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Original Article

Dose Assessment of Phosphorus-32 (^{32}P) for the Treatment of Recurrent Pterygium

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Abstract

Introduction

Pterygium is a wing-shaped, vascular, fleshy growth that originates from the conjunctiva and can spread into the corneal limbus and beyond. Beta irradiation after bare sclera surgery of primary pterygium is a simple, effective, and safe treatment, which reduces the risk of local recurrence.

Materials and Methods

Dosimetric components of strontium-90 (^{90}Sr), phosphorous-32 (^{32}P), and ruthenium-106 (^{106}Ru), in form of ophthalmic applicators, were evaluated, using the Monte Carlo method.

Results

The obtained results indicated that ^{32}P applicator could deliver higher doses (about 10 Gy) to a target, located within a close distance from the surface, compared to ^{90}Sr and ^{106}Ru; it also delivered a lower dose to normal tissues.

Conclusion

The risk of pterygium has increased given the geographical location and climate of Iran. Spread of dust in the country over the past few years has also contributed to the rising rate of this condition. Our results showed that using ^{32}P applicator is a cost-effective method for pterygium treatment.

Keywords: Pterygium, ^{32}P applicator, Monte Carlo method, MCNP.

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1. Introduction

Pterygium is a wing-shaped, vascular, fleshy growth that originates from the conjunctiva and can spread into the corneal limbus and beyond.One of the most important factors in the development of pterygium is exposure to ultraviolet rays and dust.

Most patients with pterygium reside in hot and dry regions, specially near the equator below a latitude of 40°. After cataract, pterygium is the most common eye disease. Since Iran is located in a latitude below 40°, many parts of the country have hot and dry weather; therefore, there is a high possibility of pterygium development.[1]

since pure surgery results in a high recurrence rate, ranging from 30% to 50% [1, 2]. Critical organs for radiation therapy include all parts of the eye, particularly the lens. In fact, the lens and other sensitive organs at the anterior segment of the eye should be studied in terms of delivered doses. [3]

Studies have shown that single or fractionated β-irradiation is a simple, effective, and safe treatment, which can reduce the risk of local recurrence after bare sclera surgery of primary petrygium [4-6]. Strontium-90/yttrium-90 ($^{90}Sr/^{90}Y$) applicator is used as a pure beta emitter with a maximum energy of 2.28 MeV (from ^{90}Y for postoperative irradiation after pterygium excision.

High-energy beta radiation of $^{90}Sr/^{90}Y$ can deliver therapeutic doses to the conjunctiva tendon at a 1mm distance from the applicator surface. However, $^{90}Sr/^{90}Y$ pair requires a heavy radiochemical processing for its production from the fission fragments of a nuclear reactor. This pair is classified as highly hazardous radioactive material due to its long half-life (28.8 y); in addition, its production and application require great precautions. [7]

In some cases, irradiation is performed by ^{106}Ru applicators [8]. International Committee on Radiation Units and Measurements (ICRU) is one of the most authoritative references, which has discussed the dosimetry of low-energy gamma- and beta-emitter sources (such as ^{90}Sr and ^{106}Ru ophthalmic applicators) in its 72nd report.

Phosphorous-32 (^{32}P) applicator, similar to ^{90}Sr and ^{106}Ru applicators can be considered for the treatment of pterygium and other surface lesions, given its average energy of 0.7 MeV, which is comparable to the average energy of emitted betas from $^{90}Sr/^{90}Y$ (0.9 MeV). In addition, production of ^{32}P through fast or thermal neutron activation is more facilitated in a nuclear reactor, compared to ^{90}Sr and ^{106}Ru . [7]

In this study, we evaluated dosimetric parameters for applying pure beta-emitter sources of ^{90}Sr, ^{32}P, and ^{106}Ru, in form of ophthalmic applicators, using Monte Carlo method (MCNP code) to calculate dose distribution.

2. Materials and Methods

MCNPX code was employed for modeling ^{90}Sr, ^{106}Ru, and ^{32}P ophthalmic applicators, as well as phantom; then, dose distribution along the central axis of the applicator was evaluated.

