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# Evaluating the performance of automated external contouring tool on dose calculation of treatment planning system

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**Original Article**

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## Abstract

*Introduction* The main goal of radiation therapy is to eradicate all cancer cells and minimize the damage to healthy tissues around the tumour. Treatment planning systems are used to predict the outcome of the treatment in terms of dose distribution prior to the treatment. One of the most reliable dose calculation algorithms is Monte Carlo. The aim of this study is to evaluate the performance of automated external contouring tool on dose calculation using Monte Carlo algorithm.

*Materials and methods* The external contour of thorax phantom was created by automated tools of Monaco treatment planning system, and then, the IAEA-TECDOC-1583 quality assurance tests were created. Then, the treatment plans were delivered to the phantom, and the dose was measured by the Farmer ionization chamber at specific points. The external contour was corrected according to the source surface distances (SSD) which are mentioned in TECDOC-1583, and the dose was re-calculated. Finally, a comparison was made between the results.

*Results* Dosimetric tests of TECDOC-1583 showed the errors ranged from −2·8% to +2·5%. In case of editing external contour and omitting fluctuations, the errors were decreased. The comparisons indicated that the most significant variation occurred in test 4 and the least changes were related to the tests 1 and 3.

*Conclusions* The results of the study showed that the fluctuations of the external contour affect the calculated volume of the phantom and thus the dose. In order to obtain correct results, automated external contouring tools should be used with the correct instructions and re-checked before treatment planning.

## Introduction

Based on the reports of ICRU No. 24, 46 and AAPM TG 43, 65 and 105, the accuracy of different parts of radiotherapy such as contouring, treatment planning and dose calculation, patient setup and dose delivery should be less than 5% of the actual values.[1–5] According to these reports, the error rate due to the treatment planning system (TPS) including dose calculations, algorithms and model fitting, dose display, dose volume histograms, etc should be less than 2 to 3%.[6] Thus, an accurate and efficient treatment requires a variety of quality assurance (QA) tests. To reduce the errors due to calculations, since 1950, dose calculation algorithms in planning systems have been widely developed.[7]

The performance and quality of any TPS depends on the type of its algorithms. In other words, dose calculation algorithms are one of the most important foundations of TPSs. Modern TPSs use advanced model-based numerical algorithms that are implemented to calculate the dose distribution based on physical laws and decompose the radiation beam into primary and secondary components considering each separately. Moreover, in such algorithms changes of scattering due to the variations in the beam shape, beam intensity, patient geometry and tissue heterogeneity are taken into account.[8] A TPS must not only consider all physical parameters of the beam interaction with the tissue but also must have acceptable accuracy in performing the calculations.[9] The Monte Carlo (MC) techniques are based on the transport of each individual particle (e.g., photon or electron) in the tissue. The transport of the particle is done using the physics of the interaction of the particles with the matter. It is a random method for creating dose distributions. This method calculates the dose distribution by following the history of numerous particles and their interactions with patient's body components. Therefore, among all dose calculation algorithms, MC gives the best accuracy.[5]

In order to calculate the dose, each TPS needs the exact amount of the volume and the border of the patient's body known as external contour. By determining this parameter, the TPS will be able to perform dose calculations within that volume using the dose calculation algorithm.[10,11] To acquire the external contour, most of the TPSs have automated tools. With these tools,



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a curve is created around the skin which is highly contrasted due to the differences in Hounsfield Units between the patient's body and the region around that. The created curves determine the volume of the patient's body inside the TPS.[12]

The delineated volume of patient's body can affect the amount of scattered rays, and the final fate of the particles which is very important in MC calculations. Therefore, the accuracy of external contour created by automated tools of the TPS might affect the calculated dose. The purpose of this study is to investigate the accuracy of automated external contouring tools and its effect on dose calculations using MC algorithm.

