ORIGINAL ARTICLE

Received: 04/13/2020
Accepted: 10/19/2020

Evaluation of exposure of a multidisciplinary team to ionizing radiation due to the use of fluoroscopy equipment in a surgical center

Avaliação da exposição à radiação ionizante em equipe multidisciplinar devido ao uso de equipamentos de fluoroscopia no centro cirúrgico

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ABSTRACT | Introduction: Ionizing radiation-producing equipment is used in surgical centers to guide invasive procedures. Technological advances have enabled improvements in image quality, which may be accompanied by increased radiation doses in the surgical team. Correct use of personal protective equipment and monitoring of radiation levels are required to a safe practice. **Objectives:** To evaluate radiation exposure conditions in occupationally exposed persons working at the Surgical Center at Hospital das Clínicas da Faculdade de Medicina de Botucatu for implementation of radiation protection measures. **Methods:** Three different types of fluoroscopy equipment were used: C-arms, a dosimetric system with ionization chambers, and optically stimulated dosimeters. A three-stage evaluation was conducted, consisting of a first stage for observation, a second stage for estimation of kerma rate simulating exposure conditions, and a final stage for dosimetry to estimate the effective dose in workers. **Results:** The most frequent procedures and the disposition for each team member were determined. Kerma values were estimated for both the principal physician and the assistant physician. The maximum number of annual procedures was also estimated so that the dose limits are not exceeded. **Conclusions:** Dosimetry for the surgical team is indicated as an approach to monitor occupational dose levels. The dose rates and effective dose found in this study are low but not negligible. Thus, proper use of equipment and periodic training for workers are still the best options for radiation protection.

Keywords | radiation protection; interventional radiology; dosimetry; diagnostic imaging.

RESUMO | Introdução: Equipamentos emissores de radiação ionizante são utilizados em centros cirúrgicos para guiar procedimentos invasivos. O avanço tecnológico possibilitou melhorias na qualidade da imagem, que pode causar aumento das doses de radiação na equipe. A utilização correta de equipamentos de proteção individual e a monitoração dos níveis de dose são necessárias para a prática segura. **Objetivos:** Avaliar condições de exposição à radiação de indivíduos ocupacionalmente expostos do Centro Cirúrgico do Hospital das Clínicas da Faculdade de Medicina de Botucatu para emprego de medidas de proteção radiológica. **Métodos:** Foram utilizados três equipamentos de fluoroscopia: arco cirúrgico, sistema dosimétrico com câmaras de ionização e dosímetros opticamente estimulados. Foram realizadas avaliações em três partes, consistindo em uma etapa observacional, uma segunda etapa de estimativas de taxa de kerma simulando condições de exposição e uma última etapa de dosimetria dos profissionais para estimativa de dose efetiva. **Resultados:** Foi possível determinar os procedimentos mais frequentes e a disposição para cada membro da equipe avaliada. Foram estimados valores de kerma para o médico principal e o assistente. Estimamos o número de procedimentos anuais, de modo a não extrapolar os limites de dose. **Conclusões:** A dosimetria da equipe no centro cirúrgico foi indicada como forma de monitorar os níveis de dose ocupacional. As taxas de doses e dose efetiva encontrados, ainda que baixas, não são negligenciáveis. Concluímos que a utilização adequada dos equipamentos e o treinamento periódico dos profissionais são as melhores alternativas para a proteção radiológica.

Palavras-chave | proteção radiológica; radiologia intervencionista; dosimetria; diagnóstico por imagem.

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Funding: None

Conflicts of interest: None

How to cite: Cury CS, Alves AFF, Mascarenhas YM, Magon MF, Ruiz Jr RL, Trindade Filho JCS, et al. Evaluation of exposure of a multidisciplinary team to ionizing radiation due to the use of fluoroscopy equipment in a surgical center. Rev Bras Med Trab. 2021;19(2):165-172. http://dx.doi.org/10.47626/1679-4435-2021-576.

