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Comparative study of the accuracy of measurements on X-ray images of the skull in the analog and digital systems in Benin

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Abstract

Medical imaging has been emancipated mainly following the evolution of computers in the 20th century. Thus, from conventional radiography, we move to digital radiography which offers many advantages. The objective of this study was to investigate the accuracy of measurements on conventional radiographic images in the Atlantic and Coastal departments. It is a descriptive cross-sectional experimental study with prospective data collection from August 6 to November 10, 2021. The plate named "Collimator test tool" and the human phantom head was used. An observation grid allowed us to collect information concerning the characteristics of the various digitizers. We realized on the plate and on the head of the human phantom radiographies in an analogical and digital system. Then we had to measure some distances and angles. These measurements were taken at the console for the images of the digital strategy and manually for the pictures of the analog system. The data were collected in the Excel spreadsheet to realize the tables. The study reveals that the measurements obtained on the analog radiograms are approximately equal to those obtained on the digital radiograms. Therefore, analog and digital results in approximately equal results; any of the techniques can be chosen while noting that the advantages and disadvantages of each do not significantly influence the certainty of the measurements made. However, the digital system gives more accuracy in measurement.

Keywords: Accuracy of measurements, X-ray images, analogy, digital, Benin.

Introduction

X-rays were discovered on November 8, 1895, by Wilhelm Conrad Roentgen. On December 22, 1895, he performed the first medical X-ray from the hand of his wife Bertha and thus proposed an atraumatic anatomical exploration of the living subject[1]. The capacity of this technique to observe all parts of the body made radiography a versatile and therefore commonly used tool[2].

At the beginning of radiology, we have analogical images which are a two-dimensional representation of the object but with slight magnification. Recent technological advances and the use of image archiving and communication systems have led some health institutions to abandon conventional analog radiography and rely solely on digital conventional radiography[3]. In the case of digital images, a detector is used to process the data collected, which are converted into digital images.

The interpretation is based on the qualitative description of the structures or anomalies and also on the quantitative assessment of the structures in the image. This quantitative analysis is done by means of the measurement whose result is compared to the normal values recognized by the international scientific community. Thus, the measurements allow a certain number of calculations useful for monitoring and medical diagnosis. They also make it possible to assess the evolution of pathology during treatment[4]. Most of the values used for a long time have been determined from analog radiographic images obtained on light-sensitive media (silver film or fluoroscopic screens). However, with digital technology, measurements are made at the console on images that have undergone analog to digital conversion, sometimes with loss of information[3]. This analog to digital transformation raises questions. Is the measurement carried out on the digital image identical to the analog signal at the beginning? Also, is there conformity between the accuracy of measurement carried out on different digital systems of different brands?

It is to answer these concerns that we have initiated this study on the theme "Study of the accuracy of measurements on digital radiographic images of the skull in the Atlantic and Coastal departments".

Materials and methods

Framework of the study: Our study took place in all medical imaging departments that have a digital radiography system in the Atlantic and Coastal departments from August 6 to November 10, 2021. It included centers that have both digital and analog radiography systems in operation in the Atlantic and Coastal departments. Centers that did not respond to our request during the study period were not included.

