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原著

Strength estimation for moving iodine-125 source for brachytherapy: application to source link loader

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The validity of a method for estimating the brachytherapy source strength while linking the sources has been verified in this study. The Bard brachysource STM125I (^{125}I seed) with air kerma strength of 0.369 U (μGym^{2}h^{-1}) and a plastic scintillator with dimensions of 80 mm × 50 mm × 20 mm were used in this work. The accuracy of the proposed method was investigated for a source driven by a loader. The source strength estimated from the maximum detector reading had an uncertainty below 20% inclusive of the statistical error which was deemed to be enough to identify dead ^{125}I seeds.

Keywords: Brachytherapy, ^{125}I, source strength, moving source, link loader

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1. Introduction

Brachytherapy is a radiation therapy for malignant tumors[1)]. In brachytherapy, encapsuled radiation sources are placed inside or on the surface of the human body. The tumors are irradiated with the radiation such as beta or gamma rays emitted from the source. Brachytherapy has an advantage that the dose distributions are controlled easily and precisely by adjusting the source locations. Various methods for evaluating the dose distributions in low-energy brachytherapy have been investigated in many studies[1–5)]. The American Association of Physicists in Medicine Task Group 43 Updated Protocol (AAPM-TG43U1)[6)] provides a comprehensive summary of these techniques and a formalism on how to calculate the dose with the requirement that the strengths of all implanted sources should be known prior to implantation. Additionally, the AAPM Task Group

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64 (TG64) guideline stipulates that source strengths should be measured by the qualified staff, i.e., medical physicists[7, 8]. The number of the sources needed for this measurement is recommended to be at least10% of the actual number of sources to be used. In a similar guideline, the Groupe Européen de Curiethérapie (GEC) and the European Society for Radiotherapy & Oncology (ESTRO), requires only a minimum of five sources to determine the source strength[9]. In both cases, the strengths of the remaining sources could potentially be unverified before they are used clinically. In Japan, majority of the ^{125}I sources has a strength which is in good agreement with its nominal values[2–4]. However, incidents wherein the source delivered to a hospital has 9% higher strength[10] or no strength[11], i.e., dead seed, have been reported.

In increasing the number of the source strength measurement, a reliable way is to perform measurement when the source is static, e.g. by using a well-type chamber. However, in order to reduce time and labor for medical staffs to acomplish it, a method to estimate the strength of the source while it is being implanted has been proposed as a backup for quality assurance[12]. This research activity aims at automatic measurement and analysis in the actual use stage to reduce labor for staffs. Also, in order to realize it by a simple mechanical system and to reduce time required, the strength is measured during its movement, which is different from a method to move a source into a static situation for the measurement automatically. The technical difficulty in the source strength measurement during actual implantations comes from the variation in the source speed because the source is moved manually. For a specified range of the source speed, its strength is measured within a short time interval and should commence and terminate while the source is in a region where the detection efficiency is almost constant. This method has been verified experimentally using a loose source moving at different constant speeds[12] and at varying speeds by driving it manually in conditions similar to actual treatment for prostate using ^{125}I seed[13]. Recently, linked sources are also being utilized clinically. In this case, the sources are usually linked by medical staff and the source strength measurement in hospitals is still required. The proposed method has been verified about its usefulness for the linked sources[14]. In this case, since the measurement is done while the source is being implanted, i.e. after linking the sources, the source is already inside the patient body when a source with unintended strength is found. On the other hand, the present work proposes the measurement while linking the source. In this case, it is advantageous that any source with unintended strength can be replaced because the source strength is estimated prior to implantation. In the present study, we investigate whether the proposed method can be used to estimate the strength of the sources while they are being linked, and also explore possible dosimetric verifications to which the proposed method can be applied.

2. Materials and methods

The source used in this work was ^{125}I seed (STM1251, Bard, Inc., Murray Hill, NJ). The air kerma strength of the source was 0.369 ± 0.018 U, as measured in advance by a well-type ionization chamber (HDR1000 Plus, Standard Imaging, Inc., Middleton, WI). Here, U denotes the unit combination $\mu Gy m^2 h^{-1}$ defined in TG43U1[6].

