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Analytical Study of Flatness and Symmetry of Electron Beam with 2D Array Detectors

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Abstract

Aims: The main aim of our study is to analyse Electron Beam Profiles like Flatness, Symmetry with 2D Array Detectors. The 2D Array can be used as an alternative device to measure the Electron beam profiles.

Introduction: Flatness and symmetry of a radiation beam: The flatness of the beam is defined by the following formula:

Flatness (%) = Dmax/Dmin × 100% (1)

Where Dmax and Dmin are the maximum and minimum doses respectively within the area. Radiation field symmetry is defined as the maximum ratio of doses at two symmetric points relative to the central axis of the field.

Symmetry (%) = [D(x, y)]/[D (-x,-y)] × 100% (2)

Methods and Material: The beam symmetry is easily defined and is not very dependent on the depth of measurement. However, the flatness of the beam depends on the size and shape of the measurement phantom.

However, 3% is sufficient measurement accuracy for a quick check. We measured the electron profiles of energies (4 MeV, 6 MeV, 8 MeV, 10 MeV, 12 MeV, 15 MeV and 18 MeV) from Elekta Synergy Linear accelerator for different electron applicators (6 × 6, 10 × 10, 14 × 14 and 20 × 20) at their depth of maximum dose (dm) respectively and Source-Surface-Distance (SSD) of 100 cm using PTW 729 2D array detectors.

Results: We analyzed the variations in Flatness and Symmetry of electron energies obtained from 729 2D Array Detector and compared with the standard values obtained from the Radiation Field Analyzer (RFA) during Commissioning.

Conclusions: We found that there is no significant variation in Flatness and symmetry obtained from the 729 2D Array detector as compared to the standard Flatness and symmetry obtained from the RFA .Thus we conclude that 729 2 D Array detector can be used for the routine measurement of electron beam profiles.

Aims

The main aim of our study is to analyse Electron Beam Profiles like Flatness, Symmetry with 2D Array Detectors. The "Maximum" and "Minimum" doses in the measured field can be demonstrated by this technique that provides maximum information about the radiation beam. The 2D Array can be used as an alternative device to measure the Electron beam profiles.

Introduction

In the treatment of superficial cancers electron beam therapy is globally used. Due to the unique characteristics of an electron beam it is suitable for the treatment of disease near to the skin surface and sparing the deep tissues. Thus to conform the shape of the radiation field to that of the irregular shapes of individual tumours, and sparing peripheral tissues ,the need for electron cut-outs is required [1]. The goal of this study is to compare the electron beam characteristics, such as Flatness and Symmetry.

For the clinical use of electron fields Uniformity of beam flux across the electron-beam field is a major requirement. Electron beam profiles depend on the make and arrangements of the flattening system and the jaws used for beam collimation. The flatness of the beams may change significantly with depth since scattered electrons are of lower energy.

By setting specific recommendations on field symmetry and flatness for a specified area of the beam at depth electron field uniformity can be defined. The reference depth for the measurement of electron beams is recommended at or beyond the depth of maximum dose (dm). A plane parallel to the surface of the phantom and perpendicular to the central axis is defined as a reference plane. The beam flatness from the central axis should not exceed ± 3% [2].

Flatness and symmetry of a radiation beam

In radiotherapy the dose variation over the target volume is limited so that all points in the volume receive the prescribed dose within a tolerance range. In IEC protocols, the beam flatness and symmetry are

defined at 10 cm water depth. The flatness of the beam is defined by the following formula:

Flatness (%) = Dmax/D min × 100%   (1)

Where Dmax and Dmin are the maximum and minimum doses respectively within the area.

Radiation field symmetry is defined as the maximum ratio of doses at two symmetric points relative to the central axis of the field.

Symmetry (%) = [D(x, y)]/[D (-x,-y)] × 100%   (2)

Traditionally beam uniformity is analyzed with a computer-controlled radiation field analyzer (RFA) system and the absolute values of the beam uniformity are measured at a reference depth. Since this procedure is time consuming and unfavorable for regular quality assurance testing, for short interval quality assurance purposes, one dimensional detector arrays or specially designed phantoms are commonly used. A two dimensional distribution may be obtained, e.g. with the RFA set up, by extensive scanning along the two-dimensional area investigated. Due to its time consuming procedure in set-up it is not feasible for the routine quality assurance testing in busy radiotherapy department. On the other hand, 2D Array Detectors have the ability to provide two dimensional dose distributions from a single exposure, making the acquisition of data faster and the investigation of these beam parameters more comprehensive as the whole radiation area is evaluated. Unlike the radiographic films which also provide 2D maps, there is no requirement for processing and scanning before analysis as the radiation field can be analyzed on-line [3].