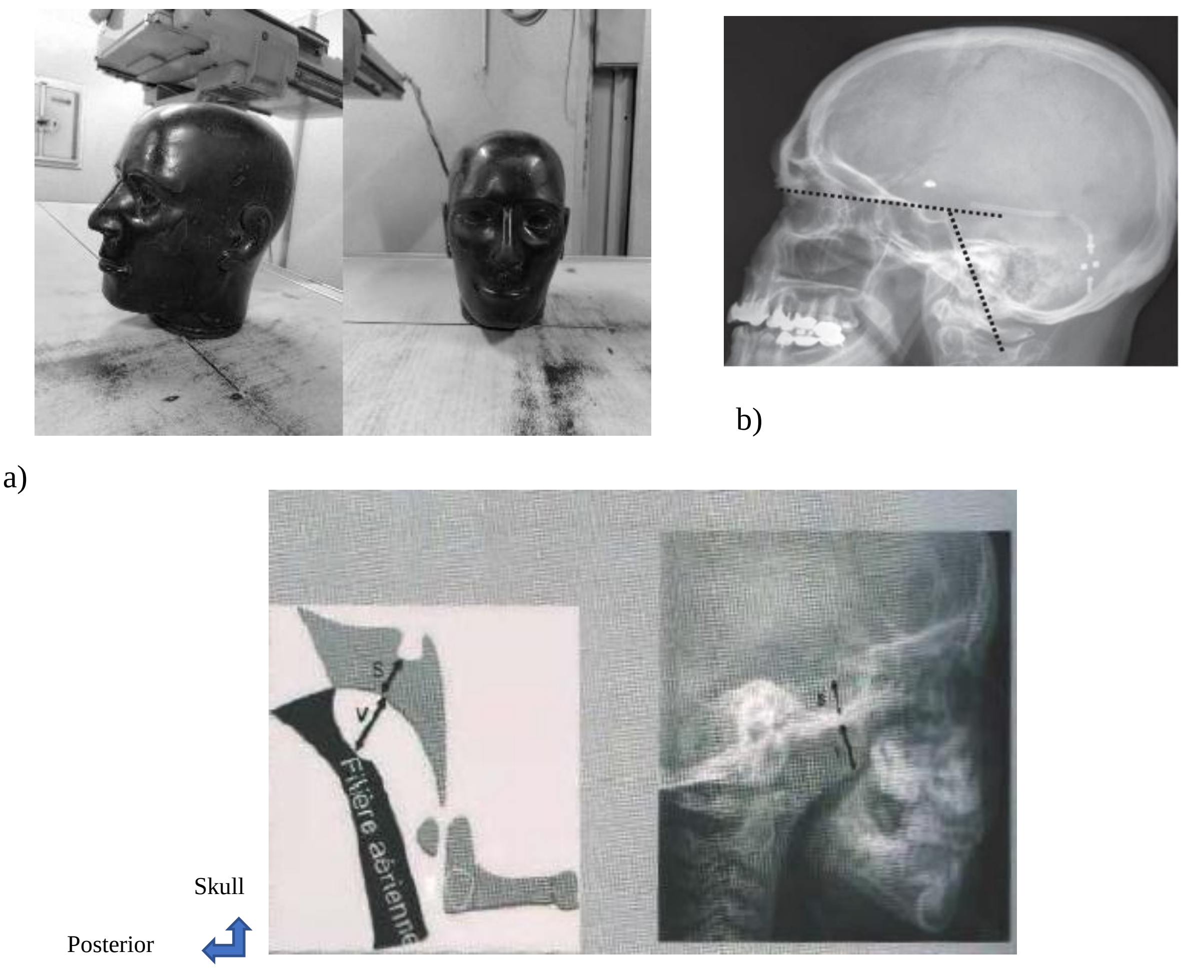
Data collection equipment and tools: The material used in our work is a mannequin (head of a human ghost named "Kokou").

The data collection tools used in our study are as follows: i. A plate named "collimator test tool". ii. Films of format 24x30cm; iii. Analogical cassettes of format 24x30cm; iv. Digital cassettes of format 24x30cm; v. A system of manual development, vi. Devices of radiography , vii. Digitizers, viii. A negatoscope, ix. A real draughtsman (double decimeter and protractor).

Study methods: This was a descriptive cross-sectional study with data collection in Prospective way.

Method of data collection: Thanks to an observation grid, we collected information concerning the characteristics of the different digitizers encountered. For the practical realization of the images, the decorative plate named "collimator test tool" and the shapely head of the human phantom were typically used.

The 'collimator test tool' consists of a plastic background printed with radiopaque lines at fixed and known intervals. It consists of a flat plate of 20x25cm with a pattern of 14x18cm engraved on its surface. There are two perpendicular axes in its center. Each axis is assumed to be graduated by 1cm on each of the two axes (the x-axis and the y-axis)[6].



(c)

Figure-1: Head of human, Welcher's angle and V and S. (a) Head of the human phantom, (b) Radiographic images showing landmarks and basal Welcher's angle[5]. (c) V and S distances on a radiographic image[5].