The ^{125}I source was moved by a loader (QUICK-LINK 70310QCA1S, Bard, Inc., Murray Hill, NJ) which is an equipment that snaps a source or a spacer in turn and joins them to form a series of linked sources. The experimental set-up and the components of the loader are shown in **Fig. 1**. The loader has a transparent window made of glass that is doped with lead for photon shielding. A part of the glass was cut and removed to guide photons from the source to the detector. The glass was supplied by the Bard Corporation and was cut to a length of 86 mm to create an opening aperture of 14 mm long. The detector was positioned so that it completely covered the opening aperture, at a vertical distance from the pathway of the source of 6 mm as illustrated in **Fig. 1**. The detector in this study was a plastic scintillation counter (G-tech, Inc., Saitama, Japan) to increase counting rate. The counter included the EJ200 scintillator (Eljen Technology, Inc., Sweetwater, TX) with dimensions of 80 mm × 50 mm × 20 mm, and the H7416 photomultiplier tube (Hamamatsu Photonics, Inc., Shizuoka, Japan). The strength of a moving source while it was being linked was estimated using the method proposed by Tanaka et al.[12]

The signal from the photomultiplier tube was amplified with a preamplifier (5607, Clear Pulse, Inc., Tokyo, Japan) and an amplifier (4467A Clear Pulse, Inc.). The amplified signal was sent to a single channel analyzer (1150, Clear Pulse, Inc.). The maximum pulse height measured by a oscilloscope

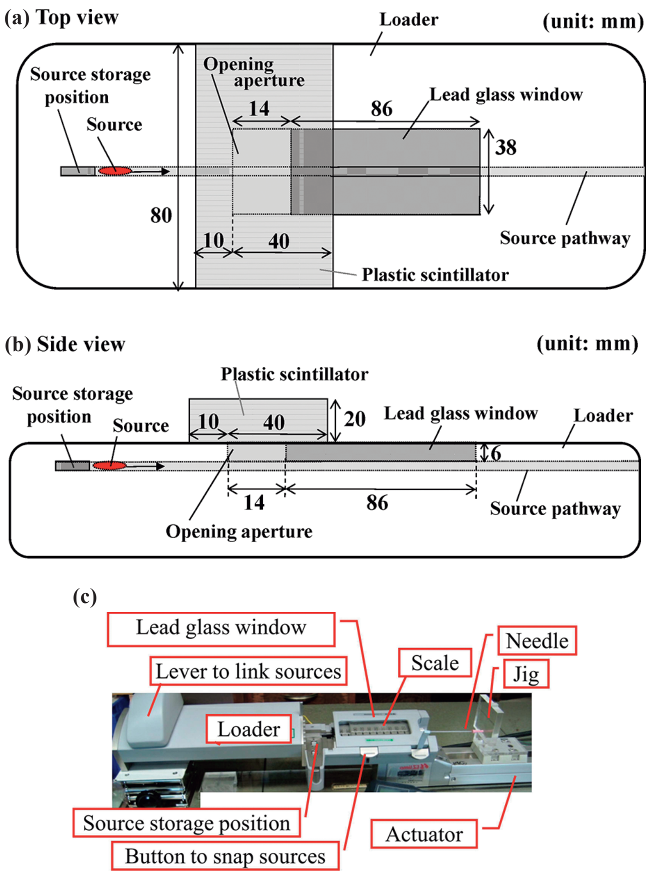

Fig. 1 Experimental setup: (a) top view; (b) side view; and (c) photograph as an overview. Figures are not drawn to scale. In order to avoid from confusion, Fig. 1(c) is shown in mirror image.

(2032, LeCroy, Inc., NW) was about 2 V for the electric noise and background radiation, and 27.2 keV to 35.5 keV photons from ^{125}I was about 8V. The threshold of the single channel analyzer was set to 2V. The signal passing through the single channel analyzer was finally transferred to a scaler (3340, Clear Pulse, Inc.).