## Methods and Materials

In this study, Monaco TPS (Elekta Co. USA) was used for calculations. Monaco supports all electron and photon treatment modalities including 3D conformal radiotherapy, intensity-modulated radiotherapy, and volumetric-modulated arc therapy. Its contouring package includes 2D, 3D and 4D automatic contouring and EZ Sketch function. Biological modelling and sensitivity analysis are the other features of this TPS. It has two computational algorithms, Collapsed Cone and MC. As mentioned above, since MC is based on transporting each particle, it is known as the most accurate algorithm for dose calculation and will be used in this study.[13]

In order to verify the QA of the Monaco TPS, the guidelines described in TECDOC-1583 of International Atomic Energy Agency (IAEA) including acceptance, commissioning and QA testing were performed (Table 1).[14]

At the onset of the study, the Electron Density phantom model 062M known as CT-ED phantom and Thorax phantom Model 002LFC, both from CIRS company (CIRS Co., USA), were scanned by GE 16 slices CT scanner with 110 kVp energy and slice thickness of 1 mm (Fig. 1). At the next step, the relative electron density conversion (CT-ED curve) was determined and used as an input in the TPS. These data have a fundamental role in the dose calculation of Monaco, because it assigns the interaction probabilities and stopping powers to each voxel based on its mass density. It converts CT numbers to EDs using the created CT-ED curve.[15]

The CT images of the CIRS thorax phantom with DICOM format were imported to Monaco TPS afterwards, and then using the automated contouring tools of the TPS, the external contour of the phantom which is the boundary between the treatment couch, air and the phantom was determined. Then, according to the instructions provided by the IAEA-TECDOC-1583, various dosimetric tests were performed, and considering the dose to water ($D_w$) conversion,[5] the dose calculations were done using the MC algorithm.

Irradiation was delivered by 6MV photon beams using Elekta synergy platform linear accelerator (linac). Then according to the instructions provided by the IAEA-TECDOC-1583, the dose measurements of previously calculated plans were performed by the Farmer ionization chamber (PTW, Freiburg, Germany). Then, the results of the TPS and ion chamber were compared and the error of each test was reported using equation 1.[14]

$$Error\ (\%) = 100 \times \left( \frac{D_{cal} - D_{meas}}{D_{meas,ref}} \right) \tag{1}$$

where ($D_{meas}$), ($D_{cal}$) and $D_{meas,ref}$ are the measured, calculated and the dose value measured at the reference point, respectively. This reference point is specified for each test case.[14]

As it is shown in Fig. 2, the external contour created by automated tools of the TPS has fluctuations. This caused the volume of the phantom to be calculated conflictingly compared to the actual value, and consequently, the source to surface distances (SSDs) of some tests in the TPS appeared slightly different than the actual values. Therefore, to evaluate the effects of this issue on MC dose calculations, the fluctuations of the external contour were smoothed manually by editing the sharp edges, and then, the dose calculation of each test was done again. Accordingly, the results were then compared to the measured values and the error of each test was reported based on equation 1 (Table 3).

## Results

Figure 3 depicts the CT-ED curve which was obtained by scanning the CIRS Electron Density Phantom model 062M. This curve indicates the correlation of CT number and relative electron density of different tissues, and Monaco uses this curve to assign the electron density to the voxels and calculates the dose.

Table 2 shows the results of the tests proposed by IAEA-TECDOC-1583. In these tests, the external contour was created by automated tools, and due to the fluctuations, the isocentre position and SSD of some tests were different than the values reported in TECDOC-1583. Also, the results of the measured doses obtained by Farmer ionization chamber and the comparisons with the TPS values, using equation (1), are listed in Table 2.

At the next step, the external contour was edited manually which led the values of SSDs to be matched with those reported in the TECDOC-1583. Then, the doses of certain points were re-calculated. The results of new calculations and comparisons between TPS calculations and SSD variations are shown in Table 3. It should be noted that MC does not support wedge calculations in Monaco TPS. Therefore, the quantified evaluation of the effect of external contour fluctuations on dose calculation could not be done in the tests with wedge.

Comparing the results of Tables 2 and 3 reveals that editing the fluctuations of external contour can lead to more accurate results. For example, the fluctuations of external contour caused 0·15 cm deviation in SSD of test 5, point 2 and editing the external contour decreased the error from 1·2 to 0·2%.

Also, the comparisons indicated that the most significant variation occurred in test 4, and the least changes were related to the tests 1 and 3 in which SSDs were 100 cm.