Interests: The presence of an orthonormal steel reference in this material (the plate) allows us to find it in the radiographic image. This makes it possible to evaluate distances and angles on the images. The use of the human phantom head allowed us to make measurements that are usually made on the human skull, namely the basal angle of Welcher and the measurement of distances on the cavum. Welcher's basal angle allows us to tell if there is platybasia (congenital or acquired "Paget's disease" of the base of the skull. Welcher's basal angle is the angle between the line joining the nasion and the tubercle of the sella turcica, and the line joining the tubercle of the sella turcica and the lower end of the quadrilateral blade. Its normal value varies from 125° to 143°. It is called platybasia when the angle is greater than 143°.

The distances measured on the cavum are used to assess whether there is hypertrophy of the adenoids. It is the thickness of the vegetation (V) related to the distance between the bottom of the sella turcica and the inferior surface of the sphenoid (S). Normally V is less than S but varies with age.

Incidences performed: On the plate of the "Collimator test tool" radiographs in anterior view on a 24X30cm cassette at distances of 100cm (when the plate is placed on the table) and 90cm (under bucky) respectively. The choice of these distances is in reference to the practice of realization of the radiographic incidences which usually take place at 100cm on the table and at 90cm under bucky.

On the head of the human phantom, an incidence of the skull is seen in profile on a 24X30cm cassette (analog and digital cassette) in width at a distance of 90cm (under bucky).

Methods of measurement: Plate "Collimator test tool'': The measurements made are those of graduation of one centimeter (1cm). The measurements from the analog system were taken manually while those from the digital system were taken on the console. After obtaining the images, we proceeded to the measurement of ten different dimensions between two consecutive points on each of the two axes of the plate (abscissa axis and ordinate axis).

For the measurement of the angles, we have traced the diagonals resulting from the two half axes (half axis of abscissa and half axis of ordinate). The angle (acute angle) between the plotted diagonal and the y-axis was measured. We have measured four acute angles. In the same way, the angle resulting from the two half-axes (half-axis of the abscissa and half-axis of the ordinate), i.e. the angle in the center was measured as well as the four right angles at the periphery of the plate (Figure-2a, 2b).

