*2017 International Nuclear Atlantic Conference - INAC 2017*
*Belo Horizonte, MG, Brazil, October 22-27, 2017*
*ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR – ABEN*

Agência Brasileira do ISBN
ISBN 978-85-99141-07-6
9 788599 141076

# COMPUTED TOMOGRAPHY SCAN OPTIMIZATION USING HEAD PHANTOM AND RADIOCHROMIC FILMS

**Lorena C. Fernandes[1], P.C. Santana[2], Carlos E. Velasquez[1] and Arnaldo P. Mourão[1,3]**

[1] Departamento de Engenharia Nuclear
Universidade Federal de Minas Gerais
Avenida Presidente Antônio Carlos, 6627
31270-901 Minas Gerais, MG
lorena.cfernandes@hotmail.com, carlosvelcab@hotmail.com

[2] Centro de Imagem Molecular do INCT-MM
Faculdade de Medicina da Universidade Federal de Minas Gerais
Avenida Av. Prof. Alfredo Balena, 190
30130-100 Minas Gerais, MG
pridili@gmail.com

[3] Centro Federal de Educação Tecnológica de Minas Gerais
Av. Amazonas 5253
30421-169 Minas Gerais, MG
apmourao@gmail.com

## ABSTRACT

The research and development in technology applied to computed tomography has been improve in the image quality, resulting in the best identification of diseases, and therefore an increase in the number of exams, among them the head exams can be highlighted. In order to promote a radioprotection and reduction on the dose of the general public some international agencies have stipulated dose limits to be followed and the implementation of the principles of ALARA in all establishments that use ionizing radiation. One of these principles is the optimization that should be treated with substantial attention, because the reduction of radiation doses can be feasible as long as it does not compromise the tomographic images; such practice is difficult to perform due to the lack of proper guidance. In optimization of the CT exams, not only the lowest dose is evaluated to obtain diagnostic image, but also should be knowledge the dose distribution throughout the scanned area. In this work were used a cylindrical head phantom of PMMA, a GE Discovery CT scan with 64 channels, and radiochromic films. The films were positioned in the phantom in their central region for the dose evaluation using the automatic control for the voltages of 80, 100 and 120 kV. The images were acquired from the scan of the phantom and the film readings were obtained through digital images. The results show an evaluation of the longitudinal kerma profiles, dose delivered, and the image noise was also observed using the central slice images.

## 1. INTRODUCTION

The evolution of the technology in Computed Tomography (CT) increased the agility of the processing data, an improvement in the image quality, and time reduction and tomography exams costs. These characteristics can highlight this technique among the other methods of

production in the medical image. In this context, there has been an increase in the number of examinations in recent years, for example is estimated that in the year of 2010 in the United States it was about 1 million examinations performed by CT. Therefore, this influenced by the increase of radiation dose used in these systems, the international agencies responsible for radioprotection propose protocols for dosimetry and optimization of CT exams [1, 2, 3, 4].

The CT examination protocol optimization consists in the measurement of the dosimetric quantities using a phantom, ionization camera and radiochromic films (method suggested by several other studies). In order to evaluate the dose levels obtained, these were compared with the diagnostic reference levels determined by international and national recommendations for the multiple average dose (MSAD), which is stipulated for an adult with standard measures, 50 mGy for head, 35 mGy for lumbar spine and 25 mGy for abdomen [1, 2, 5, 6].

According to the American Medical Physics Association, suggest the use of the dosimetric quantification in terms of the computed tomography dose index (CTDI), which is basically the dose measurement in a single CT slice. However, the code of practice TRS-457 published by the International Atomic Energy Agency (IAEA) present the measurement in kerma index (*C*), which measures the air kerma free in air or air kerma in PMMA in one rotation of the X-ray tube. The quantities suggested by both are acquired in an analogous way, but differ in the concepts and calculations [7, 8].

There is CT software that modulates the current in the tube according to the anatomical shape and body density. This software contributes to choose the best current parameters choice that reduces the dose in regions with higher radiosensitivity. There can be emphasized that not always the smallest dose is associated with better image and, consequently, better diagnosis [3, 7].

Therefore, the main objective of this paper is propose an optimization of the head exam protocol using automatic exposure control (AEC) and to present the feasibility associating the best image quality with the lowest dose in helical CT scanner.