## Discussion

One of the initial steps of treatment planning is to specify the volume of the object, phantom or the patient. This volume is known as the external contour and segregates the couch and air from the object. The accuracy of SSD which is calculated by the TPS depends on the external contour. On the other hand, the principle of MC calculation is tracking the individual particles within a specified volume. It is done by sampling appropriate quantities from the probability distributions governing the individual physical processes, using machine-generated random numbers.[16]

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**Table 1.** The list of dosimetric tests proposed by IAEA-TECDOC-1583[14]

| Test no. | Description of the test | Ref point | Meas point | Agreement criteria (%) |
|---|---|---|---|---|
| 1 | *Testing for reference conditions based on CT data* | 3 | 1 | 2 |
| | | | 3 | 2 |
| | | | 5 | 2 |
| | | | 9 | 4 |
| | | | 10 | 3 |
| | SSD: 100 cm, field size: $10 \times 10$ cm$^2$, gantry angle 0°, Coll angle 0° | | | |
| | Deliver 2 Gy to point 3 | | | |
| 2 | *Oblique incidence, lack of scattering and tangential fields* | 1 | 1 | 3 |
| | SAD technique, field size: $10 \times 15$ cm$^2$, wedge Angle : 45°, gantry angle 90°, coll angle depend on wedge orientation. | | | |
| | Deliver 2 Gy to point 1 | | | |
| 3 | *Significant blocking of the field corners* | 3 | 3 | 3 |
| | SSD: 100 cm, field size: $14 \times 14$ cm$^2$ blocked to a $10 \times 10$ cm$^2$, gantry angle 0°, coll angle 45° | | | |
| | Deliver 2 Gy to point 3 | | | |
| 4 | *Four field box* | 5 | 5 | F1:0° 2 |
| | | | | F2:90° 3 |
| | | | | F3:180° 3 |
| | | | | F4:270° 3 |
| | | | 6 | F1:0° 4 |
| | | | | F2:90° 3 |
| | | | | F3:180° 4 |
| | | | | F4:270° 3 |
| | | | 10 | F1:0° 3 |
| | | | | F2:90° 4 |
| | | | | F3:180° 3 |
| | | | | F4:270° 4 |
| | SAD technique, coll angle 0°, field size: 15 × 10 Ant, 15 × 10 Post, 15 × 8 RL, 15 × 8 LL | | | |
| | Deliver 2 Gy to point 5 | | | |
| 5 | *Automatic expansion and customized blocking* | 2 | 2 | 2 |
| | | | 7 | 4 |
| | SAD technique, field size: cylinder of 8 cm diameter and 8 cm long, gantry angle 0°, coll angle 45° | | | |
| | Deliver 2 Gy to point 2 | | | |
| 6 | *Oblique incidence with irregular field and blocking the centre of the field* | 3 | 3 | 3 |
| | | | 7 | 4 |
| | | | 10 | 5 |
| | SAD technique, field size: L-shaped 10 × 20, gantry angle 45°, coll angle 90° | | | |
| | Deliver 2 Gy to point 3 | | | |
| 7 | *Three fields, two wedge-paired, asymmetric collimation* | 5 | 5 | F1:0° 2 |
| | | | | F2:90° 4 |
| | | | | F3:270° 4 |
| | SAD technique, field size: 10 × 12 10 × 6 assym 10 × 6 assym, gantry angle: 0 °, 90°, 270°, wedge angle: 0° for Ant beam, according to wedge orientation for laterals. | | | |
| | Deliver 2 Gy to point 5 | | | |

(*Continued*)

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**Table 1.** (*Continued*)

| Test no. | Description of the test | Ref point | Meas point | Agreement criteria (%) |
|---|---|---|---|---|
| 8 | *Non-coplanar beams with couch and collimator rotation* | 5 | 5 | F1:30° 3 |
| | | | | F2:90° 3 |
| | | | | F3:270° 3 |
| | SAD technique, field size: 4 × 16 LL 4 × 16 RL 4 × 4 (table 270), gantry angle: 90°, 270°, 30°, coll angle: 330°, 30°, 0° | | | |
| | Deliver 2 Gy to point 5 | | | |