2.1. Specifications of sources

^{90}Sr is a pure beta emitter with a half-life of 29.12 y, a maximum beta energy (E_{max}) of 546 keV, and a mean kinetic energy ($<E_\beta>$) of 196 keV. This isotope transforms into ^{90}Y. ^{90}Y, with a half-life of 64.1 h, emits beta particles with an E_{max} of 2.28 MeV ($<E_\beta>$ =0.933 keV). Figure 1 shows the spectrum of emitted beta from $^{90}Sr/^{90}Y$. ^{106}Ru transforms into rhodium-106 (^{106}Rh), with a half-life of 368.2 days. ^{106}Rh decays with a half-life of 2.2 h into stable palladium-109 (^{109}Pd). The radionuclide ^{106}Ru emits beta particles with E_{max} =39 keV and $<E_\beta>$ =10 keV, while ^{106}Rh emits beta particles with E_{max}=3.54 MeV and $<E_\beta>$ = 1.428 MeV.

Beta energy spectrum is shown in Figure 2. Also, ^{32}P with a half-life of 14.26 days emits beta particles with an E_{max} of 1.17 MeV ($<E_\beta>$ =0,695 MeV). Beta energy spectrum of ^{32}P is shown in Figure 3. [7]

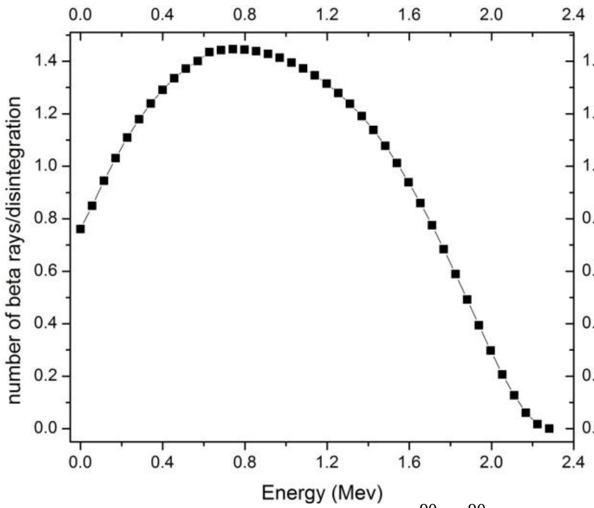

Figure 1. The energy spectrum of $^{90}Sr/^{90}Y$ [7]

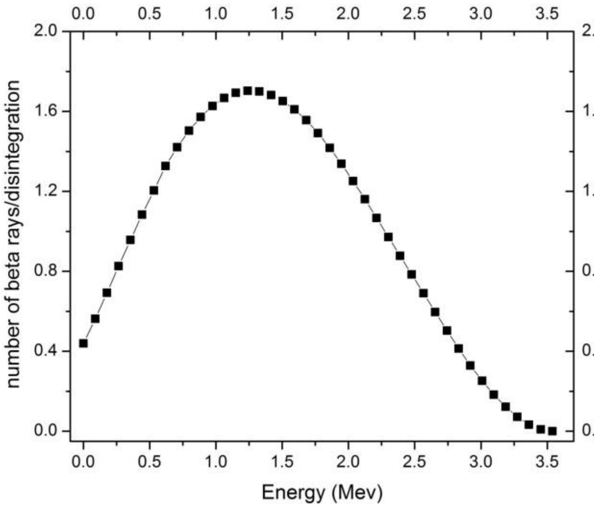

Figure 2. The energy spectrum of 106Ru/106Rh [7]

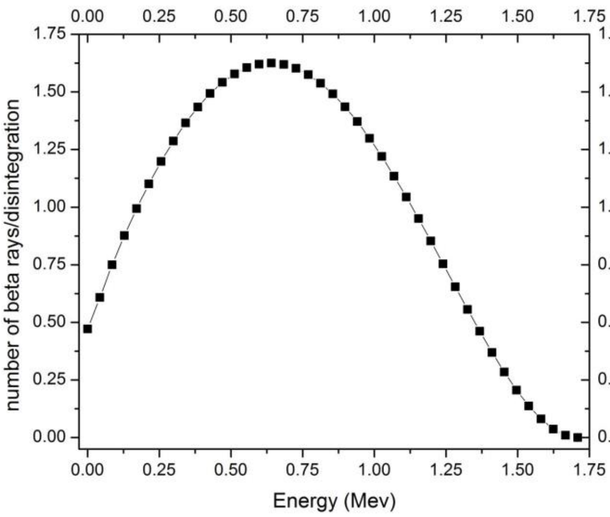

Figure 3. The energy spectrum of 32P [7]

