UNIVERSIDADE ESTUDADUAL PAULISTA

“JÚLIO MESQUISTA FILHO”

INSTITUTO DE BIOCIÊNCIAS

Nova Metodologia de Estimativa de Exposição Ocupacional em Radiologia Intervencionista

ABNER ALVES DE OLIVEIRA

BOTUCATU-SP

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ABNER ALVES DE OLIVEIRA

Dissertação apresentada ao Instituto de Biociências, Universidade Esadual Paulista "Julio de Mesquista Filho", Campus de Botucatu para obtenção do título de Mestre em Farmacologia e Biotecnologia.
Orientador(a): Prof. Associada Diana Rodrigues de Pina
Coorientador: Allan Felipe Fattori Alves

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Palavras-chave: Dosimetria; Dosimetro opticamente estimulado; Produto kerma area; Radiologia intervencionista.

...Louvai ao Deus dos deuses; porque a sua benignidade dura para sempre. (Salmos 136:2, ARC)

Agradeço primeiramente a Deus, muito obrigado pela tua graça e misericórdia, sem as bênçãos do Senhor nada posso fazer.

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Agradeço a Universidade Estadual Paulista “Júlio de Mesquita Filho”, ao Instituto de Biociências, ao Departamento de Biofísica e Farmacologia e todos os professores, pela infraestrutura, formação e todas as oportunidades.

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Resumo

A Radiologia Intervencionista é uma área da medicina que utiliza radiação ionizante como guia de intervenções. Os valores de dose aos quais os intervencionistas são expostos são difíceis de padronizar.

Nesta pesquisa é apresentado uma avaliação das exposições ocupacionais nos seguintes procedimentos vasculares: angiografia coronariana, angioplastia coronariana, angiografia cerebral, angiografia de extremidades e angioplastia de extremidades. Essa pesquisa foi abordada em 2 etapas.

A primeira etapa caracterizou-se a exposição ocupacional, através de dosimetria de Luminescência Opticamente Estimulada (OSL) em diferentes partes do corpo: cristalino, tireoide, tórax, abdômen, pés e mãos. Foi realizado em três modalidades diferentes de procedimentos de radiologia intervencionista: coronariano, cerebral e periféricas.

Na segunda etapa foi determinado a dose efetiva através da dosimetria, utilizando a conversão de 6 regiões com dose superficial em aventais plumbíferos para 26 regiões internas. Através de parâmetros de rotina, foi estimado a dose efetiva através do Produto Kerma Área (PKA) obtido através de equipamentos fluoroscópicos, onde a estimativa é realizada através de fator obtido para cada modalidade. As doses efetivas, calculada através da dosimetria e estimada por PKA, foram comparadas através do método de Bland Altman avaliando a concordância entre os dois métodos. A utilização de fatores experimentais para estimar a dose efetiva é proposta para auxiliar o programa de radioproteção.

As maiores doses equivalentes encontradas foram abdômen e mãos para as modalidades coronarianas e periféricas, cristalino e mãos para modalidades cerebrais. A dose no tórax como representativo para o corpo todo pode subestimar outras doses como abdômen, extremidades e cristalinos.

As modalidades coronarianas e cerebral apresentaram viés entre -1 e 0 µSv, onde a estimativa através do PKA infere valores de dose efetiva próximos ao calculado por dosímetros. As modalidades periféricas apresentaram um viés entre -11 e -7 µSv subestimando a dose efetiva, onde a proximidade do intervencionista implica em maiores

níveis de exposições de radiação espalhada em contraste com menores valores de PKA, devido as regiões de extremidades.

Palavras-chave: Radiologia intervencionista, dosimetria, produto kerma área, dosímetro opticamente estimulado.

Abstract

Interventional Radiology is an area of medicine that uses ionizing radiation as a guide to interventions. The dose values the interventionists are exposed to are difficult to standardize.

This presents an assessment of the occupational: coronary angiography, coronary angioplasty, cerebral angiography, borderline angiography and borderline angioplasty. This was addressed in 2 steps.

The first stage was characterized by occupational exposure, through Optically Stimulated Luminescence (OSL) dosimetry in different parts of the body: thyroid, lens, abdomen, feet and hands. It was performed in three different modalities of interventional radiology procedures: coronary, cerebral and peripheral.

In the second step, an effective dose was determined through dosimetry, using the conversion of 6 regions with surface dose in lead aprons to 26 internal regions. Through routine parameters, the effectiveness was estimated through the Product through Kerma Area (KPA) performed through fluoroscopic equipment, where a factor calculation is performed for each modality. As the effective doses, through the combination of the two methods and calculated by KPAi, were projected through alternative methods of agreement between the two methods. The use of experimental factors to estimate the effective dose is proposed to help the radioprotection program.

