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# Evolution of brachytherapy treatment planning to deterministic radiation transport for calculation of cardiac dose

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A B S T R A C T

Brachytherapy was among the first methods of radiotherapy and has steadily continued to evolve. Here we present a brief review of the progression of dose calculation methods in brachytherapy to the current state-of-the art computerized methods for heterogeneity correction. We further review the origin and development of the BrachyVision (Varian Medical Systems, Inc., Palo Alto, CA) treatment planning system and evaluate dosimetric results from 12 patients implanted with the strut-assisted volumetric implant (SAVI) applicator (Cianna Medical, Aliso Viejo, CA) for accelerated partial breast irradiation (APBI). Dosimetric results from plans calculated using homogenous and heterogeneous algorithms have been compared to investigate the impact of heterogeneity corrections. Our study showed large percent difference between mean cardiac doses $11.8 \pm 6.2\%$ ($p = 0.0007$) calculated with and without heterogeneity corrections. Our findings are consistent with those of others, indicating an overestimation of the distal dose to organs-at-risk by traditional methods, especially at interfaces between air and tissue.



## Introduction

The origin of brachytherapy can be traced to an accidental "burn" Henri Becquerel received from a sample of radium Marie and Pierre Currie had loaned to him.[1] Since its humble inception, brachytherapy (derived from the Greek word "brachy," meaning short, referring to dose delivery at close range) has undergone a constant evolution, with increased availability of a diverse array of radioisotopes, treatment applicators, and systems for dose computation.[2] Early dose calculations were most often based on a biological end point, threshold erythema dose.[3] These biological methods were superseded by classical "systems," which included a set of rules accounting for source strength and their spatiotemporal pattern of placement. Examples of these "systems" included the Stockholm, Paris, Manchester (Patterson-Parker), and Memorial (Quimby).[3] It can be inferred from their names that application of these methodologies varied with geography and was strongly dependent on where a particular brachytherapist was trained. In the United States, up until the development of computer software, the 2 systems

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[1]Retired.

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in widespread practice were Patterson-Parker and Quimby, which were both developed in the 1930s.[4]

Computer treatment planning systems (TPSs) for brachytherapy originated independently at Memorial Hospital in New York City in the late 1950s and M.D. Anderson Hospital in Houston in the early 1960s.[4] Although much work was performed on the algorithms used by the software, the adoption of a standardized quantitative process can be traced to the formation of the American Association of Physicists in Medicine (AAPM) Task Group (TG) 43 in 1988 and subsequent publication of their seminal report in 1995.[5] Before the TG-43 formalism, calculations were performed based on air exposure rates corrected for attenuation in water. TG-43 introduced a calculation based on the reference point dose rate in water, derived from Monte Carlo calculations of actual source geometry within a water sphere of 15 cm. Using derived radial dose and anisotropy functions, the relative attenuation in water could be calculated at all other points. The dose calculation algorithm found in TG-43's report has been the most widely accepted and can be found in all commercial TPS.[6]

Excluding an update and subsequent source supplements to the original TG-43 report,[7-9] only recently has a new method of dose calculation been employed commercially.

Developed at Los Almos National Laboratory and commercialized by the spin-off Transpire, Inc. (Gig Harbor, Washington),[10] Transpire was subsequently acquired by Varian Medical Systems, Inc. (Palo Alto, CA), and their "Atilla" calculation engine was adapted and integrated into BrachyVision (Varian Medical Systems, Inc.) under the moniker, Acuros BV. Acuros BV is a deterministic method that calculates heterogeneity corrected dose by solving the time-independent form of the Linear Boltzmann Transport Equation (LBTE), as a rival to the Monte Carlo method.[11] Considered the "gold standard," Monte Carlo is a stochastic method that collates a large number of individual "random" particle histories to provide a macroscopic solution. A true solution to the LBTE, an integro-differential equation, is considered impossible because of the large number of independent variables required to define fluence in any given phase space.[6] The phase space is a matrix in which the states of a system are defined; in our discussion this is the quantity, quality, position, and direction of the coupled photon and electron distributions. By reducing the number of independent variables, through discretization of the phase space parameters, a solution can be obtained.[10,11] Discretization is the conversion of a continuous function into a discrete value. An example would be reporting the mean heart dose, rather than all doses internal to the organ. This can lead to a loss of information, such as hot spots and cold spots, and the user must determine if the approximation yields results of sufficient quality. Acuros has been demonstrated to provide results with accuracy approaching Monte Carlo, and, for this reason, it has been suggested that LBTE methods be considered the "silver standard,"[11] recognizing that the required computation time is significantly less and may be more efficiently applied in the clinic.

Here we have presented a brief review of the progression of dose calculation methods in brachytherapy. We will further review the origin and development of the BrachyVision TPS and evaluate its functionality with the strut-assisted volumetric implant (SAVI) applicator (Cianna Medical, Aliso Viejo, CA) for accelerated partial breast irradiation (APBI).[12-15] APBI is a hypo-fractionated alternative to whole-breast radiotherapy, delivers localized dose to the site of disease, and is well described in the National Surgical Adjuvant Breast and Bowel Project (NSABP) B-39 protocol.[16] Dosimetric results from plans calculated with the TG-43 formalism and Acuros BV algorithm have been compared to investigate the impact of heterogeneity corrections. Considering the current emphasis on cardiac dose in breast radiotherapy, we have analyzed the dose to the heart, as well as the chest wall, skin, and D90 coverage.[17-19]

## Methods and Materials

### *Treatment planning system*

Calculations were generated using BrachyVision (version 13.7) and Acuros BV (version 1.7.0). Brachytherapy planning is integrated as a module in the Aria Oncology Information System version 13.6 (Varian Medical Systems, Inc.). Aria is accessed via Citrix (Citrix Systems, Inc., Fort Lauderdale, FL), which enables server-based computing. Planning was performed at a standard hospital workstation.

Acceptance test procedures include the creation of the brachytherapy unit and commissioning of source model(s) in the RT Administration application of Aria.[20] Digital Imaging and Communications in Medicine Image Transfer must be configured, then data sets can be imported and dose calculation tests performed. Test plans are provided by Varian with known dose values at selected reference points; the same plan is used for testing TG-43 and Acuros. Verification of plan transfer to treatment unit and image transfer over the network is performed along with tests for reproducibility and source decay. For commissioning purposes, BrachyVision includes the TG-186 shielded solid applicator for testing of heterogeneity corrections.[21] An end-to-end test incorporating all elements of data transfer and evaluation of the site-specific second check software is always recommended for a complete commissioning; additional elements are well described in TG-59.[22]

### *Plan preparation*

Computed tomography (CT) Digital Imaging and Communications in Medicine data sets ($n = 12$) were used in