2.2. Applicator specifications

^{106}Ru applicator specifications were based on the information provided by the 72nd report of ICRU. This applicator consists of an entrance window with a thickness of 0.1 mm (made of silver), an active layer with a radius of 10 mm, and a layer on the back of the active layer (made of silver) with a thickness of 1 mm (Figure 4 (a)). ^{90}Sr and ^{32}P applicators were also simulated based on the specifications of NB-1 English model Manufactured by New England Nuclear Corporation. It consisted of a steel cup with an entrance window (thickness of 0.1mm and Diameter of 10.3mm), an active ceramic layer with a thickness of 1mm, and a tungsten layer with a thickness of 3mm behind it. Finally, the steel plate with 2.7mm thickness was used (Figure 4 (b)). [7]

2.3.Phantom and dosimetry method

In order to calculate the depth dose, the applicator was simulated in front of the Plexiglass cube with a dimension of 10 cm^3. Afterwards, the received dose and percentage depth dose (PDD) were calculated using *F8 tally within spheres with a radius of 0.2 mm and a 0.1 mm distance of 0.1 mm along the central axis of the applicator. For calculating the dose profile, spheres in parallel with the applicator surface (in 0.15 mm and 1.35 mm distances from the applicator surface, respectively) were simulated. In all simulations, the relative error of the data was less than 4%.

In order to irradiate the surgical excision location of the pterygium, a total dose of 25-60 Gy is usually prescribed. This fractional dose (with a fraction of about 10 Gy) is delivered to the eyes, and in most cases, the desired depth for irradiation ranges from 0 to less than 4 mm [1, 9]. To compare the delivered doses, a reference point at the depth of 2 mm and a prescribed dose of 10 Gy were assumed. By calculating the absorbed dose rate at this point, the amount of the absorbed dose and treatment duration in the depth of the eye were measured for all three applicators.

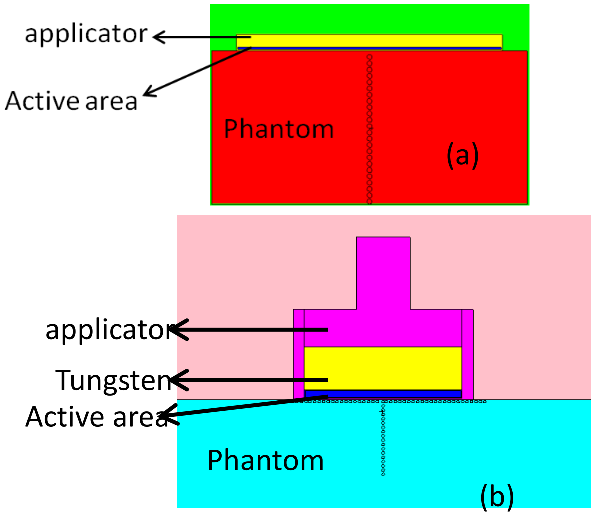

Figure 4. Simulated geometry of applicators from ICRU-72 (a) Ru-106 (B) Sr-90 and P-32

3. Results

In Table 1, the dose rate and treatment duration for different sources (per activity of 1mCi) are shown. Figure 5 shows the absolute doses at different depths along the central axis of the applicator. In Figure 6, PDD of various sources has been shown. Figures 7 and 8 represent the dose profiles of ^{90}Sr, ^{32}P, and ^{106}Ru at depths of 0.15mm and 1.35 mm, respectively.

