radiographer performing the exam.

This type of control allows us to find out the causes of variability when it is out of statistical control, making corrective actions easier to apply.

We can infer there is a necessity for improvement standardization in radiographic imaging that can be achieved through the implementation of a Quality Control of Radiographic Images.

5.1. Limitations

- The virtual absence of studies related to this field of research, making results comparisons difficult;
- Since this is a case study it is not possible to extrapolate results to other radiology departments;
- Due to schedule limitations only three anatomical structures were studied;

5.2. Improvement Suggestions

- This study focused on 3 main types of radiographic exams (chest, abdomen and foot x-rays). Further research is needed to implement the same methodology on other anatomical structures.

5.3. Recommendations

To minimize the occurrence of non-conformities, corrective actions must be applied, such as:

- The expansion of Quality Control Charts and Results through several institutions;
- The performance of x-ray exams following established guidelines;
- Always take into account collimation and the irradiated area of the patient;
- Periodic *Image Plate* maintenance;

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