The highest equivalent doses were total abdominal and hands for coronary and peripheral modalities, crystalline and for modern modalities. The dose cannot as representative for the whole body underestimate other doses such as abdomen, limits and lens.

The coronary and cerebral modalities showed a bias between -1 and 0 µSv, where the estimate through KPA infers effective dose values close to those calculated by dosimeters. Peripheral modalities showed a bias between -11 and -7 µSv, underestimating the effective dose, where the proximity of the interventionist implies higher levels of scattered radiation exposure in contrast to lower KPA values, due to the extremity regions.

Keywords: Interventional Radiology, Dosimetry, Kerma Area Product, Optically Stimulated Dosimeter.

This research was developed in the Laboratory of Physics Applied to Radiodiagnosis (LAFAR), duly approved by the Research Ethics Committee (CEP) under protocol: CAAE 16932513.5.0000.5411.

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List of abbreviations

OSL – Optically Stimulated Luminescence

IR – Interventional Radiology

KPA – Kerma Area Product

EDR - Equivalent Dose Rate

D_E - Equivalent Dose

T_f - Fluoroscopy Time

E - Effective Dose

w_t - Sensitivity Factors

Coronary AG - Coronary Angiography

Coronary AP - Coronary Angioplasty

Cerebral AG - Cerebral Angiography

Peripheral AG - Extremity Angiography

Peripheral AP - Extremity Angioplasty

Sumário

1. Introdução, justificativa e relevância do tema

O uso de equipamentos e de fontes de radiações ionizantes aumentou-se grandemente desde a sua descoberta em 1895, devido aos grandes benefícios nas diferentes áreas da saúde. Inicialmente, as propriedades dos raios x, por serem desconhecidas, fez com que muitos profissionais da radiologia viessem a obter danos a saúde devido aos efeitos deletérios do uso indevidos da radiação [1, 2].

Após o estabelecimento de protocolos de proteção radiológica, exposições indevidas aos raios x tiveram um grau maior de preocupação a comunidade científica [3]. No entanto, acidentes radiológicos continuam a ser notificados junto aos órgãos normatizadores e fiscalizadores do uso de fontes radioativas, o que exige o constante aperfeiçoamento das legislações específicas [4-6]. Após a utilização das radiações ionizantes, a ciência e a medicina se beneficiaram, mas por outro lado provocaram diversos danos em médicos, pesquisadores, indivíduos expostos e pacientes [7].

Os primeiras normas de proteção radiológica para os indivíduos ocupacionalmente expostos foram publicadas pela Roentgen Society após a confirmação do dano no tecido humano causados pela descoberta dos raios x [8]. O uso desenfreado da falta de conhecimento das radiações observou-se os danos biológicos, sendo assim, criaram normas que visam à proteção do ser humano e do meio ambiente [9].

A radiologia intervencionista é uma área da medicina que utiliza radiação ionizante como guia de intervenções [10]. Estas intervenções são realizadas com fins diagnósticos e terapêuticos, utilizando acessos percutâneos, e sendo guiados por imagens fluoroscópicas. Estes procedimentos são levemente invasivos quando comparados a outros procedimentos cirúrgicos. Onde promovem a recuperação rapidamente com maiores benefícios para os pacientes [1, 2, 11].

Durante os procedimento da RI os intervencionistas posicionam-se próximos ao paciente, onde este recebe o feixe primário da radiação ionizante [12]. Portanto, devido à proximidade dos intervencionistas ao feixe primário, esta área da medicina é responsável pelas maiores exposições ocupacionais à equipe médica [10, 13, 14].

A estimativa de dose através dos dosímetros é o método padrão ouro na dosimetria ocupacional, porém este método é mais eficiente em casos de feixe de radiação homogêneo [10, 13, 14]. Para as doses recebidas pela equipe na RI, a estimativa apresenta

complicações devido ao feixe não ser homogêneo [14]. Porem os métodos dosimétricos em procedimentos intervencionistas são os mesmos empregados em outras modalidade de procedimentos [10]. Os valores de dose efetiva alteram-se devido a diversos fatores como tempo de exposição, carga no tubo de raios X, tipo de exame, locais de intervenção e anatomia do paciente [3, 10, 14, 15].

A RI realiza intervenções em diversas áreas do corpo, como exemplo as modalidades coronariana, cerebral e de extremidades [16-18]. Para cada área de intervenção utilizam-se protocolos específicos, entregando níveis de exposições distintos aos intervencionistas [16, 19]. Isto ressalta a dificuldade de se criar metodologias que indiquem com maior eficácia e precisão a dose recebida por intervencionistas durante os procedimentos da RI [2, 10, 14].

