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Calibration of the photon component of ^{198}Au stents

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ABSTRACT

PURPOSE: ^{198}Au has promising characteristics for radioactive stent material, having properties as a mixed β-particle and γ emitter. Calibration of these radioactive stents is required to provide accurate clinical dosimetry.

METHODS AND MATERIALS: We have developed an electroplating technique to incorporate stable gold onto stents followed by activation to ^{198}Au in the University of Wisconsin nuclear reactor. The calibration method is a modification of the NIST traceable, in-air calibration technique for high-dose-rate (HDR) ^{192}Ir sources.

RESULTS: The air-kerma strength of HDR and low-dose-rate (LDR) sources was measured for proof of principle and found to agree to within 3% of values obtained with other NIST traceable calibration techniques. The photon component of two ^{198}Au radioactive stents was measured over a period of 3 days.

CONCLUSION: The air-kerma strength of HDR and LDR sources was measured for proof of principle and found to agree to within 3% of values obtained with other NIST traceable calibration techniques.

Keywords: Intravascular brachytherapy; ^{198}Au; Stents; Calibration

Introduction

Restenosis is defined as the renarrowing of a blood vessel to less than half its original diameter and has been known to occur, within 6 months after treatment, in up to 40% of patients who received percutaneous transluminal coronary angioplasty (1). However, the incidence of restenosis can be reduced by inserting a permanent stent (2). Suggested improvements of normal coronary stenting include using radioactive stents, drug coated stents, and radiation applied by afterloading sources. Recent investigations show that the use of radioactive stents is safe and feasible (3).

Various radionuclides have been investigated for use in radioactive stents including purely β-emitting radionuclides (^{32}P), mixed β and γ-emitting radionuclides (^{198}Au, ^{48}V, and ^{188}Re), and purely γ-emitting radionuclides (^{96}Tc) (4–8). Primarily, ^{32}P has been studied because of its seemingly favorable β-decay characteristics ($t_{1/2}$ = 14.3 d, E_{max} = 708 keV). Clinical research with ^{32}P radioactive stents has slowed due to the undesired rapid dose reduction at the end of the stent, which has resulted in restenosis at the ends of the stent known as the edge effect (9). On the other hand, a γ-emitter will give a greater dose beyond the end of the stent (8). Thus, a mixed β and γ-emitting radionuclide like ^{198}Au may be a suitable choice for radioactive stents. Other favorable characteristics of ^{198}Au stents may include their shorter half-life, which would deliver a higher dose over a shorter period of time, and the lower energy of the emitted beta particles, which would deliver higher relative doses to areas closer to the surface of the stent. In this work, ^{198}Au stents are produced by neutron activation in the University of Wisconsin Triga Research nuclear reactor of a stainless steel stent electroplated with stable gold. When compared with the production of ^{32}P stents by ion implantation, this procedure is less expensive and easier, and with the large ^{197}Au(n,γ)^{198}Au reaction cross section, no practical limit is placed on the activity of the ^{198}Au stents.

In preparation for the clinical use of radioactive stents, a calibration procedure is necessary with traceability to national standards. Task Group No. 60 of the American Association of Physicists in Medicine recommended that the activity, nominal diameter, deployed diameter, length, type, and model be specified for each stent used (10). Also,

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it is assumed that no contaminating radionuclides are present (10). In the case of the short lived ^{198}Au stents, the contaminating radionuclides will be present long after the ^{198}Au emission is weakened through decay. The effect of these contaminants should not be neglected. By measuring the air-kerma strength, S_k, in terms of the photon component of ^{198}Au stents, photons from all radionuclides present will be measured, thus offering a better source strength specification. The quantity S_k is normally defined as the air-kerma rate, $K_d(d)$, in vacuo, at distance d from the source, multiplied by the square of this distance, d^2.

The standard air-kerma strength, S_k, calibration for high-dose-rate (HDR) brachytherapy sources measures source output at seven consecutive distances in air, and has become known as the 7-distance measurement technique (11). In this work, modifications of this technique are made to measure the S_k for low-dose-rate (LDR) seeds and of ^{198}Au stents. In similar work, Verhaegen *et al.* (12) have measured the air kerma rate at 1 m of LDR ^{192}Ir sources with a 10 cm diameter spherical ion chamber of air equivalent plastic Exradin model A6 (800 ml C552 air equivalent Plastic-Shonka-Wyckoff [Standard Imaging, Middleton, WI]). For their work, the typical ^{192}Ir wires measured had an air kerma rate on the order of 35 cGy cm^2 hr^{-1}, whereas the ^{198}Au stents' S_k are on the order of 1 cGy cm^2 hr^{-1}. To increase the signal to noise ratio, smaller distances are used in our measurements.