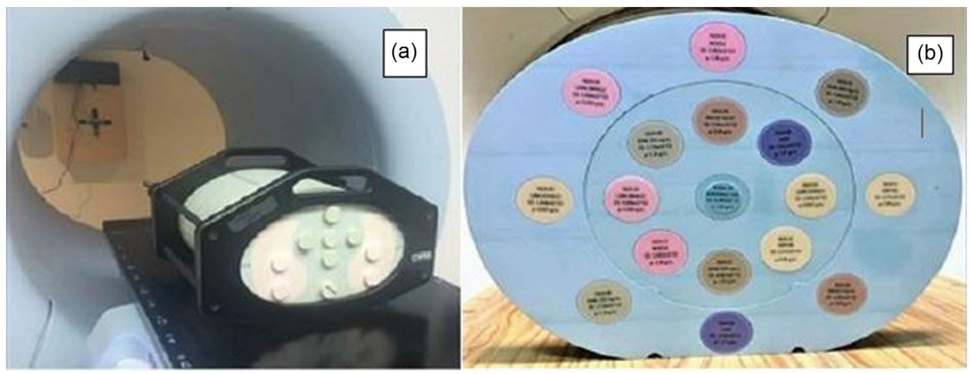

**Figure 1.** (a) Adjusting the thorax phantom and (b) CT-ED phantom.

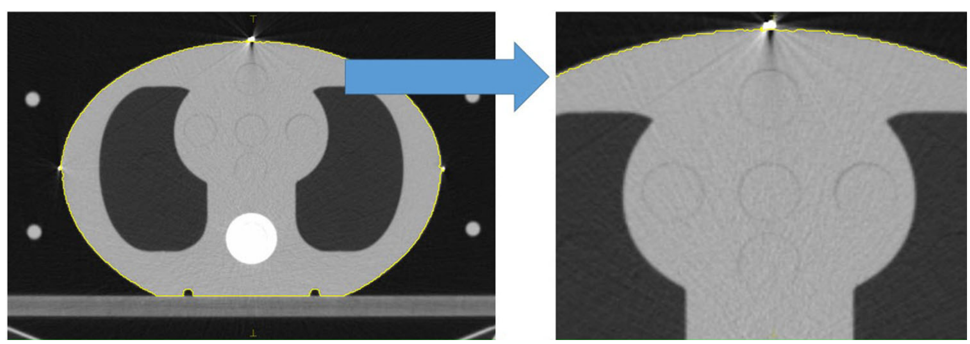
**Figure 2.** The fluctuations of external contour caused by automated tools.

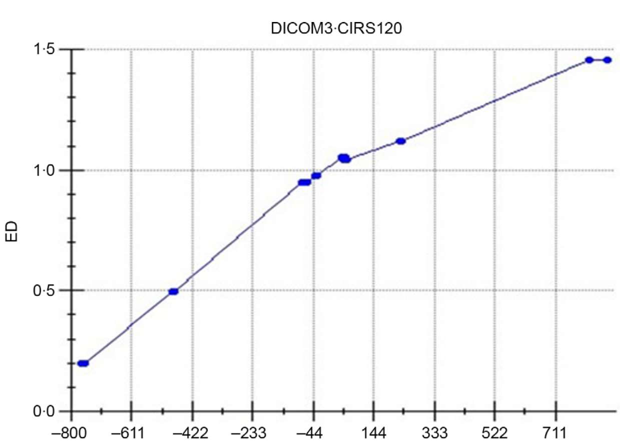

**Figure 3.** CT-ED curve.

Since MC tracks the particles until they lose their energy, the volume in which this particle tracking is done might affect the calculated dose. In routine radiotherapy workflow, the volume of the patient is obtained with the external contour, and it is usually created by automated tools of the TPSs, causing some fluctuations on the contour and consequently creating a volume that can be different compared to the real value.[17] The quantitative effects of these fluctuations on MC dose calculations were investigated in this study.

Two sets of dosimetric tests proposed by IAEA-TECDOC-1583 were done on Monaco TPS. In one category, the external contour was determined by TPS; in the second set, the external contour was modified manually to smooth the fluctuations and the results were then compared with those of the measurements.