Table 1. Dose rate and treatment duration of various sources

Source	^{106}Ru	^{90}Sr	^{32}P
Dose Rate (Gy/h)	4.42	16.6	3.30
Treatment duration (min)	135.75	36.14	181.82

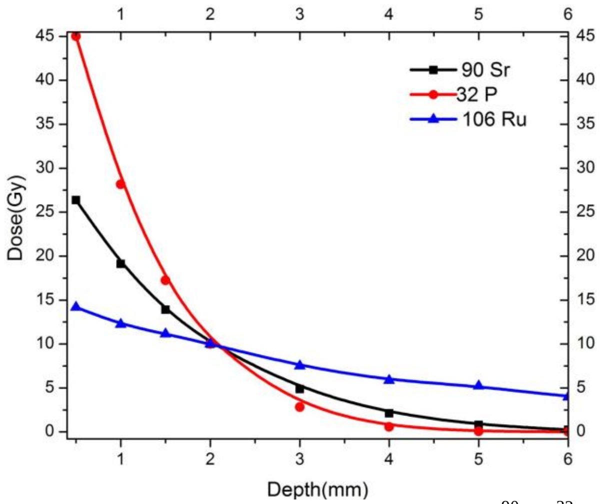

Figure 5. absolute doses at various depths by ^{90}Sr, ^{32}P and ^{106}Ru

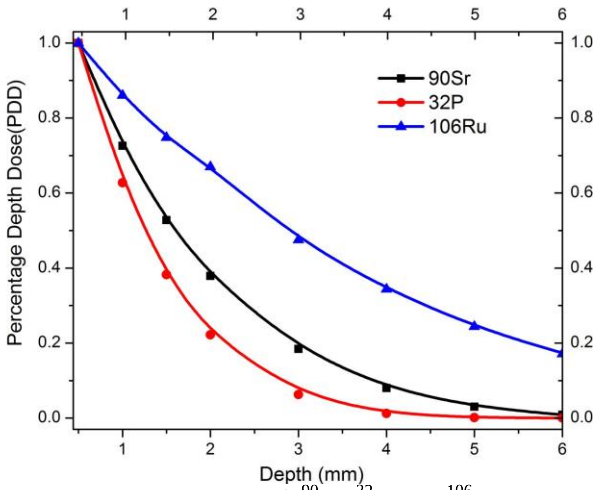

Figure 6. PDD of ^{90}Sr, ^{32}P, and ^{106}Ru

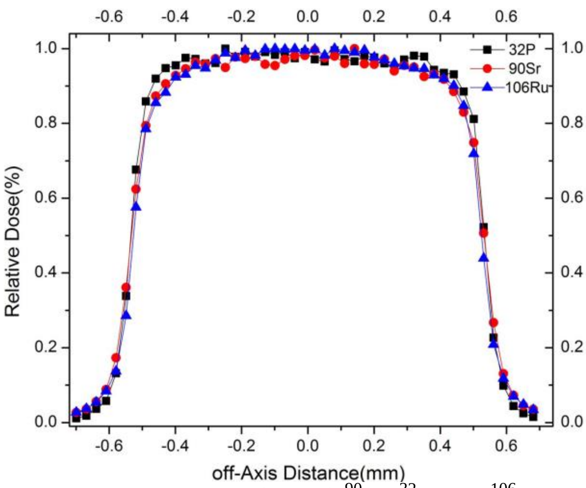

Figure 7. The dose profiles of ^{90}Sr, ^{32}P, and ^{106}Ru in a depth of 0.15mm

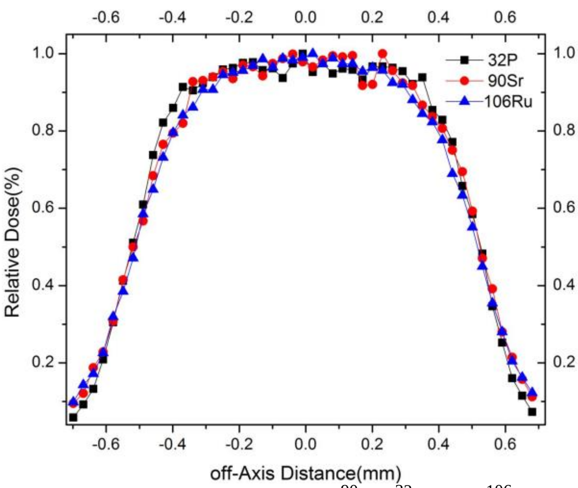

Figure 8. The dose profiles of ^{90}Sr, ^{32}P, and ^{106}Ru in a depth of 1.35mm

For validating our study results, the obtained findings were compared with the data presented in the 72nd report of ICRU [7]. Figure9 shows the absorbed dose percentage at intervals of 0 to 6 mm in our simulation and ICRU report. The difference between the present findings and the practical results of ICRU is 7%, which shows a good agreement between the results.

