

# Monte Carlo modelling of the patient and treatment delivery complexities for high dose rate brachytherapy

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## Abstract

Brachytherapy treatments are commonly performed using the American Association of Physicists in Medicine (AAPM) Task Group report TG-43U1 absorbed dose to water formalism, which neglects human tissue densities, material compositions, body interfaces, body shape and dose perturbations from applicators. The significance of these effects has been described by the AAPM Task Group report TG-186 in published guidelines towards the implementation of Treatment Planning Systems (TPS) which can take into account the above mentioned complexities. This departure from the water kernel based dose calculation approach requires relevant scientific efforts in several fields. This thesis aims to improve brachytherapy treatment planning accuracy following TG-186 recommendations and going beyond it. A software has been developed to integrate clinical treatment plans with Monte Carlo (MC) simulations; high fidelity CAD-Mesh geometry was employed to improve brachytherapy applicators modelling; different dose report quantities,  $D_{w,m}$  (dose to water in medium) and  $D_{m,m}$  (dose to medium in medium), were obtained for a head and neck case using small cavity theory (SCT) and large cavity theory (LCT); the dose component due to the source moving within the patient was evaluated for gynecological and prostate clinical cases using speed profiles from the literature. Moreover, source speed measurements were performed using a high speed camera. Dose calculations using MC showed overdosing around 5% within the target volume for a gynecological case comparing results obtained including tissue, air and applicator effects against a homogeneous water phantom. On the other hand, the same comparison showed underdosing around 5% when including tissue and air composition for an interstitial arm case. A hollow cylinder applicator was responsible for the overdosing observed for the gynecological case highlighting the importance of accurate applicator modelling. The evaluated CAD-Mesh applicators models included a Fletcher-Williamson shielded applicator and a deformable balloon used for accelerated partial breast irradiation. Results obtained were equivalent to ones obtained with conventional constructive solid geometry and may be convenient for complex applicators and/or when manufacturer CAD models are available. Differences between  $D_{m,m}$  and  $D_{w,m}$  (SCT or LCT) are up to 14% for bone in a evaluated head and neck case. The approach (SCT or LCT) leads to differences up to 28% for bone and 36% for teeth. Differences can also be significant due to the source movement since some speed profiles from literature show low source speeds or uniform accelerated movements. Considering the worst case scenario and without include any dwell time correction, the transit dose can reach 3% of the prescribed dose in a gynecological case with 4 catheters and up to 11.1% when comparing the average prostate dose for a case with 16 catheters. The transit dose for a high speed (measured with a video camera) source is not uniformly distributed leading to over and underdosing, which is within 1.4% for commonly prescribed doses (3–10 Gy). The main subjects evaluated in this thesis are relevant for brachytherapy treatment planning and can improve treatment accuracy. Many of the issues described in here can be assessed with the software, coupled with a MC code, developed in this work.

**Key words:** Brachytherapy, Monte Carlo, HDR  $^{192}\text{Ir}$ , MBDCA

## Resumo

Tratamentos braquiterápicos são comumente realizados conforme o relatório da *American Association of Physicists in Medicine (AAPM), Task Group report TG-43U1*, o qual define o formalismo para cálculo de dose absorvida na água e não considera a composição dos materiais, densidades, dimensões do paciente e o efeito dos aplicadores. Estes efeitos podem ser significantes, conforme descrito pelo recente relatório da AAPM, *Task Group report TG-186*, que define diretrizes para que sistemas de planejamento modernos, capazes de considerar as complexidades descritas acima, sejam implementados. Esta tese tem como objetivo contribuir para o aumento da exatidão dos planejamentos de tratamento braquiterápicos, seguindo as recomendações do TG-186 e indo além do mesmo. Um software foi desenvolvido para integrar planejamentos de tratamento e simulações pelo método de Monte Carlo (MC); modelos acurados, CAD-Mesh, foram utilizados para representar aplicadores braquiterápicos; Grandezas utilizadas para reportar dose absorvida,  $D_{w,m}$  (dose para água no meio) e  $D_{m,m}$  (dose para o meio no meio), foram calculadas para um tratamento de cabeça e pescoço, considerando a teoria para pequenas (SCT – *small cavity theory*) e grandes cavidades (LCT – *large cavity theory*); a componente da dose em razão do movimento da fonte foi avaliada para tratamentos de próstata e ginecológicos. Perfis de velocidade obtidos na literatura foram utilizados; medidas de velocidade de uma fonte braquiterápica foram realizadas com uma câmera de alta taxa de aquisição. Cálculos de dose obtidos usando MC (incluindo a composição e densidade dos tecidos, ar e o aplicador) mostram sobredoses de aproximadamente 5% dentro do volume alvo, em um tratamento ginecológico, quando comparados aos resultados obtidos com um meio homogêneo de água. Por sua vez, subdoses de aproximadamente 5% foram observadas ao considerar a composição dos tecidos e regiões com ar em um tratamento intersticial de braço. Um aplicador cilíndrico oco resultou na sobredose observada no caso ginecológico, ressaltando a necessidade de modelos acurados para representar os aplicadores. Os modelos CAD-Mesh utilizados incluem um aplicador Fletcher-Williamson, com blindagem, e um balão deformável para irradiação de mama. Os resultados obtidos com estes modelos são equivalentes aos obtidos com modelos geométricos convencionais. Este recurso pode ser conveniente para aplicadores complexos e/ou quando o projeto dos aplicadores for disponibilizado pelo fabricante. Cálculos de dose, com a composição real dos tecidos humanos, podem apresentar diferenças significativas em razão da grandeza adotada. Diferenças entre  $D_{m,m}$  e  $D_{w,m}$  (SCT ou LCT) chegam a 14% em razão da composição do osso. A metodologia adotada (SCT ou LCT) resulta em diferenças de até 28% para o osso e 36% para os dentes. A componente de dose de trânsito também pode levar a diferenças significativas, uma vez que baixas velocidades ou movimentos uniformemente acelerados foram descritos na literatura. Considerando a pior condição e sem incluir nenhuma correção no tempo de parada, a dose de trânsito pode chegar a 3% da dose prescrita para um caso ginecológico, com 4 cateteres, e até 11.1% da dose prescrita para um tratamento de próstata, com 16 cateteres. A dose de trânsito para a fonte avaliada (velocidade obtida experimentalmente) não é uniformemente distribuída e pode levar a sub ou sobredoses de até 1.4% das doses comumente prescritas (3–10 Gy). Os tópicos estudados são relevantes para tratamentos braquiterápicos e podem contribuir para o aumento de sua acurácia. Os efeitos estudados podem ser avaliados com o uso do software, associado a um código MC, desenvolvido.

**Palavras chave:** Braquiterapia, Monte Carlo, HDR  $^{192}\text{Ir}$ , MBDCA