According to the results in Table 2 and based on the equation (1), dosimetric tests of TECDOC-1583 showed the errors ranged from −2·8% to +2·5%. Then, according to Table 3 and using the same

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**Table 2.** Results of dosimetric tests proposed by IAEA-TECDOC-1583. The external contour of the phantom is created by automated tools

| Test number | Calculated dose by TPS | Measured dose by ion chamber | Error (%) |
|---|---|---|---|
| Test 1 | D3 = 0·789 | D3 = 0·783 | 0·8 |
| | D9 = 0·069 | D9 = 0·073 | −0·5 |
| | D10 = 0·481 | D10 = 0·501 | −2·5 |
| Test 2 | Due to the existence of wedge, MC algorithm could be used. | Due to the existence of wedge, MC algorithm could be used. | – |
| Test 3 | D3 = 0·776 | D3 = 0·778 | −0·2 |
| Test 4 | D5(G0) = 2 | D5(G0) = 1·983 | 0·8 |
| | D5(G90) = 2 | D5(G90) = 1·994 | 0·3 |
| | D5(G180) = 2 | D5(G180) = 2·057 | −2·8 |
| | D5(G270) = 2 | D5(G270) = 2·009 | −0·4 |
| | – | – | – |
| | D6(G0) = 0·161 | D6(G0) = 0·143 | 0·9 |
| | D6(G90) = 1·356 | D6(G90) = 1·348 | 0·4 |
| | D6(G180) = 0·203 | D6(G180) = 0·183 | 1·0 |
| | D6(G270) = 2·726 | D6(G270) = 2·700 | 1·3 |
| | – | – | – |
| | D10(G0) = 1·447 | D10(G0) = 1·464 | −0·9 |
| | D10(G90) = 0·160 | D10(G90) = 0·153 | 0·3 |
| | D10(G180) = 2·836 | D10(G180) = 2·847 | −0·5 |
| | D10(G280) = 0·162 | D10(G280) = 0·151 | 0·5 |
| Test 5 | D2 = 0·923 | D2 = 0·913 | 1·2 |
| | D7 = 0·801 | D7 = 0·783 | 2 |
| Test 6 | D3 = 0·838 | D3 = 0·841 | −0·3 |
| | D7 = 0·467 | D7 = 0·466 | 0·1 |
| | D10 = 0·050 | D10 = 0·048 | 0·3 |
| Test 7 | D5(G0) = 0·779 | D5(G0) = 0·770 | 1·2 |
| | D5 (G90): Due to the existence of wedge in this field, MC algorithm could not be used. | D5(G90): Due to the existence of wedge in this field, Monte Carlo algorithm cannot be used. | – |
| | D5 (G270) = Due to the existence of wedge in this field, MC algorithm could not be used. | D5(G270) = Due to the existence of wedge in this field, MC algorithm could not be used. | |
| Test 8 | D5(G0) = 0·676 | D5(G0) = 0.V673 | 0·5 |
| | D5(G90) = 0·773 | D5(G90) = 0·755 | 2·4 |
| | D5(G270) = 0·768 | D5(G270) = 0·759 | 1·2 |

equation, in case of editing external contour manually and omitting the fluctuations, the errors ranged from −2·5% to +2·3 %. The comparisons indicate that the most significant variation occurred in test 4, and the least changes were related to the tests 1 and 3.

Each TPS with automated contouring tools has certain instructions to use, and to get the correct results, it is very important to follow those instructions.[17,18] In case of executing wrong steps in creating external contour, delineation of the patient's body will not show correct volume in the TPS. Therefore, as shown in Table 3, it will affect dose calculations.

## Conclusion

The results of this study showed that the fluctuations of the external contour created by automated contouring tools cause changes in the calculated volume and consequently the calculated dose. Based on the type of the TPS and the way of executing the steps of creating external contour, there might be a variation in the calculated dose. Therefore, it is important to use automated tools of contouring with caution and check the accuracy of the contours before treatment planning.

