Automatic Analysis of Collimator Structure for Quality Assurance

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Abstract

A non-destructive, automatic and quantitative method was developped in order to characterize the structure of the gamma camera collimators because they remain the weakest part of the system. As the quality of a collimator depends on the regularity of the hole shape, we developped a software implemented on a microcomputer using the macro programming language provided by the image processing program NIH *Image* 1.52. A radiography is first performed by means of a home made rectilinear scanner and digitized with a film scanner. These data are then analyzed. The hole dimension and septal thickness are determined by applying a matched mask on the digitized image made binary. The hole inclination is estimated by the shift of the center of gravity determined from the gray level image. For foil collimators the results show a big spread ; e.g. S.D. are equal to 0.98 and 0.24 mm for 2.3 mm diameter and 0.15 mm septal thickness (manufacturers data) respectively. A cast collimator with the same characteristics has S.D. equal to 0.16 and 0.08 mm. In terms of hole inclination, a value of up to 1.3 degrees was found with foil technology. This method allows to detect automatically the manufacturing defaults of a collimator. Any geometry (parallel, fan beam) may be evaluated with minor changes in the technique.

I. INTRODUCTION

The gamma camera is the basic instrument in nuclear medicine department. It can be dedicated to a particular organ (brain and heart) or build for multi-purpose examination. Since the gamma camera was introduced by Anger in the 1960s a lot of improvements have been implemented such as on-line corrections, auto-tune and last, but not least, the all-digital detector. These improvements led to better intrinsic characteristics in terms of homogeneity, linearity, spatial and energy resolution. In the same way the collimator fabrication techniques have improved over the years because the collimator plays a fundamental role in image quality particularly during single photon emission computer tomography (SPECT) procedures.

As new nuclear medicine applications put high demands on image quality [1], many procedures concerning quality assurance have been published [2,3]. For instance mechanical characteristics of the gantry as well as stability of the detector during SPECT acquisition are dealt with in standards and publications. It is known that the collimator is the limiting factor in SPECT resolution and sensitivity, transforming an intrinsic resolution of 3.5 mm into a system resolution of 10 to 20 mm depending on the distance from the collimator face and the energy of the radionuclide. Independently of these geometrical effects due to the inherent constraints imposed by gamma ray detection, some mechanical defects about hole shape regularity (thickness and inclination of septa) can induce local variations of collimator response [4]. Variation in septal thickness induce modification of septal penetration which produces inhomogeneity and resolution loss. Regional variation in septal hole angulation or a shift in an overall angle of collimator, which must be accurately defined with respect to the axis of rotation, can cause lack of linearity. During SPECT image reconstruction these additional defaults can induce artifacts [5], such as those due to the misadjustment of detector head or the misalignment of gantry.

In order to improve the quality of collimators, some companies changed their manufacturing processes and are now proposing cast instead foil collimators. Since detector, gantry, and computer interface are being studied extensively, the collimator must also be investigated to check its structure in the whole field of view, by using a non-destructive method, particularly in the case of foil collimators.

II. MATERIAL AND METHODS

As collimators are usually protected by thin aluminum plates, preventing an optic inspection of their structure, a method based on X-ray radiography has been developed. After acquisition the radiographic film is digitized and then analysed with a software implemented on a microcomputer.

A. Collimator Radiography

The method is based on an X-ray examination using a home made rectilinear scanner [6,7] equipped with an X-ray tube providing a very narrow beam (diameter ≈ 2 mm). This device allows a 12 cm x 12 cm field of view scanned at 1 cm s^{-1} with a step of 2.5 mm. The radiographies were recorded on a conventional X-ray film (Kodak X-omat MA), with a high voltage ranging from 60 to 80 kV and an intensity from 4 to 10 mA. Fig. 1 represents the geometry of X-ray film acquisition. The distance between the X-ray output and the

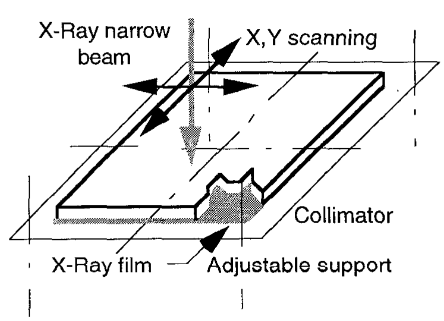

Fig. 1 Geometry of X-ray film acquisition

collimator is kept in the range of 5 cm in order to maintain X-ray beam intensity and avoid inhomogeneity of the radiography due to the watered effect. Fig. 2 shows the radiography of a cast collimator structure.