Methods and materials

The measurement technique

The technique used to measure the strength of the stents is a modification of a technique developed by Goetsch *et al.* (11) and DeWerd and Thomadsen (13), which was used to measure the S_k of HDR ^{192}Ir brachytherapy sources. The average energy of ^{192}Ir after removing X-rays strongly attenuated by the source encapsulation results in a weighted average of 397 keV. The ^{198}Au spectrum contains 11 strong photon lines ranging from 8 to 1088 keV. The weighted average energy of ^{198}Au after removing the strong L-shell X-rays below 10 keV, which are almost completely attenuated by the beta shield and chamber wall, is 403 keV. With such similar energies, it follows that the technique used for ^{192}Ir will work appropriately for ^{198}Au.

In the original technique, source output is measured with a calibrated ionization chamber at seven distances from the source. To measure the air-kerma strength of the source accurately, a precision lead screw is used to determine corrections c and M_s due to chamber placement uncertainty and room scatter, respectively (11, 14). Making measurements at more than three distances over-determines the result for the three unknowns (S_k, c, and M_s) and allows averaging of the solutions.

The apparatus is positioned more than 1 m from any wall while performing the measurement in accordance with the suggestion in the report of Task Group No. 41 (15). According to Selvam *et al.* (16), by keeping these minimum distances, the wall, floor, and ceiling scatter should remain mostly constant (less than 3% variation) for each of the measurement positions. According to these authors, the exponential attenuation of ^{192}Ir primary photons in air exactly cancels the air scatter. Because these components cancel each other and ^{198}Au and ^{192}Ir photon energy spectra are so similar, no correction is made for air scatter or air attenuation for ^{198}Au stent measurements. Except for the positioning track Velmex motor-driven precision lead screw unislide (MB400 series) (Velmex, Bloomfield, NY) and the laser, all parts of the measurement apparatus are made of acrylic. The low atomic number materials used and the large distances between the apparatus components and the chamber and source minimize the scatter and, therefore, the effect of the apparatus on the measurement (14).

Interpolative calibration of cavity ion chambers

To obtain an accurate $(N_k)_{Au}$ chamber calibration factor for the average energy of ^{198}Au, an energy for which no National Institute of Standards and Technology (NIST) traceable S_k calibration is available, an interpolation between two neighboring energies is used. The ^{198}Au average energy falls approximately halfway between the ^{137}Cs γ-ray energy of 662 keV and the effective energy (146 keV) of a 250 kVp X-ray beam (HVL 3.2 mm Cu) (11), the nearest energies available for ionization chamber calibrations at both NIST and the University of Wisconsin Accredited Dosimetry Calibration Laboratory (UWADCL). A proper interpolation between ^{137}Cs and X-rays requires that the same chamber-wall thickness be used in both measurements, and that wall thickness must be sufficient to provide charged particle equilibrium. The 0.18 g/cm^2 C552 thick wall of the Exradin A6 (Standard Imaging, Middleton, WI) chamber satisfies this requirement.

As given by Goetsch *et al.* (11), the equation for the calibration factor $(N_k)_{Au}$ can be written as

$$(N_k)_{Au} = \frac{[(A_w N_k)_{x-ray} + (A_w N_k)_{Cs}]}{2(A_w)_{Au}} \quad (1)$$

where A_w is the wall attenuation for the respective energy in subscript. The difference between the calibration factors at the ^{137}Cs point and the 250 kVp X-ray point is less than 2% for the ionization chamber used.

A special characteristic of the ion chamber used is its large collecting volume (800 cc), which causes recombination effects when measuring higher fluence radiation beams such as the M250 X-ray beam. To minimize recombination, a chamber bias of +1000 V was used during the M250 X-ray and ^{137}Cs calibrations, which resulted in a collection efficiency of approximately 99.05% and 100% respectively. When making measurements at lower dose rates, approximately 100% collection efficiency is attained with a normal