INTRODUCTION

Ionizing radiation is an electromagnetic energy that can ionize atoms and molecules, thus interacting with the tissues and structures of a biological system.[1] Hospital units such as the surgical center (SC) and the interventionist sector use ionizing radiation-producing equipment to guide invasive procedures. During these procedures, the multidisciplinary support team is exposed to nonuniform radiation levels.[2,3] Several factors may influence those exposure levels, including height of the worker, position in the room, position of the X-ray tube, appropriate use of protective equipment, total exposure time, and image acquisition condition.[2,3] The effects of radiation exposure can be grouped into two general categories: deterministic effects (harmful reactions in tissues) due to cell apoptosis following high doses; and stochastic effects due to a mutation in somatic or hereditary cells, which will manifest later than the deterministic effects.[4]

The effects of exposure to low radiation doses (below 100 mSv) remain poorly understood, as they may be influenced by genetic predisposition.[1] In addition to the dose, the effects of ionizing radiation depend on absorption rate, exposure characteristics (acute or chronic), and type of irradiated tissue.[5,6] Thus, the likelihood of having adverse effects is lower when the person receives small doses over a long period, allowing the exposed cells to regenerate between exposures.[7]

The use of ionizing radiation in the hospital environment is essential for many diagnostic and therapeutic modalities. Advances in equipment technology have led to improved image quality; however, this improvement may be associated with higher levels of radiation. Thus, all equipment must be used properly and consciously, under adequate safety conditions, including personal protective equipment (PPE),[8] thus ensuring the protection of multidisciplinary teams, the public, and the environment.

This study aimed to evaluate the radiation levels to which occupationally exposed persons (OEPs) are exposed in the Hospital das Clínicas da Faculdade de Medicina de Botucatu, Universidade Estadual Paulista (HCFMB-UNESP), with the ultimate purpose of implementing the use of dosimeters and radiation protection measures.

METHODS

This study was conducted at the Diagnostic Radiology Physics Laboratory and was duly approved by the Research Ethics Committee with CAAE protocol number 42225115.4.0000.5411. Fifty multidisciplinary team members from different specialties were recruited. The study was conducted over a 4-month period at the Botucatu Medical School Hospital.

The materials used in this study were an electrometer and an 1800-cc ionization chamber (Radcal Corporation, model 9015), both calibrated (2018 Aug 02 – Radiation Metrology Laboratory – Universidade Federal do Pernambuco); an anthropomorphic phantom[9]; a tripod; optically stimulated luminescence (OSL) dosimeters; and PPE. The dosimeters were kindly supplied, read, and sent by the company Sapra Landauer.

Three C-arms were used: one Philips BV Pulsera and two Siemens Siremobil Compact L. All equipment underwent constancy tests according to Resolution of the Collegiate Board of Directors (Brazilian National Health Surveillance Agency/Agência Nacional de Vigilância Sanitária [Anvisa]) No. 330[10] and Normative Instruction (Anvisa) No. 53.[11] Lead PPE (apron and thyroid shield) was also assessed for integrity and transmittance quality assurance. This study was divided into three stages, as described in the flowchart shown in Figure 1.

Stage 1 was observational, i.e., a large sample of procedures performed at the SC was observed. The purpose of this stage was to assess the disposition of the multidisciplinary team during SC procedures. Most frequent surgical modalities (neurology, urology, anesthesiology, and orthopedics), mean fluoroscopy time, most used techniques and methods of exposure, as well as methods of collimation were recorded. Most importantly, the number of workers present in each operating room and their demarcated position on the ground (30, 60, 100, 200 cm) in front of the radiation source (X-ray tube) were observed. Thus, the modi operandi for SC procedures were recorded, including the most frequent disposition of the intensifier tube in relation to the patient table, methods of use, field size, frame rates, dose rates, and mean fluoroscopy time.

In stage 2, the commonly used exposure conditions, previously observed in stage 1, were reproduced. The experimental arrangement shown in Figure 2 was used, with workers X (principal physician) and Y (assistant physician) positioned at distances of 30 and 60 cm from the device, respectively. In this arrangement scheme, the distance (100 cm) between the radiation source and the lens of worker X is also presented. This arrangement scheme represents the conditions for estimating dosimetric quantities, named air kerma, and then the effective dose. This procedure was also performed for workers positioned at distances of 100 and 200 cm from the radiation source.