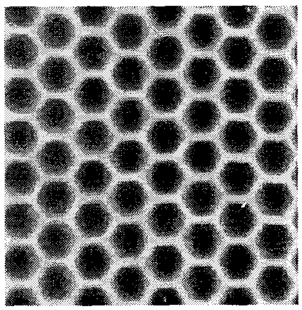

Fig. 2 Enlarged radiography (scale ≈ 2.8) of cast collimator structure

B. Quantitative analysis

After irradiation the film is digitized using a film digitizer (Vidar VXR-12) equipped with a low noise CCD camera and then analysed with software implemented on a microcomputer (Apple Macintosh). This software is based on the macro programming language provided by the image processing program NIH *Image* 1.52. The analysis concerns the hole characteristics and inclination.

The hexagonal structure of the collimator holes is well adapted for measuring their characteristics by applying a matched mask. In order to create the mask, the user defines the three main directions of the hexagon on the binary image (obtained by thresholding the grey digitized image). For each direction a suitable logical function is then performed between the processing mask and the binary image. When hole dimension is needed the logical function "AND" (by convention black is equal to 1 and white to 0 in NIH *Image* environment) is applied between collimator binary image and mask (fig. 3). The mask is a frame composed of equally spaced

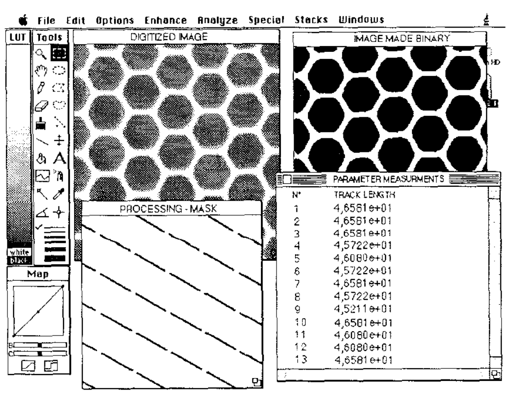

Fig. 3 Example of cast collimator hole measurements which correspond to the track length (in pixel) in the lower right window

straight lines. The distance between two consecutive lines is equal to the collimator pitch. When septal thickness is needed the same operation is done employing the same inverted binary image.

During manufacturing some technical problems can occur leading to a misalignment of hole axis. As the X-ray tube moves strictly parallel to the surface of the collimator, any tilt of holes produces a non-homogeneous gray level distribution on the X-ray film as shown on fig. 4. To estimate the hole

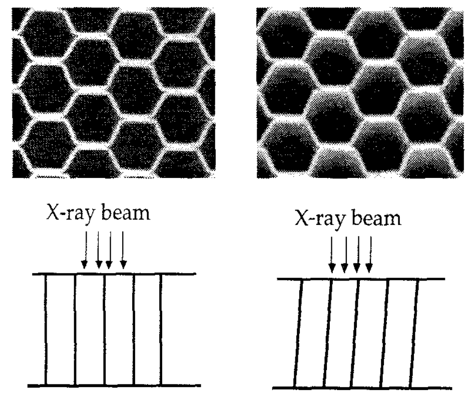

Fig. 4 Radiography of a foil collimator, left image corresponding to a well aligned region of the collimator, right image to a misaligned one

inclination we measured the center of gravity shift of the gray level in front of the collimator projection. Our method is based on a double thresholding (10 and 95 %) of the same image aera to obtain two sets of data. The first set corresponds to the segmentation between septa and holes. From these data, hexagonal in shape, the center of gravity is located close to the geometrical center of the hole. From the second set of data, irregular in shape, the center of gravity shift is proportionnal to the hole inclination as this effect induces a non-homogeneous X-ray field.

Six collimators, normally used for clinical application, were analysed with this method, four general purpose foil collimators (3 rectangular, 1 circular), and two high resolution rectangular cast collimators. Table I summarizes their main geometrical characteristics. In all cases the hole shape is hexagonal.