Measurement of beam flatness and symmetry

Some automatic devices cannot be used easily with accelerators that employ scanning electron beams. Other systems, such as those that use film, that integrate the dose for the entire scanned field are necessary. Electrons scattered off in those cases from the machine elements like beam defining system, jaws arrangements, trimmers, can change flatness. At the time of machine installation beam uniformity are measured and should be subsequently verified at least weekly and following any major servicing of the accelerator (e.g., wave guide, gun, bending magnet, scattering foils, etc.). Regular verification of beam uniformity is part of any good quality assurance program.

Methods and Material

The beam symmetry is easily defined and is not very dependent on the depth of measurement. However, the flatness of the beam depends on the size and shape of the measurement phantom. At commissioning of an accelerator it is necessary to state that the beam profile suits with the accelerator's specification. This must be carried out in a water phantom making measurements at the depth or depths (usually at the maximum and at 10 cm deep) at which the flatness is given. Subsequently it is important to check that the profile has not changed significantly since the beam data were measured. Therefore the profile should not be differ more from its shape at commissioning than 2%.

In beams the minimum is usually close to the central axis of the beam. Although the IEC specification allows an asymmetry of 3%, it should be easier to achieve better beam symmetry with a modern accelerator. However, 3% is sufficient measurement accuracy for a quick check. A very convenient measuring of the beam profile is with a multi-

element array of diodes or ionisation chambers. Not only their use is fast, they also give some information about the temporal stability of the beam and are particularly convenient for setting up beam steering.

We measured the electron profiles of energies (4MeV, 6MeV, 8MeV, 10MeV, 12MeV, 15MeV and 18MeV) from Elekta Synergy Linear accelerator for different electron applicators (6×6, 10×10, 14×14 and 20×20) at their depth of maximum dose (dm) respectively and Source-Surface-Distance (SSD) of 100cm using PTW 729 2D array detectors.

D-array: PTW 729 2D-arrays consisting of a plan matrix of 27 × 27 air–filled ionization chambers is used (PTW, Freiburg, Germany). The detector spacing (center to center) is 1 cm. The dimensions of each detector are $0.5 × 0.5 × 0.5$ cm^3.

Verisoft software

The Verisoft software assists physicists in comparing dose distributions in IMRT verification phantom with dose distributions computed by radiotherapy treatment planning system. This also helps to determine the Relative as well as Absolute dosimetry [4]. The Schematic diagram of the Detector is as shown in Figure 1.

Results and Discussions

We estimated the variations in Flatness and Symmetry of electron energies obtained from 729 2D Array Detector and compared with the standard values obtained from the Radiation Field Analyzer (RFA) during Commissioning. The values of Flatness and symmetry for energies (4,6,8,10,12,15, and 18MeV) for different electron applicators (6×6,10×10,14×14 and 20×20 cm^2) were tabulated in Tables 1a-2d and Tables 2a-2d respectively. The average and Standard Deviation have been determined. The electron beam flatness in cross-plane (CP). In-Plane (IP)as well as Diagonal decreases as energy increases for all applicator (6×6,10×10,14×14 and 20×20 cm^2) which also reveal the fact that the flatness of the electron beam is field size dependent. The average decrease in Cross-plane (CP) and In-plane (IP) Profile for energies 4MeV-8MeV is -3.17%, -3.70% while for energies from 10MeV -18MeV is -4.5%, -5.0% respectively for applicator 6×6 cm^2. The average decrease in Cross-plane (CP) and In-plane (IP) Profile for energies 4MeV-8MeV is -1.20%, -1.19% while for energies from 10MeV -18MeV is -2.1875%,-2.1875% respectively for applicator 14×14 cm^2 and the average decrease in Cross-plane (CP) and In-plane (IP) Profile for energies 4MeV-8MeV is -1.11%, -1.5214% while for energies from 10MeV -18MeV is -1.17%, -2.72% respectively for applicator 20×20 cm^2. The diagonal profile also
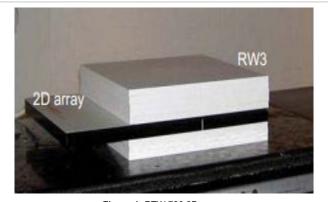

Figure 1: PTW 729 2D-array.