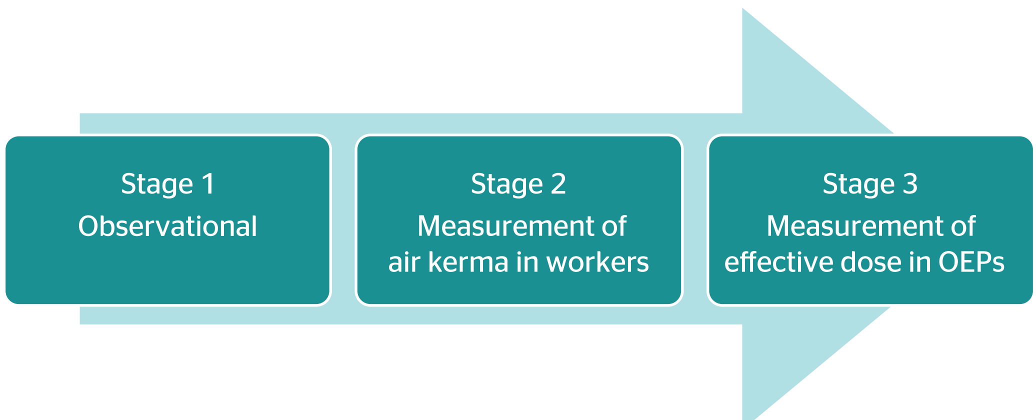

Figure 1. Flowchart showing the stages for evaluation of radiation exposure in the surgical center multidisciplinary team. OEPs = occupationally exposed persons.

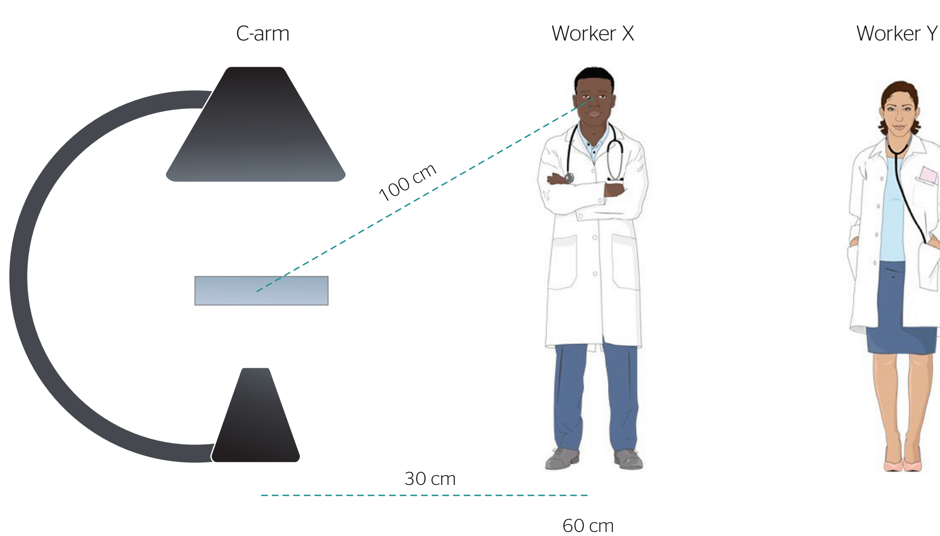

Figure 2. Schematic representation of the disposition of workers during a surgical procedure. Image generated on SMART – Servier Medical Art website (https://smart.servier.com). Worker X = principal physician at a distance of 30 cm from the radiation source; worker Y = assistant physician at a distance of 60 cm from the radiation source.

These quantities are generally used to assess the dose to which a person is being exposed, and air kerma is a measure of kinetic energy in the air that can be used for checking purposes, so that the worker is not exposed to radiation. Effective dose is the dose to which a person is being exposed. Because it considers type of radiation and radiosensitivity of exposed organs and tissues, this quantity is the most adequate for radiation protection in OEPs.[12]

Air kerma was estimated for workers X and Y positioned at the previously defined distances. Exposure was measured with a properly calibrated 1800 cc ionization chamber (RADCAL, model 9015). Philips BV Pulsera and Siemens Siremobil Compact L devices and an anthropomorphic phantom were used to reproduce the scattered radiation.

The exposure of workers positioned at distances of 100 and 200 cm from the radiation source and the distance between the radiation source and the lens of worker X were also measured. Fifteen-second exposures were conducted on accumulated dose mode to ensure greater reproducibility in measurements. All measurements were repeated three times to estimate the standard deviation of dosimetric quantities. Exposures for different tube projections were also assessed, as shown in Figure 3. Figure 3A shows the posteroanterior projection, while Figure 3B shows the lateral projection, both illustrating the position of the tube and the table.