Table I
Main geometrical collimator characteristics

Collimator N°	Relative sensitivity (a)	Energy keV (b)	Resol. mm (c)	Geometry			
				Hole cm^{-2}	l (mm)	d (mm)	t (mm)
1,2,3,4 L.E.G.P.	1	150	8	≈20	45	2.3	0.15
5 L.E.H.R.	0.47	190	6.5	≈24	52	2.0	0.20
6 L.E.H.R.	0.39	200	6	≈28	55	1.9	0.20

L.E.G.P. : Low Energy General Purpose
L.E.H.R. : Low Energy High Resolution
l : hole length
d : "diameter" of hexagon
t : septal thickness
a : collimator and detector
b : 5% of septal penetration
c : 100 mm in air

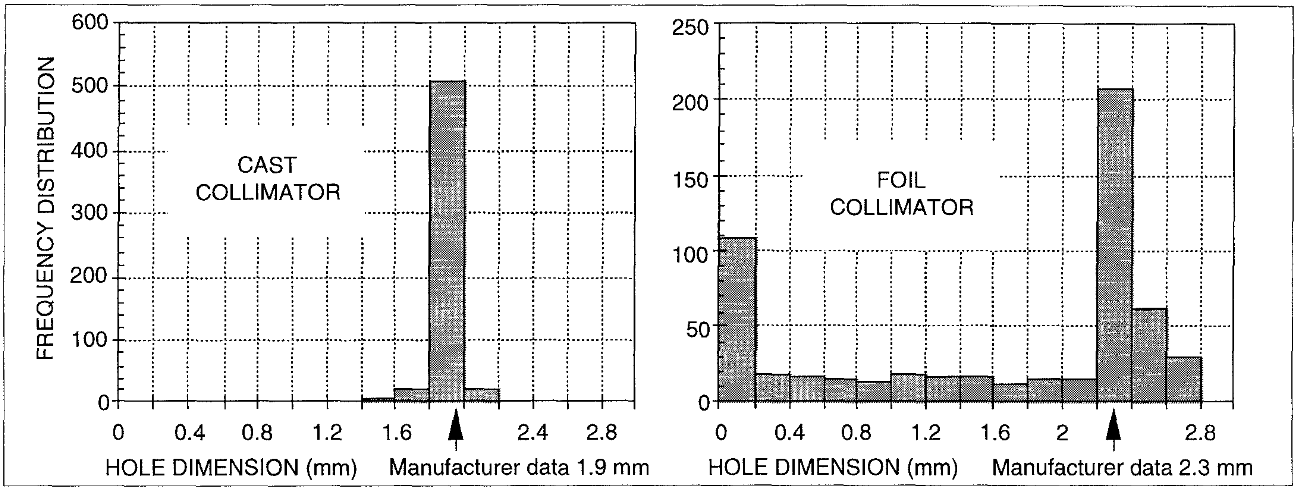

Fig. 5 Histogram of the distribution of hole diameter in the case of cast (left) and foil (right) technique