Energies(MeV)	Cross Plane (CP)	CAD(mm)	In Plane (IP)	CAD(mm)	Diagonal			
	%		%		X	CAD	Y	CAD
4	0.65	-0.08	0.66	0.32	0.6	0.19	0.6	-0.24
6	0.64	-0.07	0.64	0.25	0.57	0.14	0.57	-0.2
8	0.6	-0.08	0.61	0.17	0.54	0.09	0.54	-0.16
10	0.58	-0.05	0.58	0.15	0.52	0.08	0.52	-0.13
12	0.56	-0.05	0.56	0.09	0.51	0.03	0.51	-0.1
15	0.54	-0.13	0.54	0	0.49	-0.08	0.49	-0.1
18	0.54	-0.16	0.53	-0.05	0.49	-0.13	0.49	-0.08
Average	0.58714	-0.08857	0.58857	0.132857	0.5314	0.04571	0.53142	-0.1442
Std.dev.	0.04498	0.041404	0.04980	0.13124	0.0414	0.11530	0.04140	0.0588

Table 1a: Electron Beam Flatness (6X6): At Depth of Maximum dose (dm) of respective energies.

Energies(MeV)	Cross Plane(CP)	CAD(mm)	In Plane(IP)	CAD(mm)	Diagonal		
	%		%		X	CAD	Y
4	0.78	0.05	0.79	-1.7	0.8	-1.22	0.8
6	0.77	0.01	0.78	-1.67	0.77	-1.28	0.78
8	0.76	0	0.76	-1.69	0.75	-1.3	0.75
10	0.76	-0.43	0.75	-0.85	0.74	-1.22	0.74
12	0.75	-0.05	0.73	-1.7	0.72	-1.48	0.72
15	0.72	-0.07	0.71	-1.8	0.71	-1.39	0.71
18	0.71	-0.16	0.7	-1.81	0.67	-1.69	0.67
Average	0.75	-0.09286	0.745714	-1.60286	0.737143	-1.36857	0.73857
Std.dev.	0.02582	0.163372	0.034087	0.336537	0.042314	0.154018	0.04375

Table 1b: Electron Beam Flatness (10x10): At Depth of Maximum dose (dm) of respective energies.

Energies(MeV)	Cross Plane(CP)	CAD(mm)	In Plane(IP)	CAD(mm)	Diagonal			
	%		%		X	CAD	Y	CAD
4	0.84	0.09	0.84	0.43	0.86	0.69	0.86	-0.29
6	0.83	0.04	0.83	0.42	0.85	0.58	0.85	-0.27
8	0.82	0.04	0.82	0.42	0.82	0.61	0.82	-0.25
10	0.82	0.01	0.82	0.39	0.81	0.4	0.81	-0.25
12	0.81	0	0.81	0.37	0.79	0.38	0.8	-0.22
15	0.8	-0.06	0.8	0.32	0.78	0.26	0.78	-0.21
18	0.78	-0.08	0.78	0.32	0.75	0.24	0.75	-0.24
Average	0.814286	0.005714	0.814286	0.381429	0.808571	0.451429	0.81	-0.24714
Std.dev.	0.019881	0.065013	0.019881	0.046701	0.038914	0.176864	0.038297	0.027516

Table 1c: Electron Beam Flatness (14x14): At Depth of Maximum dose (dm) of respective energies.