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**Table 3.** Results of dosimetric tests proposed by IAEA-TECDOC-1583. The fluctuations of the external contour are modified manually

| Test number | Calculated dose by TPS when contour was corrected | Measured dose by ion chamber | Error (%) | SSD reported by TECDOC-1583 | SSD calculated by TPS |
|---|---|---|---|---|---|
| Test 1 | D3 = 0·789 | D3 = 0·783 | 0·8 | SSD1 = 100 | $SSD_1$ = 100 |
| | D9 = 0·069 | D9 = 0·073 | −0·5 | | |
| | D10 = 0·481 | D10 = 0·501 | −2·5 | | |
| Test 2 | Due to the existence of wedge in this field, Monte Carlo algorithm cannot be used. | Due to the existence of wedge in this field, Monte Carlo algorithm cannot be used. | – | Due to the existence of wedge in this field, Monte Carlo algorithm cannot be used. | Due to the existence of wedge in this field, Monte Carlo algorithm cannot be used. |
| Test 3 | D3 = 0·776 | D3 = 0·778 | −0·2 | $SSD_1$ = 100 | $SSD_1$ = 100 |
| Test 4 | D5(G0) = 1·99 | D5(G0) = 1·983 | 0·3 | $SSD_1$ = 90 | |
| | D5(G90) = 1·998 | D5(G90) = 1·994 | 0·2 | $SSD_2$ = 85 | |
| | D5(G180) = 2·08 | D5(G180) = 2·057 | 1·1 | $SSD_3$ = 85 | |
| | D5(G270) = 2·000 | D5(G270) = 2·009 | −0·4 | $SSD_4$ = 90 | |
| | – | – | – | | |
| | D6(G0) = 0·151 | D6(G0) = 0·143 | 0·4 | | |
| | D6(G90) = 1·350 | D6(G90) = 1·348 | 0·1 | | |
| | D6(G180) = 0·192 | D6(G180) = 0·183 | 0·4 | | |
| | D6(G270) = 2·71 | D6(G270) = 2·700 | 0·4 | | |
| | – | – | – | | |
| | D10(G0) = 1·467 | D10(G0) = 1·464 | 0·1 | | $SSD_1$ = 90·02 |
| | D10(G90) = 0·152 | D10(G90) = 0·153 | −0·05 | | $SSD_2$ = 85·01 |
| | D10(G180) = 2·850 | D10(G180) = 2·847 | 0·1 | | $SSD_3$ = 85·1 |
| | D10(G280) = 0·152 | D10(G280) = 0·151 | 0·04 | | $SSD_4$ = 89·91 |
| Test 5 | D2 = 0·915 | D2 = 0·913 | 0·2 | $SSD_1$ = 93·4 | $SSD_1$ = 93·25 |
| | D7 = 0·785 | D7 = 0·783 | 0·2 | | |
| Test 6 | D3 = 0·839 | D3 = 0·841 | −0·2 | $SSD_1$ = 88·3 | $SSD_1$ = 88·19 |
| | D7 = 0·465 | D7 = 0·466 | −0·1 | | |
| | D10 = 0·049 | D10 = 0·048 | 0·1 | | |
| Test 7 | D5(G0) = 0·771 | D5(G0) = 0·770 | 0·1 | | |
| | D5(G90): Due to the existence of wedge in this field, Monte Carlo algorithm cannot be used. | D5(G90): Due to the existence of wedge in this field, Monte Carlo algorithm cannot be used. | – | $SSD_1$ = 93 | SSD1 = 92·89 |
| | D5(G270): Due to the existence of wedge in this field, Monte Carlo algorithm cannot be used. | D5(G270): Due to the existence of wedge in this field, Monte Carlo algorithm cannot be used. | – | Due to the existence of wedge in this field, Monte Carlo algorithm cannot be used. | Due to the existence of wedge in this field, Monte Carlo algorithm cannot be used. |
| Test 8 | D5(G0) = 0·671 | D5(G0) = 0·673 | −0·2 | $SSD_1$ = 88·5 | $SSD_1$ = 88·38 |
| | D5(G90) = 0·773 | D5(G90) = 0·755 | 2·4 | $SSD_2$ = 85 | $SSD_2$ = 85 |
| | D5(G270) = 0·768 | D5(G270) = 0·759 | 1·2 | $SSD_3$ = 85 | $SSD_3$ = 85 |

**Competing interests.** None.

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