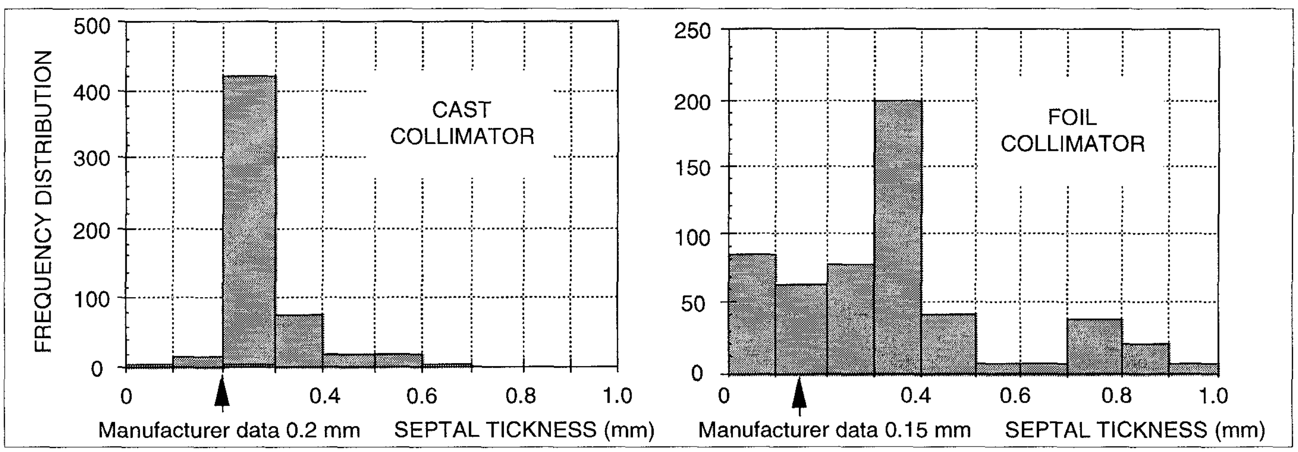

Fig. 6 Histogram of the distribution of septal thickness in the case of cast (left) and foil (right) technique

III. RESULTS

A. Hole dimension and septal thickness

The procedure previously described was applied to foil and cast collimators to determine hole characteristics. As the X-ray scanners field of view is limited, compared to that of the collimator's, the area investigated is always located in front of the central part of the collimator. Both types of collimator were scanned under similar conditions of scanning speed and radiographic parameters (kV and mA). Visual inspection of images obtained from cast and foil manufacturing process shows a better quality of cast technology which improves the regularity of shape for holes as well as septa. The results presented in figs. 5 and 6 show the histogram of the distribution of hole "diameter" and septal thickness for the analysis performed on collimators n° 2 and 6 (Table I). Each population contains the same number of samples (558). Assuming that the Gaussian distribution is the most probable, cast collimator populations are strongly correlated with it ($p = 0.9982$), whereas foil collimator populations are not ($p = 0.0001$). As a matter of fact, the results obtained for the foil collimator show an important spread for both, hole dimensions and septal thickness. This effect is due to the non-periodic spatial structure of the collimator which induces a spatial shift between the matched mask and the object in the plane of analysis.

B. Hole inclination

Hole inclination was measured for a foil collimator which yielded a distorted image. In order to calibrate our method we first measured the angle tilt according to the method described by Chang et al [9]. The authors propose to measure the channel tilt angle resulting from the shift of point source image location, when increasing the distance from the collimator surface, and performing the acquisition in air. This method yielded for the same collimator area a shift of 15 pixels corresponding to a tilt of 1.3 degree, as measured by the center of gravity shift. Fig. 7 shows an example of this analysis performed on a cluster of seven holes.

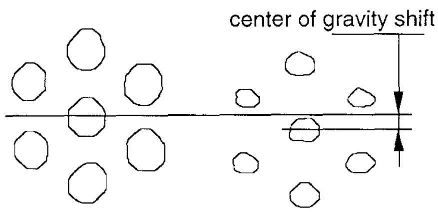

Fig. 7 Example of center of gravity shift for a foil collimator measured on a cluster of seven holes

IV. Discussion

The intrinsic performaces of gamma cameras have improved continually during the last decade. For instance, the improvements atteined by the new digital detectors in terms of uniformity, linearity, energy and intrinsic spatial resolution are respectively 1.3 %, 0.2 mm, > 10 % and ≈ 3 mm. Concurrently with the technological progress the medical requirements have increased. New radiopharmaceuticals have appeared inciting the manufacturers to propose a more sophisticated equipment in the field of whole body cameras or SPECT cameras. SPECT is a very demanding modality [8] compared to planar imaging, so the system characteristics, including collimator, must be kept at a high quality level. Moreover, some of the new algorithms implemented on commercial SPECT systems to correct the reconstructed data for attenuation and scatter suppose that the collimator response is spatially invariable throughout the whole field of view.

Collimators are at present the weakest part of the detection system. Most of the time low system performance can be imputed to them, although new designs have improved collimator quality. Today, gamma cameras are generaly available with a foil or cast collimator. The traditional design of the foil collimator consists of corrugated lead foils which are sealed to form a succession of holes and septa. The second one consists of a cast lead matrix. In a previous paper Gillen et al [4] reported some results about non-isotropic point spread function due to collimator defects and recommended to include the collimator in the gamma camera quality assurance program. As the intrinsic characteristic improvements of gamma cameras are now already limited by the physical capabilities of this kind of detector, the collimator remains the last principal component, which can be improved in order to obtain better performances in clinical use.