Energies(MeV)	Cross Plane(CP)	CAD(mm)	In Plane(IP)	CAD(mm)	Diagonal			
	%		%		X	CAD	Y	CAD
4	0.88	-0.1	0.89	-4.96	0.87	-3.64	0.86	3.42
6	0.87	0.32	0.88	-3.22	0.88	-1.17	0.87	2.78
8	0.86	0.37	0.86	-3.25	0.86	-1.03	0.86	2.73
10	0.86	0.29	0.87	-3.39	0.87	-1.34	0.86	2.57
12	0.86	0.33	0.86	-3.39	0.86	-1.3	0.86	2.51
15	0.85	0.29	0.86	-3.44	0.85	-1.4	0.85	2.52
18	0.83	0.27	0.83	-3.42	0.79	-1.3	0.8	2.52
Average	0.858571	0.252857	0.864286	-3.58143	0.854286	-1.59714	0.851429	2.721429
Std.dev.	0.015736	0.15903	0.019024	0.613771	0.029921	0.909115	0.023401	0.326672

Table 1d: Electron Beam Flatness (20x20): At Depth of Maximum dose (dm) of respective energies.

showed the same type of decrement. The study showed that the flatness of electron beams obtained from the 729 2 D Array detector is well within the limit of 3%.

The symmetry of electron beams gradually decreases with the increase in electron beam energies. The average change in the electron beam symmetry for the applicator 6×6 to 14×14 cm² for the energies 4 MeV to 18 MeV is found to be 0.14% in Cross-Plane (CP) and 0.216% in In-Plane (IP). The maximum average change in CP and IP for symmetry is found for the applicator of 20×20 cm² (0.36% and 0.2%) respectively. This showed that the symmetry of electron beam slightly changes with electron energies but independent with Field sizes. The study showed that the symmetry of electron beams are well within the limit of 2% obtained from the 729 2D Array detector.

Energies(MeV)	Cross Plane	In Plane	Diagonal	
	(X-axis)%	(Y-axis)%	X	Y
4	0.08	0.39	0.38	0.33
6	0.02	0.23	0.22	0.23
8	0.01	0.14	0.14	0.15
10	0.03	0.03	0.03	0.07
12	0.06	0.03	0	0.08
15	0.09	0.02	0.02	0.08
18	0.06	0.02	0.03	0.06
Average	0.05	0.122857	0.117143	0.142857
Std.dev.	0.030551	0.142328	0.14056	0.10226

Table 2a: Electron Beam Symmetry (6x6): At Depth of Maximum dose (dm) of respective energies.

Energies(MeV)	Cross Plane	In Plane	Diagonal	
	(X-axis)%	(Y-axis)%	X	Y
4	0.51	0.24	1	0.12
6	0.31	0.25	0.86	0.32
8	0.29	0.14	0.75	0.22
10	0.02	0	0.36	0.11
12	0.01	0.02	0.38	0.36
15	0	0.1	0.32	0.28
18	0.01	0.03	0.42	0.36
Average	0.164286	0.111429	0.584286	0.252857
Std.dev.	0.204927	0.103349	0.27844	0.105942

Table 2b: Electron Beam Symmetry (10x10): At Depth of Maximum dose (dm) of respective energies.

Energies(MeV)	Cross Plane	In Plane	Diagonal	
	(X-axis)%	(Y-axis)%	X	Y
4	0.63	0.38	0.81	0.31
6	0.32	0.34	0.55	0.03
8	0.32	0.34	0.6	0.01
10	0.03	0.07	0.08	0.02
12	0.04	0.12	0.11	0.15
15	0.09	0.09	0.07	0.17
18	0.04	0.17	0.27	0.17
Average	0.21	0.215714	0.355714	0.122857
Std.dev.	0.225536	0.133023	0.296977	0.109