Measurements for a static and a moving source were performed. For the static source, measurements of 1-s duration were repeated 10 times. For the moving source, 3 measurements for each time duration of 1, 5, 10, 20, 100 ms were carried out as the loader snapped the sources. The deviation of the detector readings among measurement durations was evaluated to be within ±1%, in advance. This deviation was corrected in the analysis of the moving source measurement.

In the static source measurement, the position of the source was controlled with an electric actuator (EZS3D025-A, Oriental Motor Inc., Tokyo, Japan) as shown in **Fig. 1(c)**. In order to avoid from confusion, **Fig. 1(c)** is shown as an mirror image. The actuator was connected to a needle to push the source through the exit of the loader. In the moving source measurement, the needle was removed. In this case, the source was driven by pressing the button to snap the source.

In order to estimate the source speed roughly and to consider the movement of the source during the measurement, a movie of the moving source snapped as it is being joined by the loader was taken using a digital camera (EOS KISS X5, Canon, Inc., Tokyo, Japan). In this case, the plastic scintillator in **Fig. 1(b)** was not located. Instead, the camera was set at about 50 mm above the source pathway. On the source pathway of the loader, the scale is printed in increment of 5 mm (**Fig. 1(c)**). The movie was obtained at a frame rate of 60 fps to ensure that the motion of the source was clearly tracked. The distance of the movement of the source in one frame was estimated by reading the scale in the movie. This measurement was performed 3 times.

3. Results and discussion

The dependence of detection efficiency on the source position, as indicated by its counting rate for a static source, is shown in **Fig. 2**. The source position in the graph is its relative distance from the source storage position. The error bars correspond to one standard deviation of 10 measurements. The counting rate of the background signal was 70 ± 8 cps. This was subtracted from the measured

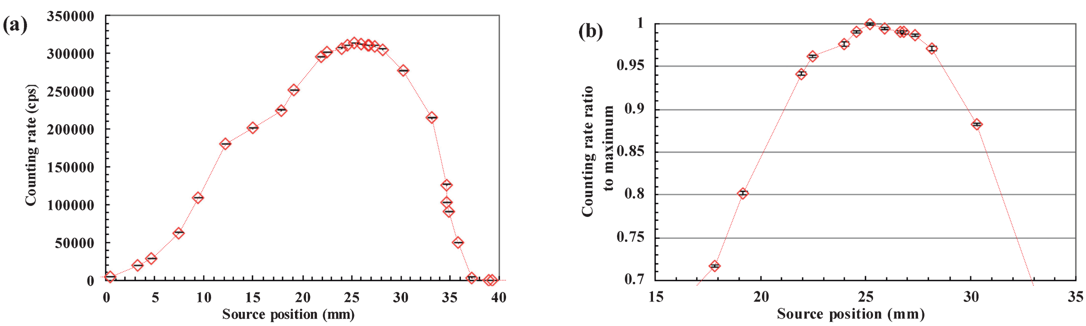

Fig. 2 Dependence of detection efficiency on source position indicated by its counting rate for static source: (a) raw data, and (b) relative distribution normalized at 25 mm, where the counting rate reaches its maximum. Dashed lines are visual guides.

values and shown in **Fig. 2**. The position where the counting rate reaches its maximum of 313,647 ± 245 cps was about 25 mm. In this case, the source was approximately at the center of the opening aperture of the loader shown in **Fig. 1**. The corresponding detection efficeincy was about 1%, i,e, 1% of photons emitted from ^{125}I nuclei is detected by the plastic scintillation counter used in this study. With this geometry, the calibration factor for converting measured counting rate to source strength was determined to be 0.369/313,647 = 1.18 × 10^{-6} U/cps. The counting rate at 37 mm was almost the same as background value. At this position, the source was behind the shielding glass. The change in detection efficiency was about 1% at positions of about 24 to 26 mm (2 mm length), 5% at 23 to 28 mm (5 mm length), 10% at 21 to 29 mm (8 mm length).