Kerma values at chest and lens levels (mean height of workers' lens in this study was 100 cm above the table level) were estimated using the equation below:

$$K_{ac} = R_{ac} * 0.0087 * k_{T,P*} F_{c.}$$

in which K_{ac} is kerma accumulated in 15 seconds of fluoroscopy, R_{ac} is the exposure in mR measured by the ionization chamber, 0.0087 is the conversion factor of mR to mGy, $k_{T,P}$ is the correction factor for temperature and pressure, and F_c is the ionization chamber calibration factor.

Based on the accumulated kerma, absorbed dose rates were calculated for each worker in each specialty, with mean fluoroscopy time considered for each procedure. In stage 3, effective doses were estimated in multidisciplinary team members. For this purpose, workers were instructed to wear the OSL dosimeter over the lead apron at chest height.[13] The workers wore the dosimeter for 4 months, and the dosimeters were changed and read monthly. Doses measured in Hp(10) values were used to estimate the effective dose in the whole body.[14]

Then, the highest effective dose values found in the procedures were used for all evaluated equipment.

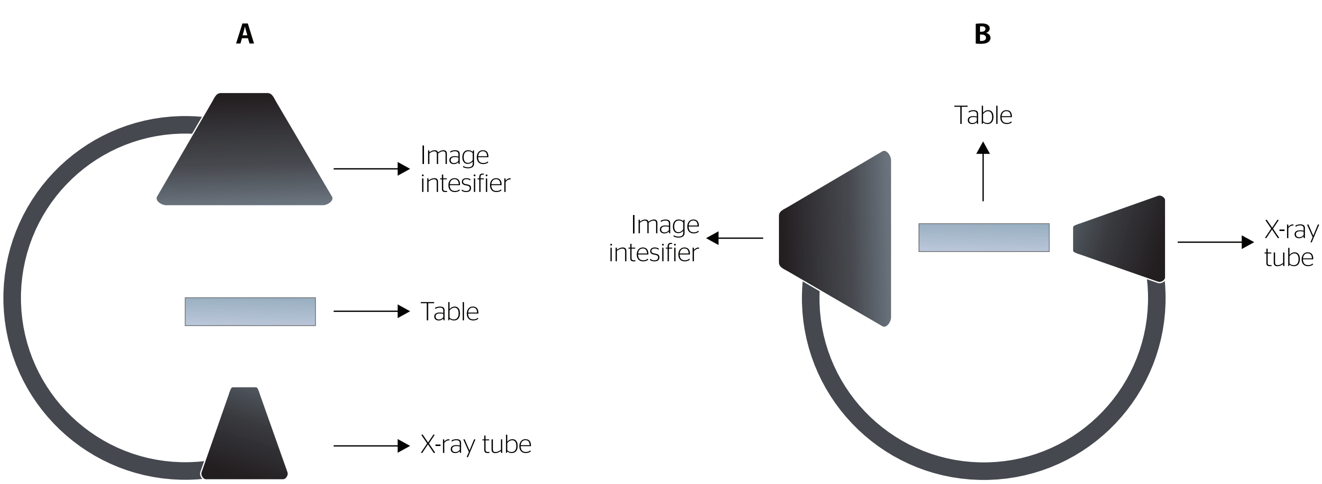

Figure 3. Tube/intensifier projection. A) posteroanterior projection; B) lateral projection.

This quantity was divided by the annual effective dose limit for OEPs.[15] It is worth mentioning that, for the whole body and the lens, the annual reference level is 20 mSv in the arithmetic mean in 5 consecutive years, and it should not exceed 50 mSv in any given year. Thus, for the procedure that had greatest exposure, the maximum number of procedures that each worker can perform without exceeding the dose limits was estimated. Two scenarios (with and without PPE) were considered for assessing whether the SC workers needed the dosimeters.