Table 2c: Electron Beam Symmetry (14x14): At Depth of Maximum dose (dm) of respective energies.
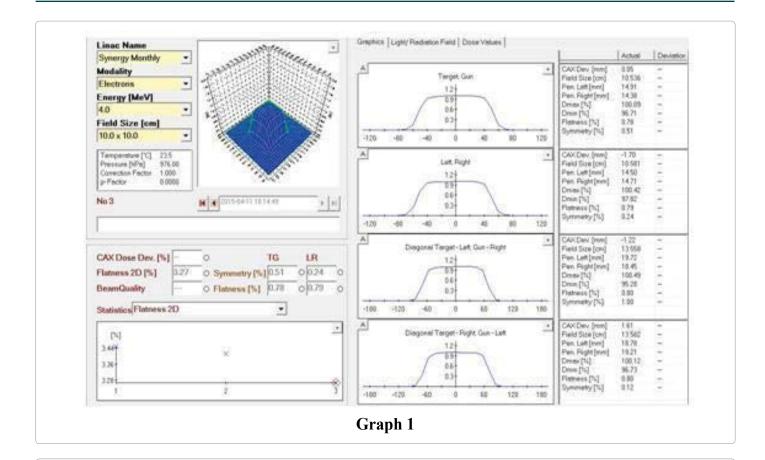
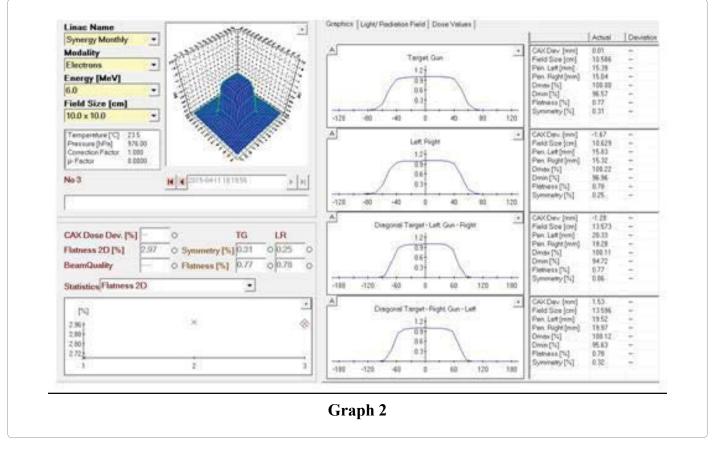| Energies(MeV)	Cross Plane	In Plane	Diagonal	
	(X-axis)%	(Y-axis)%	X	Y
4	1.05	0.05	1.19	0.64
6	0.63	0.22	0.8	0.37
8	0.65	0.42	1.04	0.31
10	0.09	0	0.02	0.2
12	0	0.21	0.11	0.06
15	0.03	0.2	0.13	0.04
18	0.12	0.3	0.38	0.09
Average	0.367143	0.2	0.524286	0.244286
Std.dev.	0.408604	0.142244	0.480862	0.215318

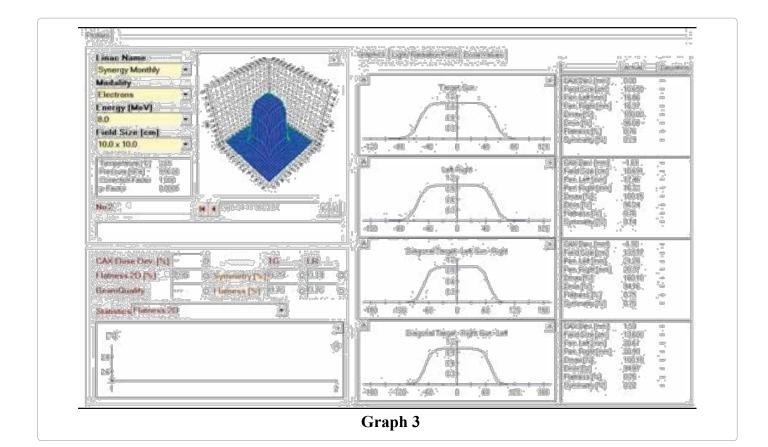**Table 2d:** Electron Beam Symmetry (20x20): At Depth of Maximum dose (dm) of respective energies.

The Graphs 1-7 shows the graphical representation of electron beam profiles (flatness, symmetry and diagonal) for the standard field size of 10×10 cm² for each electron energies (4,6,8,10,12,15 and 18 MeV).
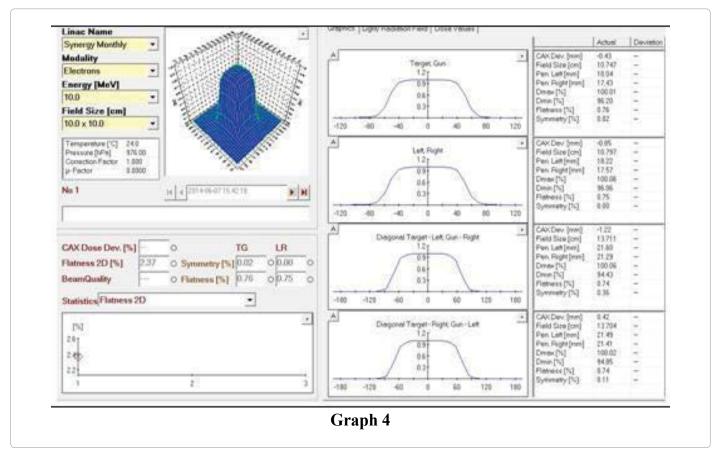
Conclusions