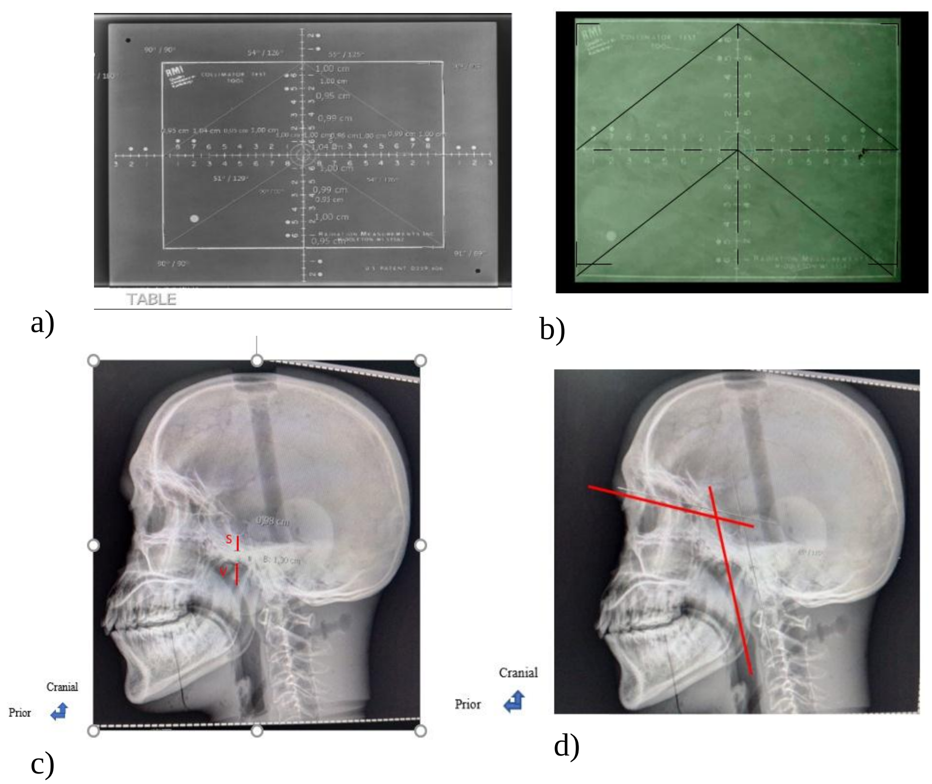


Figure-2: The two methods of measurements: (a) Drawing of dimensions and angles for taking measurements at the console (digital case), (b) Plotting of dimensions and angles manually for measurements (analog case) (c) Welcher's basal angle taken on a digital system, (d) V and S distances on a digital radiographic image.

Head of the human phantom: Welcher's basal angle is the angle between the line joining the nasion and the tubercle of the sella turcica, and the line joining the tubercle of the sella turcica and the lower end of the quadrilateral blade. Thus, the basal angle was measured (Figure-2c).

Concerning the distances measured on the cavum (Figure-2d), it is the thickness of the vegetation's (V) related to the distance between the bottom of the sella turcica and the lower face of the sphenoid (S).

For the validation of the measurements, we measured the distances and angles concerned three times. When there is a small difference, we averaged the three measurements and entered them into the database.

Statistical method: The collected data (characteristics and measurements) were entered into Microsoft Excel 2016. They were analyzed with the R software version 4.1.1. The analyses consisted of: i. A descriptive analysis in which we calculated the mean, and standard deviation and determined the minimum and maximum values per center for each system; ii. An inferential analysis that allowed us to implement the non-parametric Wilcoxon-Mann-Whitney statistical test to evaluate the significance between the values obtained at the level of the two systems and also the values obtained between the centers.

The test was considered significant at the $p<0.05$ threshold.

Results and Discussion

In our study, we had a total of 10 centers with digital radiographic equipment in the Atlantic and Littoral departments. Both types of systems were used (direct and indirect systems) in the centers visited. However, the indirect system is the most widely used, as seven of the 10 centers surveyed use it. The AGFA brand is the one most used in the centers. In the same way, each brand of digitizer has its own image processing software.

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Table-1: Characteristics of the various digitizers met in each center and their images.

Centers	Characteristics of digitizers				Characteristics of images		
	System	Digitizer	Year	Software	Size (µm)	Resolution (Pixels/mm)	Definition (Pixels)
Chuz- of Abomey –Calavi	Indirect	FUJIFILM FCR CAPSULA XLII	2021	K-Pacs	150	10	2295*2980
Police Center	Indirect	iCR 3600M	2020	iCRco XC	100	10	2180*2328
Army Training Hospital	Indirect	AGFA-CR 15-X	2021	NX Viewer	100	10	2328*2928
Cnhu-Hkm	Indirect	AGFA-CR 30-Xm	2016	NX Viewer	100	10	2328*2928
Mènontin Hospital	Direct (flat-plate sensors)	Huq	2021	iRayTechnology	100	6	2048*1536
Bethesda Hospital	Direct (flat-plate sensors)	CARERAY1500 CW	2021	DROC	154	7	2304*2816
Suru-Léré hospital	Indirect	CODONICS	2021	Quantor med +	150	12,6	2304*2800
Autonomous Radiology Center	Indirect	AGFA-CR 30-Xm	2017	NX Viewer	100	10	2328*2928

Legend:

System	Digitizer	Year	Software	Size (µm)	Resolution (Pixels/mm)	Definition (Pixels)
System Type	Digitizer Brand	Year of Installation	Image Processing Software	Size pixel (µm)	Space resolution(Pixels/mm)	definition of magus (Pixels)

The characteristics of the images differ from one system to another (direct system and indirect system). The different types of digitizers do not have the same unit of measurement. Some are in "cm", some in "mm" and others in "inch".

The average of the measurements made at the analog system is greater than that made at the digital system. The p-value is less than 0.001 in each center at each distance. There is a statistically significant difference between the analog and digital system measurements. However, the measurements from the analog system are close to reality.