The method proposed in this paper is able to measure accurately the main characteristics of the collimator such as hole dimension, septal thickness and hole inclination. Compared to the isotopic methods previously published [5, 9] which indicate the septal angulation error, or the regional efficiency, our method can supply a detailed analysis of collimator characteristics and provide all the quantitative information from the same set of data. As shown in figs. 4 and 5 the analysis provides both, the mean values and the individual variations of the hole dimension and septal thickness. These results plainly prove the superiority of the cast manufacturing process compared to foil technology, since, assuming that the Gaussian distribution is the most probable, a strong correlation is observed with cast collimator. The aberrant values obtained for cast collimator analysis are due to a shift between the mask and collimator structure. As a matter of fact, the first straight line direction and the mask step are defined by the operator at the beginning of the automatic procedure. Obviously, the analysis is then based on the periodicity of the collimator. If a mechanical constraint occurs during the manufacturing, the hole regularity can be altered leading to a big spread of the characteristics measured by our method. So the spread of the values obtained from the analysis of a region in the collimator field of view is a powerfull indicator which strongly correlates with collimator quality. In the case of hole inclination measurements our method has been first applied to a cluster including few holes in order to validate the concept. The results obtained (fig. 6) showed a good correlation between the center of gravity shift and the hole tilt measured by an isotopic reference method. This new method can be easily extended to the whole area obtained by X-ray radiography. The angular distribution, in terms of pixel shift, will be analysed as hole characteristic distribution assuming that a complete no-tilt collimator should yield a Gaussian distribution centered in zero.

In conclusion, this non-destructive method allows to check the main parameters of the collimators, namely hole dimension, septal thickness and hole inclination in order to compare them with the manufacturer's specifications. It detects and localizes precisely the fabrication defects (foil misalignment, differences in septal thickness, ...) and verifies the exact shape of the holes and uniformity of manufacturing. Moreover, artefacts, such as induced by lead dust, can be detected. Finally, the results indicate that cast collimators are definitively superior to foil collimators, and must be used for tomographic acquisitions. They further suggest that each collimator should be delivered with a certificate giving the mean value and S.D. of its characteristics.

V. References

[1] S.I. Heller and P.N. Goodwin, SPECT Instrumentation : Performance, Lesion Detection, and Recent Innovations, Semin Nucl Med, XVI, pp. 184-199, July 1987.

[2] International Electrotechnical Commission (IEC), publication n° 789 "Characteristics and Test Methods for Anger Type Gamma Camera", central office Geneva, Switzerland.

[3] National Electrical Manufacturers Association (NEMA), standards publication NU 1-1986 "Performance Measurements of Scintillation Cameras", Washington, DC 20037, USA.

[4] G.J. Gillen, T.E. Hilditch and A.T. Elliott, Nonisotropic Point Spread Function as a Result of Collimator Design an Manufacturing Defects, J Nucl Med, 29, pp. 1096-1100, June 1988.

[5] R.E. Malmin, P.C. Stanley and W.R. Guth, Collimator Angulation Error and Its Effect on SPECT, J Nucl Med, 31, pp. 655-659, May 1990.

[6] B. Aubert, P. Fragu, M. Di Paola, P. Rougier and M. Tubiana, Application of X-Ray Fluorescence to the Study of Iodine Distribution and Content in the Thyroid, Eur J Nucl Med, 6, pp. 407-410, 1981.

[7] M. Ricard, B. Aubert, N. Boisson and R. Fraiderik, A Method to Verify and Analyse the Collimator Structure, J Nucl Med, 33, pp. 1006, May 1992 (Abstract).

[8] S.C. Moore, K. Kouris and I. Cullum, Collimator design for single photon emission tomography, Eur J Nucl Med, 19, pp. 138-150, 1992.

[9] W. Chang, S.Li, J.J. Williams, P.M. Bruch, C.A. Wesolowski, J.C. Ehrhardt and P.T. Kirchner, New Method of Examining Gamma Camera Collimators, J Nucl Med, 29, pp. 676-683, May 1988.