We found that there is no significant variation in Flatness and symmetry obtained from the 729 2D Array detector as compared to
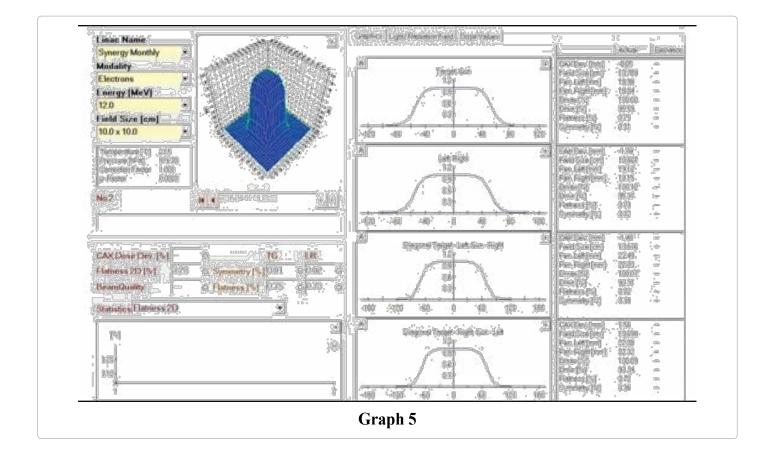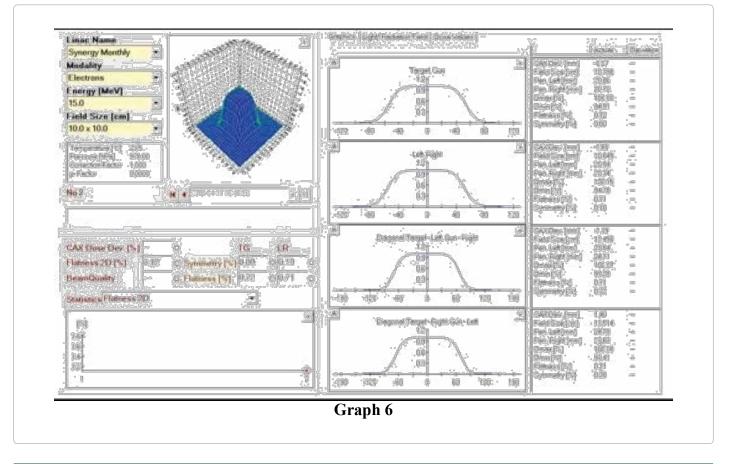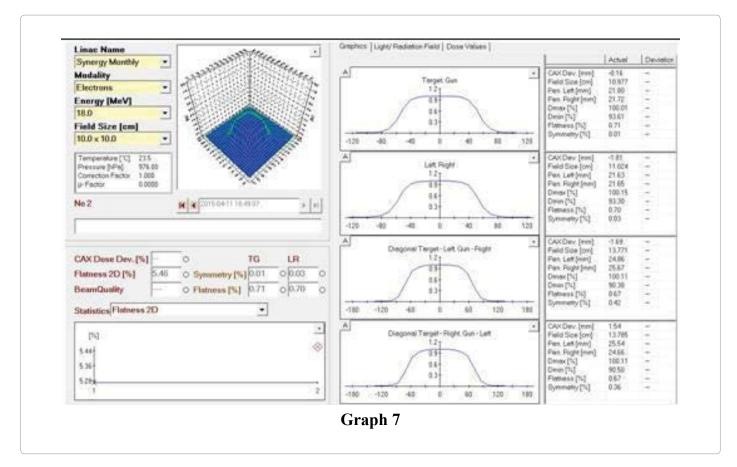
Graph 1

Graph 2

Graph 3

Graph 4

Graph 5

Graph 6

Graph 7

the standard Flatness and symmetry obtained from the RFA. Thus we conclude that 729 2 D Array detector can be used for the routine measurement of electron beam profiles.

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