## 2. MATERIAL AND METHODS

The materials used were a Gafchromic XRQA2 radiocromatic film strips (0.5 wide by 12 cm length), one scanner HP, a 64-channel GE Discovery CT scanner, a cylindrical PMMA simulator of 16 cm in diameter and 15 cm in length, which has 5 openings of 1.25 cm in diameter and their positions correspond to one central hole and four peripherals, such their locations identified as clock hours at 3am, 6am, 9am, 12pm; and one ionization pencil chamber, Accu-Gold model 10X6-0.6CT. The ionization chamber was calibrated by a standard calibration laboratory and to guarantee its reliability, the dose constancy test was performed.

### 2.1. Optimization of the head exam protocol

Using a laser orientation, the phantom was positioned in the CT isocenter region, as presented in figure 1, with the following parameters: AEC activated, fixed the noise index in 10, slice thickness of 40 mm, reconstruction image of 5 mm, tube rotation time of 0.8 s, and pitch in

0.984. Images were acquired for the voltages of 80, 100 and 120 kV. From each image acquired, the central slice current was selected; they were used in the optimized protocol.

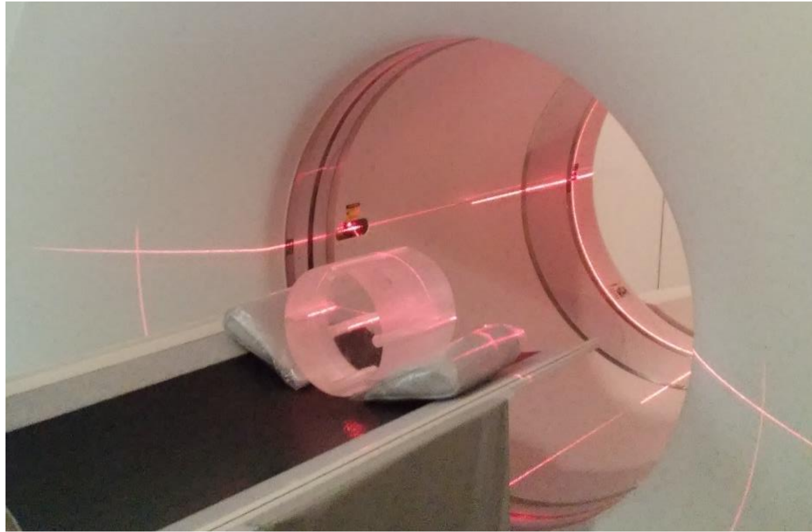

**Figure 1: Positioning of the phantom at the CT scanner.**

Using the optimized current and parameters: fixed the noise index in 10, slice thickness of 40mm, reconstruction of 5mm, tube rotation time of 0.8s, and pitch in 0.984. Irradiations were performed without the radiochromic films, with the objective of the analysis image noises, and the irradiations using the films positioned in the PMMA support, placed into the five openings of the head phantom. One film strip was used for the measurement of the background radiation. Radiations were performed for the voltages of 80, 100 and 120 kV with the scout. For comparison purpose, the irradiations with and without the film of the head protocol used in the hospital (non-optimized protocol) were performed with the parameters: AEC activated, fixed the noise index in 4.94, slice thickness of 20 mm, reconstruction of 1.25 mm, Tube rotation time of 0.7 s, and pitch in 0.969.

Film strips were scanned by the color image scanner in JPEG format, 300 ppi and reflection mode. The readings were performed through the ImageJ software [10], using the red channel, because the film has greater sensitivity in this region and selected an ROI of 10 cm long by 0.22 cm in height.

For the calibration of the radiochromic film was performed by measurements of kerma with the ionization chamber. The measurements with the ionization chamber were performed for the voltages of 80, 100 and 120 kV, fixed current at 200 mA and tube rotation time of 0.5 s, slice thickness of 10 mm, measurements were taken with the ionization chamber in all 5 phantom openings, which was positioned in the isocenter. These measures were then corrected for the optimized charge using equation (1). It is possible to used, because the Kerma is proportional a charge to low voltage [9].

$$K = K_c \frac{C_0}{C_c} \tag{1}$$

Since $K$ is the new value kerma (converted to the optimized charge range), $K_c$ is the kerma measured with the ionization chamber, $C_0$ is the optimized charge, $C_c$ is the charge used for measurements with the chamber.