After the analysis by center of the dimensions, the acute angles and the right angles obtained on the analogical and digital radiograms of the plate at 90 cm and 100 cm, we found that the p value is greater than 0.05 in all the centers whatever regardless of the film focus distance. There is no statistically significant difference between the measurements of the analog system and those of the digital system.

Table-2: Inter-center analysis of the distances obtained on the digital radiograms of the 100cm plate.

Centers	Mean (SD)	Range	P-Value
Autonomous radiology center (n=20)	1.024 (0.041)	0.930 - 1.080	0.455
Police center (n=20)	1.006 (0.041)	0.930 - 1.080	0.455
CHUZ-Abomey Calavi (n=20)	1.012 (0.032)	0.960 - 1.080	0.455
CNHU-HKM (n=20)	1.008 (0.039)	0.920 - 1.050	0.455
Pierre boni clinic (n=20)	1.000 (0.029)	0.940 - 1.040	0.455
Burili ulcer center (n=20)	1.002 (0.038)	0.930 - 1.080	0.455
Hospital Bethedsa (n=20)	1.000 (0.000)	1.000 - 1.000	0.455
Hospital Suru-Lere (n=20)	1.016 (0.035)	0.950 - 1.080	0.455
HIA- Cotonou (n=20)	1.002 (0.046)	0.940 - 1.080	0.455
Hospital Menontin (n=20)	1.001 (0.040)	0.930 - 1.050	0.455

The p value is less than 0.05 in all centers. In this case there is a statistically significant difference between the measurements taken from one digitizer to another.

Table-3: Intercenter analysis of the acute angles obtained on the digital radiograms of the plate at 90 cm.

Centers	Mean (SD)	Range	P-Value
Autonomous radiology center(n=20)	50.750 (2.363)	49.000 - 54.000	< 0.001
Police center (n=20)	49.750 (1.500)	49.000 - 52.000	< 0.001
CHUZ-Abomey Calavi (n=20)	50.250 (1.500)	49.000 - 52.000	< 0.001
CNHU-HKM (n=20)	51.000 (1.414)	49.000 - 52.000	< 0.001
Pierre boni clinic (n=20)	50.115 (1.039)	49.000 - 51.000	< 0.001
Burili ulcer center (n=20)	51.858 (3.191)	49.000 - 56.430	< 0.001
Hospital Bethedsa (n=20)	0.000 (0.000)	0.000 - 0.000	< 0.001
Hospital Suru-Lere (n=20)	50.830 (1.370)	49.000 - 52.320	< 0.001
HIA- Cotonou (n=20)	51.000 (1.414)	49.000 - 52.000	< 0.001
Hospital Menontin (n=20)	50.750 (1.258)	49.000 - 52.000	< 0.001

The p-value is greater than 0.05 in all centers. There is not a statistically significant difference between the measurements taken from one digitizer to another.

Table-4: Intercenter analysis of acute angles obtained on digital radiograms of 100cm plate.

Centers	Mean (SD)	Range	P-Value
Autonomous radiology center (n=20)	53.500 (1.732)	51.000 - 55.000	0.522
Police center (n=20)	51.250 (0.500)	51.000 - 52.000	0.522
CHUZ-abomey calavi (n=20)	52.000 (1.414)	51.000 - 54.000	0.522
CNHU-HKM (n=20)	51.000 (1.414)	49.000 - 52.000	0.522
Pierre boni clinic (n=20)	50.898 (1.330)	49.000 - 52.000	0.522
Burili ulcer center (n=20)	52.148 (3.749)	49.000 - 57.590	0.522
Hospital Bethedsa (n=20)	51.000 (1.414)	49.000 - 52.000	0.522
Hospital Suru-Lere (n=20)	51.000 (1.414)	49.000 - 52.000	0.522
HIA- Cotonou (n=20)	51.500 (0.577)	51.000 - 52.000	0.522
Hospital Menontin (n=20)	51.000 (1.414)	49.000 - 52.000	0.522

The p value is greater than 0.05 in all centers. There is not a statistically significant difference between the measurements taken from one digitizer to another.

Table-5: Intercenter analysis of right angles obtained on digital radiograms of the 90 cm plate.