The source speed estimated using a digital camera was 600 to 1800 mm/s. This is based on the observation that the source moved 10 to 30 mm along the opening aperture in one frame for duration of 1/60 s. The raw data of the source motion in 3 measurements were 10, 20, 30 mm in 1/60 s, respectively.

An example of the measured values for a moving source is shown in **Fig. 3** for a duration of 1 ms. At zero-time, the source is at its starting position, i.e., the storage position. The source was considered to be in the region at 0 to 37 mm until the measured value was down to 0–1 count. Here, the measured value at 37 mm will be 1 or no count because the counting rate at 37 mm was 64 ± 10 cps from **Fig. 2(a)**. The speed of the source passing through this region was estimated from time elapsed before the count reached 1 or no count was registered, by using the number of the readings while the source was in the region between 0 and 37 mm. The result is listed in **Table 1**. The speed estimated from the measured value agreed roughly with that estimated with the digital camera, which supports the validity of both

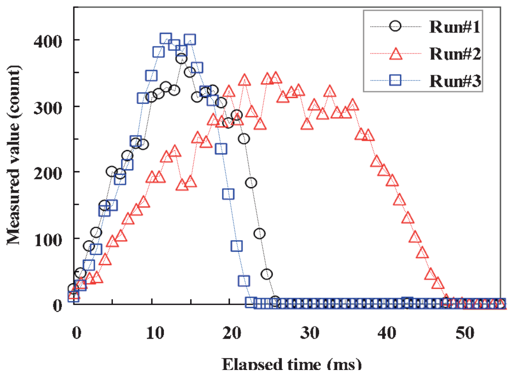

Fig. 3 Raw data of 1-ms measurement for moving source after the source left its storage position. Lines are visual guides.

Table 1 Speed of moving source estimated from photon measurement

Measurement time (ms)	Run#	Number of reading with measured value when the source was at 0–37 mm	Estimated source speed (mm/s)
1	1	26	1423
	2	50	740
	3	23	1609
5	1	7	1057
	2	6	1233
	3	6	1233
10	1	3	1233
	2	3	1233
	3	2	1850

methods. As to the speed deviation by about three times for each of camera measurement and radiation measurement, it will be because of statistical deviation. The source is snapped by a spring included inside the loader. By pressing the button in **Fig. 1(c)**, the source is snapped. The speed depends on when the button releases the spring. It will be influenced by the pressure and speed of pressing the button.

In each of the measurements for the moving source, the maximum count among the values such as those in **Fig. 3** was used to represent the source strength assuming that this maximum count was obtained when the source passed the 25 mm position. The measured value was converted to the source strength by multiplying the calibration factor of 1.18×10^{-6} U/cps. The ratio of the converted source strength to the well-type chamber measured strength, abbreviated as "ratio (present/well)", is plotted in **Fig. 4**. The error bars indicate the standard deviation for 3 runs. The ratio (present/well) was 1.12 ± 0.09 for the measurement time of 1 ms, and 1.05 ± 0.07 for 5 ms.

The source strength ratio (present/well) in **Fig. 4** was below the unity for the measurement times above 10 ms and it decreased as the measurement time increased. This is because for long measurement times the source is no longer in the region where detection efficiency was constant. For example, for 100 ms, the source moved 60 to 180 mm during the measurement and reached the region with a lower detection efficiency at the positions over 37 mm where the counting rate in **Fig. 2** is zero. On the other hand, the ratio (present/well) increased and was greater than unity for as the measurement time decreased. This is due to the fluctuation in the rate of the decay process, photon detection, etc. At 1-ms duration, for example, the source at an assumed speed of 1800 mm/s proceeds by 1.8 mm during one reading. In this case, 2 readings are available while the source is in 5 mm long region with detection efficiency change within 5% in **Fig. 2**, and 8 mm long region with the detection efficiency change within 10%. As previously mentioned, the source strength for the moving source was estimated using the maximum of the measured value in each run. On the other hand, the source strength for the static source corresponded to the average of measured values; this was used to determine the calibration factor. Therefore, the source strength estimated with the proposed method for the moving source increased above unity. This is a potential origin of the systematic error of this method. This trend is observed in **Fig. 4**. One potential way of compensating this error is to determine a correction factor as one divided the ratio (present/well) in **Fig. 4**, and multiplying it with the estimated source strength.