The results of the films and the ionization chamber were related and then the calibration coefficient of the film was obtained, with this coefficient the data of the film in kerma were obtained and then the calculation of the $CTDI_{vol}$ and the MSAD.

### 2.2. **Image evaluation for optimized and non-optimized protocol**

The image evaluation was done through the RadiAnt DICOM View software [11], where it is possible to open DICOM format images. The images obtained from the optimized protocol were then analyzed through a ROI selection of the simulator central slice, from this region the standard deviation value and the mean of the Hounsfield scale value were taken for the calculation of the image noise, according to equation 2. This is used to calculate the noise of CT images, so the mean of the grays colors is increased by 1000.

$$R = \frac{\sigma}{M + 1000} \tag{2}$$

Since $R$ is the image noise, $\sigma$ is the standard deviation, and $M$ is the average intensity value in Hounsfield scale.

## 3. RESULTS AND DISCUSSION

In table 1 are presented the calibration coefficients of the film, $CTDI_{vol}$, and MSAD were calculated for the optimized and non-optimized protocols, using the simulator, ionization chamber and radiochromic film.

**Table 1: Results of calibration coefficients, MSAD and $CTDI_{vol}$ for the optimized and non-optimized adult head exam protocol**

| Protocol | Optimized | | | Not optimized |
|---|---|---|---|---|
| Voltage (kV) | 80 | 100 | 120 | 120 |
| Weighted calibration coefficient (mGy. Intensity$^{-1}$) | 0.353 | 0.394 | 0.390 | 0.781 |
| $CTDI_{vol}$ of the radiochromic film (mGy) | 8.303 | 8.906 | 9.022 | 67.867 |
| $CTDI_{vol}$ of the ionization chamber (mGy) | 8.140 | 8.596 | 8.581 | 67.098 |
| MSAD (mGy) | 8.016 | 8.459 | 8.458 | 64.43 |

Table 1 shows that the lowest $CTDI_{vol}$ value for the dosimeters used was the protocol whose voltage was 80 kV, but the values of 100 and 120 kV presented their values very close. Comparing 80 kV protocol with the one used in the hospital, it was possible to reduce the mean dose by approximately 87.5%.

Comparing the calculated MSADs for the optimized protocols presented lower doses than those suggested by the NRD for adult head examinations, and in the case of the non-optimized protocol it exceeded the recommended dose of 50 mGy.

The image noise value is presented in table 2. The standard deviation represents the uncertainty associated with the image and the average of the grays colors is the signal produced by the system, the calculated noise is the ratio between these quantities. It is observed that the noises for the optimized protocols are close and below 1%, since the protocol used by the hospital was below 0.5%.

**Table 2: Data noise for optimized and non-optimized protocol.**

| Protocol | Optimized | | | Not Optimized |
|---|---|---|---|---|
| Voltages (kV) | **80** | **100** | **120** | **120** |
| Standard deviation | 7.705 | 7.642 | 7.48 | 4.908 |
| Average Hounsfield value (intensity) | 87.06 | 103.34 | 112.55 | 110.75 |
| Noise (%) | 0.708 | 0.693 | 0.672 | 0.442 |

The protocols optimized and not optimized in its methodology used the AEC with the fixed noise index. Comparing table 1 with table 2, it is observed in the non-optimized protocol that it has a high dose and a low noise that in contrast in the optimized protocols there is a low dose and a noise considered medium, but this noise is acceptable for the image Diagnosis.

Figure 2, shows the relationship between dose (calculated from the radiochromic film) and noise. It is possible to observe which is the better protocol of acquisition to be chosen, through the protocol that presented less noise and lower dose for the patient, without interfering in the image quality.