Durante os avanços tecnológicos, parâmetros dosimétricos foram implementados nos aparelhos fluoroscópicos, permitindo o controle através de cada procedimento do nível de exposição ocupacional [20]. Portanto parâmetros como tempo de fluoroscopia, Kerma e Produto Kerma Área (PKA) foram implementados permitindo o monitoramento [20]. Estudos demonstram a utilização do PKA como um fator representativo para a dose [21-23]. Onde o PKA tem uma maior representação da dose distribuída em relação ao Kerma, pois leva-se em consideração a distribuição da dose em área [24].

2. Objetivo

O objetivo deste estudo é representado por dois tópicos distintos.

- Realizar uma dosimetria com maior eficácia e precisão para os procedimentos da RI.
    - O intuito da dosimetria é avaliar as diferenças dos níveis de exposição para 6 distintas regiões do corpo dos intervencionistas.
    - Avaliar o perfil de exposições para distintos protocolos de intervenção (coronariano, cerebral e de extremidade).
- Determinar uma nova metodologia de cálculo de dose efetiva que auxilie o programa de proteção radiológica.
    - Realizar o cálculo de dose efetiva através da dosimetria, utilizando conversão de 6 regiões externas do corpo para 27 regiões internas e seus respectivos fatores de radiossensibilidade.

- Estimar a dose efetiva através do produto kerma área através de fatores de conversão.
- Comparar o nível de concordância entre os métodos estimados.

3. Fundamentos teóricos

3.1. Grandezas Dosimetricas

3.1.1. Exposição

A exposição é definida como a razão de dQ dividido por dm, demonstrado na equação 1, onde dQ é a carga total de íons produzidos no ar quando todos os elétrons são liberados numa determinada massa de ar dm [3, 25]. A unidade de medida é denominada Röntgen (R), medida no Sistema Internacional (SI) a razão entre coulomb (C) por quilograma de ar (kg_{ar}).

1 $$Exposição = \frac{dQ}{dm} \left(\frac{C}{Kg_{ar}}\right)$$

3.1.2. Kerma

O Kerma (K) representa a energia cinética transferido ao meio, definido como o quociente de dEtr/dm, demonstrado na equação 2, onde dEtr é a soma das energias cinéticas iniciais de todas as partículas ionizantes carregadas (elétrons e pósitrons), liberados pelas partículas sem carga (fótons) em um material de massa dm [3, 25]. A unidade de medida é denominada Gray (Gy), medida no SI como a razão entre Joule (J) por quilograma (kg).

2 $$Kerma\ (K) = \frac{dE_{tr}}{dm} \left(\frac{J}{kg}\right)$$

3.1.3. Dose absorvida

A dose absorvida (D) é definida como a quantidade de energia depositada (dE_{ab}) pela radiação ionizante em um determinado volume de massa dm, representada pela equação 3 [3, 25]. A unidade de medida é denominada Gray (Gy), medida no SI como a razão entre Joule (J) por quilograma (kg).

3 $$Dose\ Absorvida\ (D) = \frac{dE_{ab}}{dm} \left(\frac{J}{kg}\right)$$

3.1.4. Dose equivalente

A dose específica recebida por cada tecido e representada pela ggrandeza dose equivalente (H_T). A somatória das doses absorvidas (D) em um volume de massa dm, provenientes de diferentes tipos de radiação, multiplicados pelos fatores de ponderação de cada tipo de radiação (w_R), resulta na H_T representado pela equação 4 [3, 25]. A unidade de medida é denominada Sievert (Sv), medida no SI como a razão entre Joule (J) por quilograma (kg).

4 $$Dose\ Equivalente\ (H_T) = \sum D.w_R$$

3.1.5. Dose Efetiva

A Dose Efetiva (E) definida como o somatório das doses equivalente (H_T) ponderadas pela radiossensibilidade de cada tecido (w_T), apresentado na equação 5. Onde esta unidade de medida é a que melhor associa a quantificação dos danos biológicos ao nível de exposição radiológico [3, 25]. A unidade de medida é denominada Sievert (Sv), medida no SI como a razão entre Joule (J) por quilograma (kg).

5 $$Dose\ Efetiva\ (E) = \sum H_T.w_T$$

3.1.6. Produto Kerma Área

O Produto Kerma Área (PKA), é o produto do kerma no ar (K_{ar}) em uma área A, de um plano perpendicular ao eixo central do feixe de raios X representado pela equação [26]. A unidade de medida no SI e determinada como o produto entre Gy e a unidade de área m^2.