Centers	Mean (SD)	Range	P-Value
Autonomous radiology center (n=20)	90.000 (0.000)	90.000 - 90.000	0.456
Police center (n=20)	90.000 (0.000)	90.000 - 90.000	0.456
CHUZ-abomey calavi (n=20)	90.000 (0.000)	90.000 - 90.000	0.456
CNHU-HKM (n=20)	90.000 (0.000)	90.000 - 90.000	0.456
Pierre boni clinic (n=20)	90.000 (0.000)	90.000 - 90.000	0.456
Burili ulcer center (n=20)	90.000 (0.000)	90.000 - 90.000	0.456
Hospital Bethedsa (n=20)	-	-	-
Hospital Suru-Lere (n=20)	90.000 (0.000)	90.000 - 90.000	0.456
HIA- Cotonou (n=20)	90.000 (0.000)	90.000 - 90.000	0.456
Hospital Menontin (n=20)	90.000 (0.000)	90.000 - 90.000	0.456

The p value is greater than 0.05 in all centers. There is not a statistically significant difference between the measurements taken from one digitizer to another.

Table-6: Intercenter analysis of right angles obtained on digital radiograms of 100 cm plate.

Centers	Mean (SD)	Range	P-Value
Autonomous radiology center (n=20)	90.200 (0.447)	90.000 - 91.000	0.456
Police center (n=20)	90.000 (0.000)	90.000 - 90.000	0.456
CHUZ-abomey calavi (n=20)	90.000 (0.000)	90.000 - 90.000	0.456
CNHU-HKM (n=20)	90.000 (0.000)	90.000 - 90.000	0.456
Pierre Boni clinic (n=20)	90.000 (0.000)	90.000 - 90.000	0.456
Burili ulcer center (n=20)	90.000 (0.000)	90.000 - 90.000	0.456
Hospital Bethedsa (n=20)	90.000 (0.000)	90.000 - 90.000	0.456
Hospital Suru-Lere (n=20)	90.000 (0.000)	90.000 - 90.000	0.456
HIA- Cotonou (n=20)	90.000 (0.000)	90.000 - 90.000	0.456
Hospital Menontin (n=20)	90.000 (0.000)	90.000 - 90.000	0.455

The measurements of the basal angle of Welcher performed on the mannequin allowed us to observe that the majority of the angles in the analog system are approximately equal to those in the digital system with some slight differences in some places.

Table-7: Basal Welcher angle of the human phantom head in analog and digital systems.

Centers	Basal Welcher Angle	
	Analogique	Numérique
CHUZ- of Abomey –Calavi	116,5°	115°
Police Center	116°	116°
Hospital of Instruction of The Armed Forces	116°	115°
CNHU-HKM	116°	115°
Hopital ofMenontin	116,5°	116°
Hopital Bethesda	115,5°	115°
Hopital Suru- Léré	116°	116°
Autonomous Radiology Center	116°	115°
Pierre Boni Clinic	116°	116°
Buruli Ulcer Center	117°	116°

The remark made previously at the level of Welcher's angle is also observed at the level of the distances V and S on the cavum.

Table-8: Measurement of the thickness of the vegetations (V) related to the distance between the bottom of the sella turcica and the lower face of the sphenoid (S) of the human phantom head in analog and digital systems.

Centers	Cavum distance in Cm			
	Analogic		Digital	
	Distance S	Distance V	Distance S	Distance V
CHUZ- of Abomey –Calavi	1	1.4	0.97	1.28
Police Center	1	1.4	0.98	1.2
Hospital of Instruction of The Armed Forces	1.1	1.4	1,00	1.3
CNHU-HKM	1	1.4	0.98	1.3
Hopital of Menontin	1	1.3	0.99	1.2
Hopital Bethesda	1.2	1.5	1,00	1.3
Hopital Suru- Léré	1.1	1.4	0.99	1.3
Autonomous Radiology Center	1	1.4	0.98	1.3
Pierre Boni Clinic	1	1.4	0.98	1.2
Buruli Ulcer Center	1	1.3	0.97	1.3