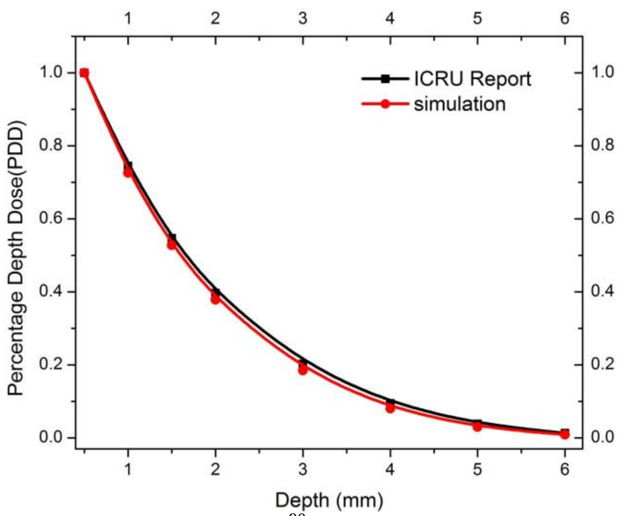

Figure 9. PDD of ^{90}Sr and ICRU report

4. Discussion

As shown in Figures 5 and 6, ^{32}P could deliver higher doses to a target located within a close distance from the surface, compared to ^{90}Sr and ^{106}Ru; it also could deliver lower doses to healthy tissues, located on the back of the target.

In this study, given that the prescribed dose of 10Gy was absorbed at a depth of 2 mm, the received doses to the surface of eyeballs for ^{32}P, ^{90}Sr, and ^{106}Ru were 45.2, 26.37, and 14.94 Gy, respectively. At a 5mm distance from the surface of the eyeball, where the lens is at risk, the absorbed dose of the three above radioisotopes were calculated as 2.82, 4.87, and 7.10 Gy, respectively (Figure 5).

As the results indicated, use of ^{32}P applicator, instead of ^{90}Sr and ^{106}Ru applicators, results in a lower absorbed dose to normal tissues at the back of a tumor (including the lens); therefore, it is less likely to develop cataracts in the eye (given the dose of 4 Gy and higher). As shown in Figures 7 and 8, as the distance from the central axis increases, the dose gradient of ^{32}P increases more than ^{90}Sr and ^{106}Ru gradients. Therefore, ^{32}P delivers a lower dose to healthy tissues in a lateral distance from the tumor.

According to Table 1, the dose rates resulting from phosphorus, strontium, and ruthenium at a depth of 2 mm are 3.30, 16.6, and 4.42 Gy/h, respectively; thus, the duration of irradiating the pterygium excision site by ^{32}P would be longer, compared to ^{90}Sr and ^{106}Ru. Given that ^{90}Sr/^{90}Y treatment duration is approximately 30 seconds, the treatment duration of ^{32}P is estimated at 150 seconds (these durations are comparable).

^{32}P can be used as a suitable substitute for ^{90}Sr in clinics. In case ^{106}Ru is used for irradiation of pterygium surgical excision site, the received dose to the lens in an irradiation session (at a depth of about 5mm) is nearly 7Gy and the risk of cataract is very high.

5. Conclusion

Finally, considering the mentioned results and given the geographical location and climate of Iran (given the spread of dust in the country over the past few years, which has increased the risk of pterygium), use of a ^{32}P ophthalmic applicator is of utmost importance. Meanwhile, the ability to produce ^{32}P solution and radioactive ophthalmic applicators in Iran allows us to use this cost-effective, radioactive applicator for the treatment of pterygium if dosimetric considerations are taken into account.

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