RESULTS

Tables 1 and 2 show results for kerma and air kerma rate in workers at distances of 30, 60, 100, and 200 cm

Table 1. Results for means and standard deviations of air kerma and air kerma rate measurements for the posteroanterior projection, with the workers positioned at distances of 30, 60, 100, and 200 cm from the radiation source

Device	Source-worker distance (cm)*	Air kerma (µGy)	Air kerma rate (µGy/s)
Philips BV Pulsera	30	7.57±0.37	0.50±0.01
Philips BV Pulsera	60	2.80±0.13	0.19±0.01
Philips BV Pulsera	100	1.50±0.64	0.10±0.00
Philips BV Pulsera	200	0.37±0.02	0.02±0.00
Siemens Siremobil Compact L (B)	30	7.56±0.38	0.50±0.01
Siemens Siremobil Compact L (B)	60	3.12±0.16	0.21±0.01
Siemens Siremobil Compact L (B)	100	1.29±0.07	0.09±0.00
Siemens Siremobil Compact L (B)	200	0.50±0.01	0.03±0.00
Siemens Siremobil Compact L (C)	30	2.36±0.02	0.16±0.01
Siemens Siremobil Compact L (C)	60	1.03±0.01	0.07±0.00
Siemens Siremobil Compact L (C)	100	0.55±0.01	0.04±0.00
Siemens Siremobil Compact L (C)	200	0.28±0.00	0.02±0.00
Siemens Siremobil Compact L (C)	30 (height: 100 cm)†	1.10±0.01	0.07±0.00

* Values expressed in centimeters consist of the distances between the middle of the phantom and the measurement point on the horizontal axis.
† A height of 100 cm in relation to the vertical axis was used to simulate the exposure in the lens of worker X.

Table 2. Results for air kerma and air kerma rate measurements for the lateral projection, with the workers positioned at distances of 30, 60, 100, and 200 cm

Device	Source-worker distance (cm)	Air kerma (µGy)	Air kerma rate (µGy/s)
Philips BV Pulsera	50 (tube side)	13.13±0.65	0.87±0.04
Philips BV Pulsera	50 (intensifier side)	0.55±0.01	0.04±0.00
Philips BV Pulsera	60	0.52±0.01	0.03±0.00
Siemens Siremobil Compact L (B)	50 (tube side)	7.02±0.35	0.47±0.01
Siemens Siremobil Compact L (B)	50 (intensifier side)	0.50±0.01	0.03±0.00
Siemens Siremobil Compact L (B)	60	0.70±0.01	0.05±0.00
Siemens Siremobil Compact L (C)	50 (tube side)	12.57±0.62	0.84±0.04
Siemens Siremobil Compact L (C)	50 (intensifier side)	0.52±0.01	0.03±0.00
Siemens Siremobil Compact L (C)	60	0.68±0.01	0.04±0.00
Siemens Siremobil Compact L (C)	50 (height: 100 cm) (tube side)	9.43±0.48	0.63±0.00
Siemens Siremobil Compact L (C)	50 (height: 100 cm) (intensifier side)	4.51±0.22	0.30±0.00

from the radiation source, in the posteroanterior and lateral projections, respectively, for each device.

Table 3 shows the results for estimated effective dose for orthopedic, neurologic, urologic, and vascular procedures in workers X and mean fluoroscopy time by specialty. The estimations were based on OSL dosimeter routine readings during a 4-month period.

Table 4 shows the maximum number of procedures that worker X at a distance of 30 cm and worker Y at a distance of 60 cm from the radiation source can perform per year. These data disregard the use of PPE, which contrasts with radiation protection standards but is very common in SCs.

Table 5 shows the maximum number of procedures that worker X at a distance of 30 cm and worker Y at a distance of 60 cm from the radiation source can perform per year when wearing PPE. The estimations were obtained by dividing the dose limits for OEPs[15] by the estimated effective dose values for each modality.

The results for personal dosimetry, performed for 50 workers, showed that six workers were above the acceptable dose limit (0.1 mSv). The highest doses were 0.2 and 0.5 mSv.

DISCUSSION

This study obtained quantitative estimations of the radiation doses to which OEPs are exposed in the SC at a medical school hospital of excellence in Brazil. Air kerma values were estimated to compare dose rates between the principal physician and the assistant physician. The results in Table 1 show that the air kerma rate in worker X is 63% higher than that in worker Y; previous studies have demonstrated that the principal physician receives higher doses than the assistant physician.[2] The results in Table 2 show that, when a C-arm is used in the lateral position, the worker must stay behind the image intensifier because then the received dose will decrease by 96%. The explanation is that most radiation is backscattered. Thus, the worker receives a decreased dose when the position is correct.