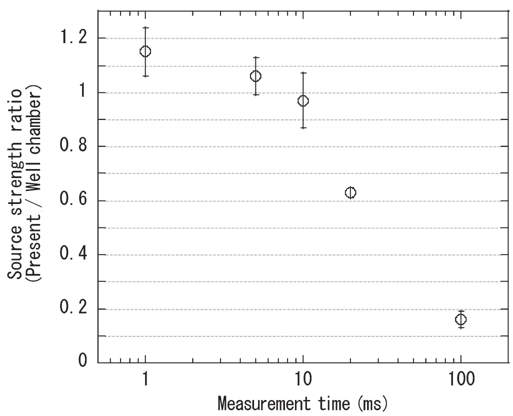

Fig. 4 Source strength ratio of method in present study to well-type chamber for varied measurement time.

In the source strength measurement while linking the source, the proposed method will be useful as:

(1) An alternative to the measurement by the manufacturer with a comparable uncertainty within 5% in the case of Bard STM1251.

(2) A method to identify accidental switching of sources, i.e., from among the currently sup-

plied strengths of 0.392, 0.462, and 0.533 U. They differ by 15% or more. The uncertainty, a, of the proposed method should satisfy $1 + a < 1.15(1 - a)$ resulting in the uncertainty tolerance of 7%.

(3) A means of finding the accidental replacement of the sources with those which have decayed after being kept in the clinical facility for longer time than half life. The uncertainty of 33% is acceptable for this purpose to find the sources with the strengths of 50% or less of their initial values.

(4) As a way of identifying dead seeds or an event that the source is not released when it is stuck in the loader. This can be performed if the measured values are more than the fluctuation of the background signal.

For each of items, when the unintended matter is found, the loader will be opened before the source-linking process using the lever shown in **Fig. 1(c)**, and the unintended source will be removed manually.

The difference from the estimation method during the implantation is that one need not consider accidental simultaneous implantations of two or more sources[13], and that the possibility of stuck sources, as mentioned in (4) is considered. From technical viewpoint, the difference is the way of driving the source when the strength is measured with the proposed method. In the estimation during the implantation, the source is driven manually. Typical source speed is below about 200 mm/s[12]. On the other hand, in the estimation during linking the sources, the source is snapped by a loader with a typical speed below about 1800 mm/s.

In **Fig. 4**, the source strength ratio estimated from the maximum has the ratio (present/well) count was 1.12 ± 0.09 for the measurement time of 1 ms and 1.05 ± 0.07 for 5 ms. Even if these values are not used as correction factors, the uncertainty of this estimate is roughly within 20% including the statistical error, and therefore the requirements for applications (3) and (4) are satisfied.

4. Conclusion

The present paper has shown that the strength of a moving source, which is snapped by a loader while being linked, can be estimated using the method proposed in this study. For the loader QUICKLINK 70310QCA1S (Bard, Inc.) which has a 14 mm long opening aperture in the lead glass window, estimation using the maximum of the measured values in each run for durations of 1 to 5 ms is potentially usable. The accuracy of the method described here was about 20% including the statistical error, which is enough to find dead ^{125}I seeds, identify events where the source is not released when it is stuck in the loader, and the accidental replacement of the sources with those which have decayed below the half of its nominal strength.

The advantage of estimating the source strength from the maximum measured detector reading for the moving source is that one does not need to know the source speed. But its disadvantage is that it overestimates the source strength as the number of readings achievable increases, e.g. by low speed of the source motion since the calibration factor for converting counts to strength is determined using the average value of the static source measurements.

In practical use, one should choose the required condition such as measurement time, size of opening aperture in the lead glass window, detector dimensions etc., based on the desired accuracy of the estimated source strength.

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【Ethics approval and consent to participate】

There is nothing to declare.

【Conflict of Interest】

The authors declare no conflict of interest

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