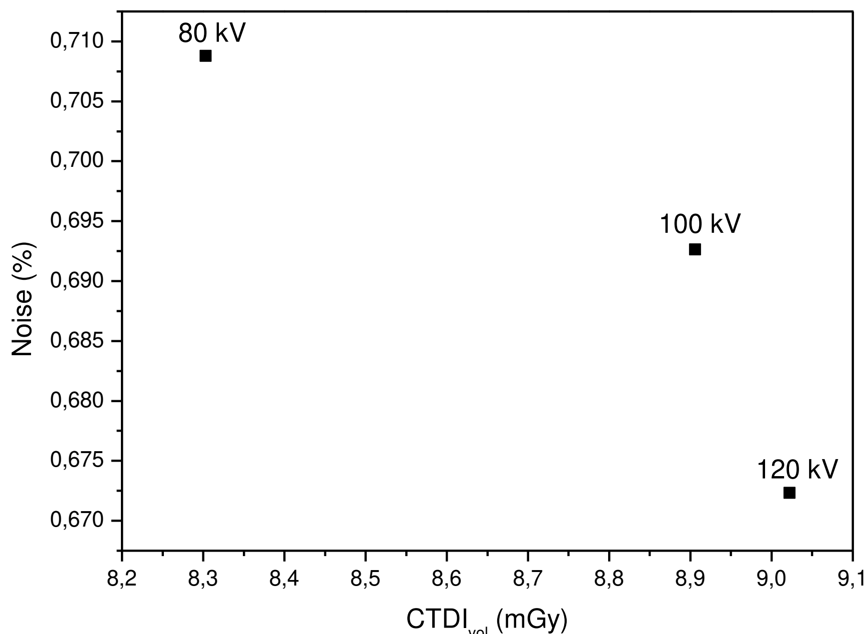


**Figure 2: Graph of the $CTDI_{vol}$ versus noise for optimized 80, 100 and 120 kV protocols.**

Note that the protocol that has the best dose-noise ratio is the 80 kV protocol, because its noise is close to 100 and 120 kV protocols, presenting a noise value of 0.051% higher, and has the lowest dose between them. Comparing the optimized 80 kV protocol with the non-optimized protocol, this optimized protocol has a noise value of 0.62% higher than in the non-optimized.

The kerma profiles of the optimized and non-optimized protocols for the five regions of the simulator are shown in figures 3, 4, 5 and 6, and it is possible to note that, the kerma is higher in position 12 than positions 6 and central position. The central position is lower due to attenuation in the peripheries of the simulator and in region 6 is due to attenuation of the CT table.

Figures 4 and 5 show the kerma profiles proximity for all regions of the simulator, since the beam is more penetrating and contributes to the kerma increase in the region 6 and central position, and consequently there is a kerma decrease in the positions 3, 9 and 12.