Our study shows that both types of digital systems are used (direct and indirect systems) with a predominance of the AGFA brand in the centers visited (Table-1). But the indirect system is the most used. Dagbé et al[7] in Lomé reported that out of 03 centers with digital radiology, 02 centers use the indirect system and 01 centers use the direct system[7]. Similarly, Ba et al.[8] in Dakar reported that out of 12 centers, eight centers use the indirect system[8]. These results could be explained by the fact that the indirect system is less expensive (low cost required for the initial installation) than the direct system[9]. But the indirect system is compatible with most existing conventional systems, whereas direct systems come in expensive packaging and are not compatible with existing X-ray equipment[10]. The predominance of the AGFA brand is due to the fact that the AGFA brand digitizer is a versatile and compact digitized radiography solution offering high image quality and productivity[11].

In the present study, the image characteristics (Table-1) differed between the two systems (Direct System and Indirect System). With regard to pixel size, the values recorded on each type of digitizer vary from 100µm to 150µm for the indirect system and 100µm to 154µm for the direct system. According to the work of Indrajit and Verma[12] in India, in radiography, depending on the equipment and the type of model, the size of the pixels in the indirect system varies from 50µm to 200µm, and in the direct system from 100µm to 200µm[12]. The size of the pixels according to the different systems encountered in the Atlantic and Coastal departments is in agreement with the work of the authors previously cited. Table-8 images of the indirect system and from 6 to 7 pixels/mm for the images of the direct system. Compared to our study, Bonvin et al[14] reported a spatial resolution of 4 pixels/mm for the direct system images and 3.6 pixels/mm for the indirect system images. Therefore, they claim that the direct system has a better spatial resolution than the indirect system[13]. In our case, we can affirm that the indirect system gives a better image quality than the direct system since it is the most used. In view of the results obtained, we could conclude that the technology of the indirect system has evolved more.

In this study, due to the use of two different measurement methods, the uncertainty related to the measurement method and the experimenter would certainly not be the same. The majority of the averages of the measurements made in the analog system are larger than those made in the digital system (Table-2). The p-value is lower than 0.001 in each of the centers according to each distance. There is a statistically significant difference between the measurements of the analog system and the measurements of the digital system.

This is related to the work of Almenar et al[14] and Burger et al[15]. This difference observed between the values of the analog and digital systems of each center could be explained by the fact that the measurements of the analog system were taken manually. Tools such as the pencil and double decimeters used for this manual approach may be the basis for this variation in the measurement. The difference between the units of measurement observed from one digitizer to another could be a source of errors in the realization of the measurements (Table-1). Then before having the measurement in a given unit it is necessary to conversion[16, 17]. This observation was less marked with the use of the protractor for the measurement of the angles where one obtained a strong similarity between the measurement of the angles to the analogical one and to the digital one (Table-3, 4, 5).

Regarding the accuracy of measurements from one digitizer to another, we note that for most types of measurements there was no statistically significant difference. A difference was only obtained at the level of the images at 90cm (Table-2, 3, 4, 5, 6). This difference could be due to the experimenter.

Since the collimator test tool used in the first part of this study was not thick, and therefore had less of the characteristics of the structures that are often radiographed, we thought it would be useful to verify the findings obtained on it with a dummy.

The measurements concerning the basal angle of Welcher and the distances V and S on the cavum (Table-7 and 8) carried out on the dummy allowed us to note that the majority of the angles in the analog system are approximately equal to those of the digital system. The causes of the few fluctuations obtained would be the same as mentioned above, which are the measurement method and the experimenter.

Conclusion

In radiology, quantitative analysis is done through measurement. However, with digital radiography, measurements are made at the console on images that have undergone analog to digital conversion, sometimes with a loss of information. The results obtained from this study on the accuracy of measurements of digital radiographic images have shown that the measurements made on digital radiograms are approximately equal to those obtained on analog radiograms, even when there is a change in the focus-film distance. Also, the measurements made using digital tracing are approximately equal to those obtained on analog images by manual tracing. Also from one digitizer to another, there is no difference in the measurement. The digital system offers a great advantage in the work of making measurements in radiology. This has also been done on the mannequin for cranial measurements. But it would be useful for technicians to master the methods of converting measurements to avoid the differences in units observed.

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