Table 3. Mean effective dose in workers estimated from OSL dosimeters

Specialty	Mean time (seconds)	Mean Hp(10) in worker X (mSv/proc.)	Mean Hp(10) in worker Y (mSv/proc.)
Orthopedics	529	0.26	0.11
Neurology	120	0.06	0.02
Urology	582	0.30	0.12
Vascular surgery	900	0.45	0.18

Standard deviations were all lower than 0.01.
Hp(10) = personal dose equivalent; proc. = procedure; OSL = optically stimulated luminescence.

Table 4. Maximum number of annual procedures without PPE for workers X at a distance of 30 cm and workers Y at a distance of 60 cm from the radiation source

Specialty	Worker X (proc./year)	Worker Y (proc./year)
Orthopedics	77	181
Neurology	333	1,000
Urology	67	167
Vascular surgery	45	111

PPE = personal protective equipment; proc. = procedure.

Table 5. Maximum number of annual procedures with PPE for workers X at a distance of 30 cm and workers Y at a distance of 60 cm from the radiation source

Specialty	Worker X (proc./year)	Worker Y (proc./year)
Orthopedics	500	2,000
Neurology	2,000	6,666
Urology	500	1,000
Vascular surgery	333	1,000

PPE = personal protective equipment; proc. = procedure.

Another finding was that the exposure at lens height for worker X, which is closest to the equipment, is 1.10 μGy, which is the same dose that worker Y receives in the chest. Thus, recommendation for worker X is to use lead glasses. Even with a shielding efficiency of approximately 60%, the glasses are required to protect the lens and ensure the dose is within the limits.[14]

The results in Table 3 demonstrate that air kerma rates for worker Y, positioned at 60 cm from the radiation source, are more than half the rates for worker X, who is 30 cm away. This shows, once again, that positioning at the time of exposure is one of the major factors for radiation protection. Häusler et al.[15] demonstrated that the maximum number of examinations that an OEP wearing PPE can perform increases considerably according to the thickness of the lead apron. Also, workers should be instructed to stay as far away as possible from the radiation source during the exposure, without, however, compromising the quality of the procedure.

Effective dose values were then estimated based on a dosimetric quantity named Hp(10), measured by OSL dosimeters. These dosimeters are known to have a linear dose response for the entire detection range (50 μSv - 10 Sv).[16] Based on the effective dose, as shown in Tables 4 and 5, the maximum number of examinations that a worker X can perform in one year with or without PPE was estimated. The results indicate that all workers inside the operating room must be wearing PPE and that dosimeters are essential for those who perform SC procedures. PPE, when worn correctly, is able to block about 86% of the scattered radiation.[17]

Estimating the dose to which the workers were exposed is important so that the dose limits are not exceeded.[18] In monthly monitoring, effective dose values above 1.0 mSV are investigated and may lead to corrective actions such as training, decreased workload, or reallocation to other procedures. Monitoring dosimeters is useful in the measurement of effective doses received by workers and should be used to optimize their positioning during exposure, thus improving the radioprotection of OEPs.

CONCLUSION

The dose measurements conducted in this study suggest that workers performing SC procedures need individual monitoring. This study contributed to the literature with findings on radiation exposure at the HCFMB-UNESP. These findings were used by the Radiation Protection Department for implementing actions in the evaluated unit. With these data, radiation protection within the SC can be optimized with actions such as using less exposure time, lifting the trunk of worker X during the procedure, reducing the number of workers within the operating room, etc.

These actions are reviewed periodically, given that this is a teaching hospital where professors, residents, and nursing staff are frequently changing in this unit. The same procedure with a team of more experienced residents can provide lower doses. Therefore, frequent evaluations should be conducted. The method described in this study shows reliable results and, therefore, can be widely used in any hospital.

Continuing education of workers who are exposed to ionizing radiation in the SC is of fundamental importance to reduce the effective dose. Effective dose levels are expected to remain below the annual limits set by CNEN NN 3.01 with periodic training and the development of an adequate quality assurance program for all procedures and equipment.

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