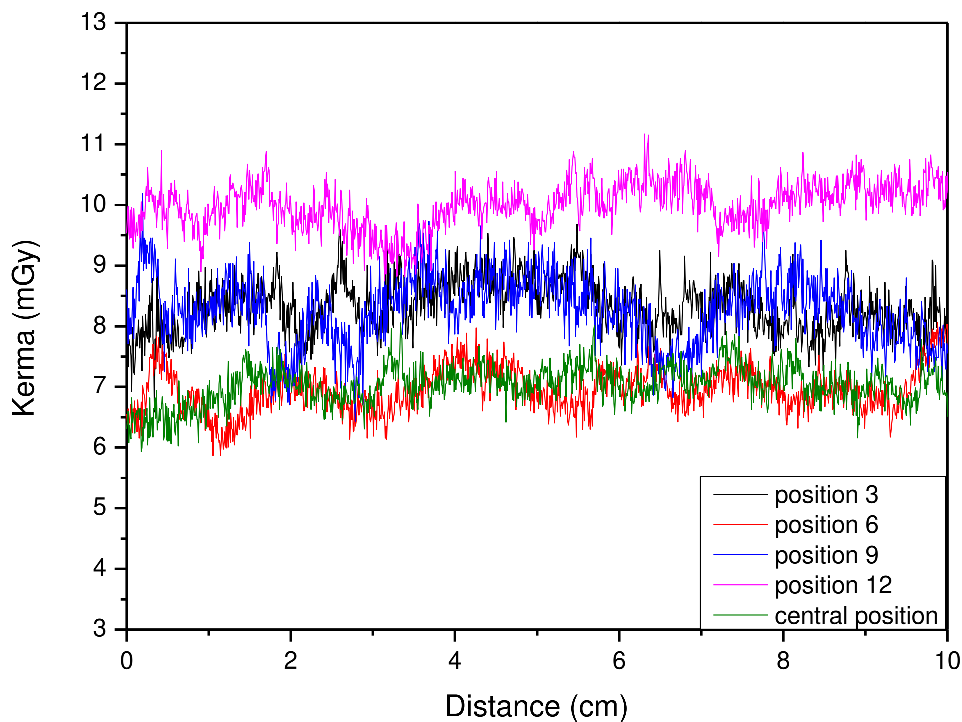


**Figure 3: Kerma profile for optimized protocol of 80 kV.**

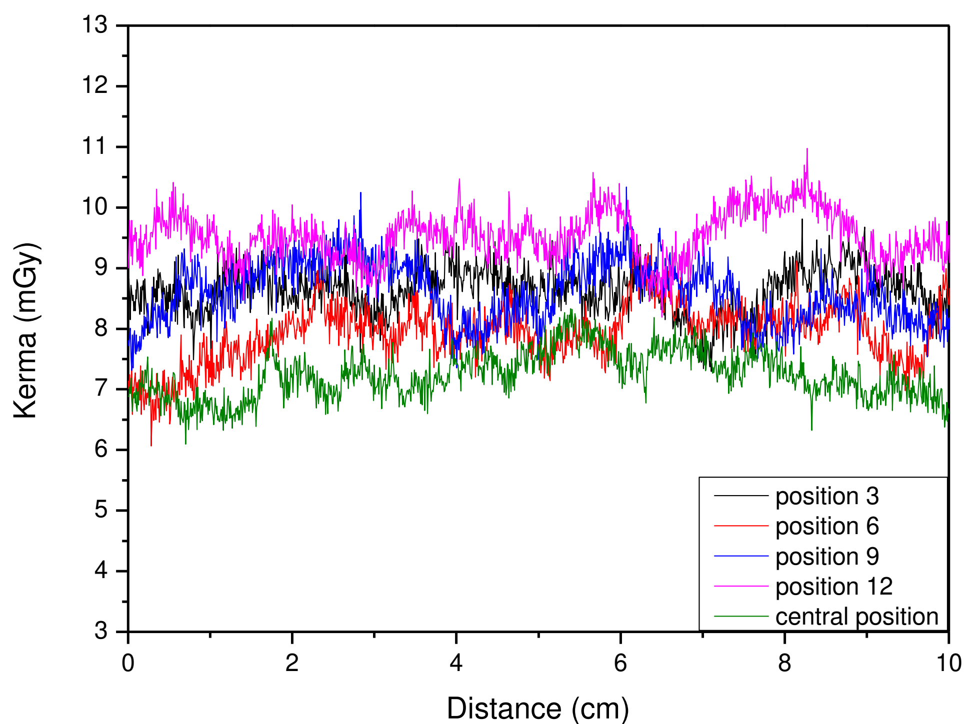


**Figure 4: Kerma profile for optimized protocol of 100 kV.**

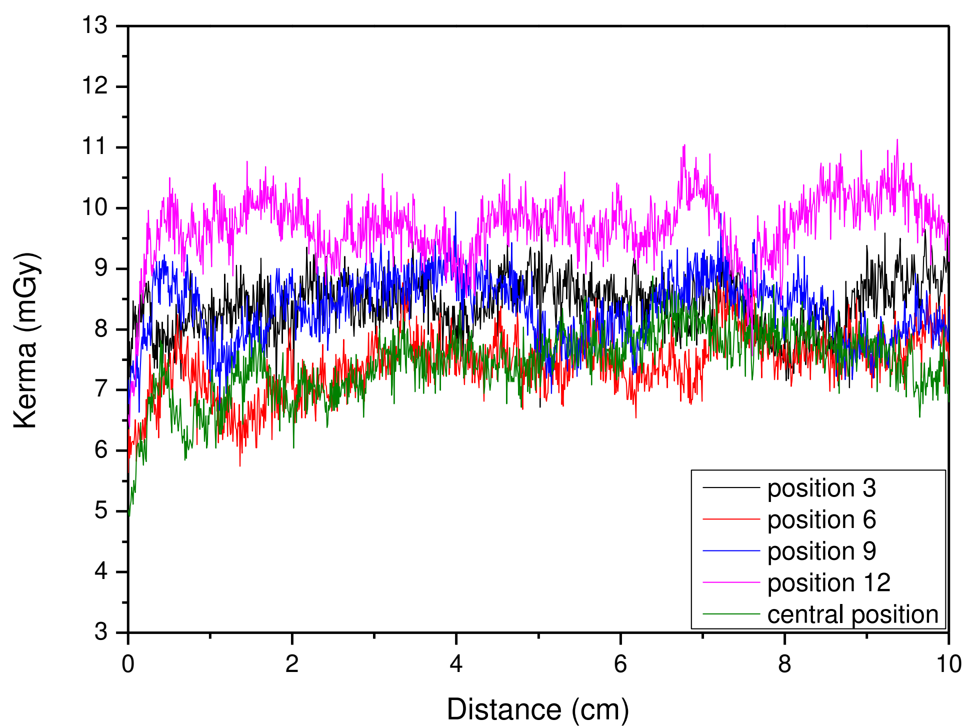


**Figure 5: Kerma profile for optimized protocol of 120 kV.**

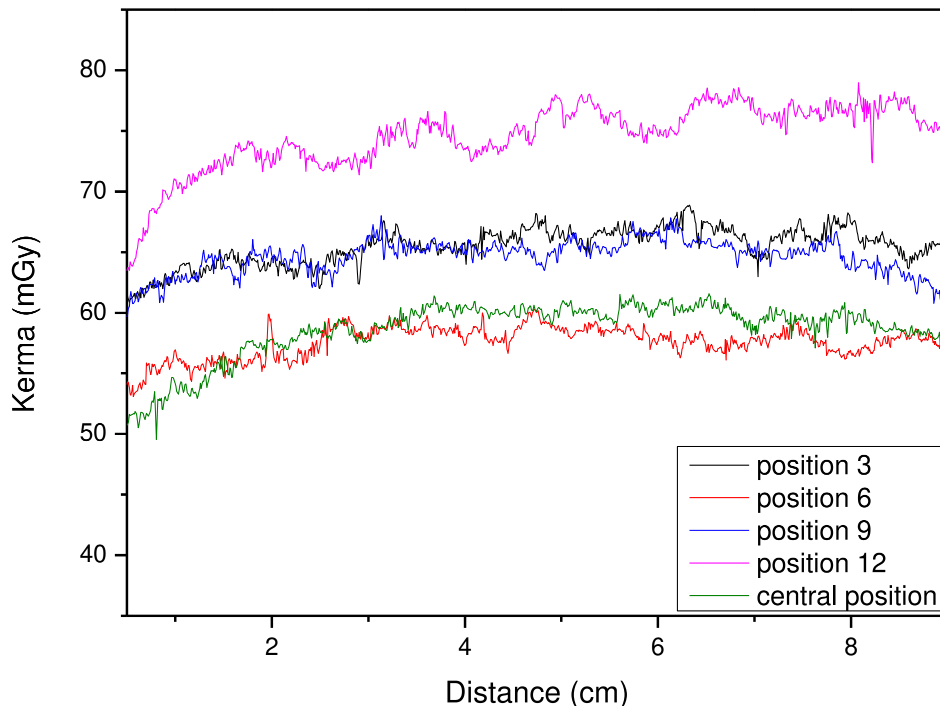


**Figure 6: Kerma profile for the non-optimized protocol.**

## 3. CONCLUSIONS

The advantages of using the radiochromic film in the service protocols optimization are: the time reduction to the acquisition of the dosimetric data compared to the use of the ionization chamber, can provide information when the kerma profile for later analyzes and easy handling.

The use of the AEC contributed to a quick and efficient choice of the best current to be used. In the case of the optimized protocols and the one used by the service, both were acquired with different methodologies, but in common they used the AEC and fixed the noise index. In the method used in the optimization of the service protocol the dose was reduced by up to 87.5% and a noise below 1% in homogeneous area, which is acceptable for the CT image. The high dose is due to the choice of the noise index fixation, which consequently interferes in the increase in the dose in the patient, so the analysis of the dose-noise ratio must be made to choose the best protocol to be used by the service.

The obtained MSAD results presented for the optimized protocols below the value of the NRD, being the protocol of 80kV the lowest value with 8.016mGy, and for the non-optimized protocol was 22.4% above the suggested value.

## ACKNOWLEDGMENTS

Thanks to CAPES, FAPEMIG and to Centro de Imagem Molecular (CIMol) of Faculdade de Medicina of UFMG.

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