6 $$Produto\ Kerma\ Área\ (PKA) = K_{ar}.A\ (Gy.m^2)$$

3.2. Dosimetro OSL

A Luminescência Opticamente Estimulada (OSL) é um dos muitos fenômenos que ocorrem na matéria que podem ser induzidos por radiações ionizantes e se tornou uma ferramenta prática e bem sucedida na dosimetria das radiações [27]. Trata-se da emissão de sinal luminescente de um determinado cristal previamente irradiado quando exposto à luz [27, 28]. Utilizando o cristal óxido de alumínio dopado com carbono (Al_2O_3:C) que, devido à sua fotosensibilidade, passou a ter ampla utilização como um detector OSL [28]. Devido a utilização de filtros pode-se criar janelas de senssibilidade

diferentes no dosimetro, tornando o dosímetro OSL uma ferramente de distinção para os niveis de exposição em acordo com cada filtro [28, 29].

4. Conclusão Geral

- As dosimetrias realizadas nos procedimentos de RI, demonstraram grande variabilidade nas exposições corporais.
- Nota-se que para todas modalidades de procedimentos dosimetradas, apresentaram grandes diferença estatísticas entre as regiões.
- Profissionais em rotina normal, com o uso de equipamentos plumbíferos, não se submetem a riscos que causem danos, mas algumas regiões corporais podem receber níveis de exposição proxímos aos limites imposto pelo orgão governamental.
- As diferentes modalidades apresentam diferenças nos níveis de exposição nas regiões dosimetradas, logo as diferentes regiões de intervenção implicam em riscos diferentes a equipe intervenionista.
- Devido ao feixe não homogêneo, a radiologia intervencionista necessita de formas diferentes de dosimetria e análise dos níveis de exposição do programa de proteção radiológica hospitalar.
- Utilizar o Produto Kerma Área como parâmetro auxiliar para predizer a Dose Efetiva implica em um program de proteção radiológica mais seguro. Porém este método não substitui a utilização do dosímetro, a qual é o método padrão ouro.
- Os protocolos das diferentes modalidades apresentaram Kerma e PKAs distintos quando comparados com o tempo fluoroscopia, onde maiores tempos de exposição não implicam em maiores doses atribuidas a equipe médica.
- A utilização do PKA como parâmetro de estimativa da Dose Efetiva é intrinseco de cada setor, onde para cada setor, o fator multiplicative de estimativa é especifico daquele local, não podendo ser aplicado em outro setor.

5. Submissão do Artigo

5.1. Formato Revista

Revista a ser submetido o artigo: Physics in Medicine & Biology.

Formato da revista para artigos Single-anonymous retirados do Guia para Autores [30], mostrado nas duas figuras a seguir.

5.1.1. Abstract

Your abstract should give readers a brief summary of your article. It should concisely describe the contents of your article, and include key terms (especially in the first two sentences, to increase search engine discoverability). It should be informative, accessible and not only indicate the general aims and scope of the article, but also state the methodology used, main results obtained and conclusions drawn. The abstract should be complete in itself; it should not contain undefined acronyms/abbreviations and no table numbers, figure numbers, references or equations should be referred to. Articles relying on clinical trials should quote the trial registration number at the end of the abstract. The abstract should be suitable for direct inclusion in abstracting services and should not normally be more than 300 words. If you submit an article with an abstract longer than 300 words, we may rescind the manuscript and ask you to re-write it. Some journals ask for abstracts to follow a particular structure. Check the instructions for specific journals to see if you need to submit a structured abstract.

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This should be concise and describe the nature of the problem under investigation and its background. It should also set your work in the context of previous research, citing relevant references. Introductions should expand on highly specialised terms and abbreviations used in the article to make it accessible for readers.

5.1.3. Method

This section should provide sufficient details of the experiment, simulation, statistical test or analysis carried out to generate the results such that the method can be repeated by another researcher and the results reproduced.

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The results section should detail the main findings and outcomes of your study. You should use tables only to improve conciseness or where the information cannot be given satisfactorily in other ways such as histograms or graphs. Tables should be numbered serially and referred to in the text by number (table 1, etc.). Each table should have an explanatory caption which should be as concise as possible.

5.1.5. Discussion

This should discuss the significance of the results and compare them with previous work using relevant references.

5.1.6. Conclusion

This section should be used to highlight the novelty and significance of the work, and any plans for future relevant work.

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Some articles will require an ethical statement, particularly those that are reporting research involving humans or animals. This should state if the research was approved by any ethical committee, and which national or international standards were complied with.

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Carefully chosen and well-prepared figures, such as diagrams and photographs, can greatly enhance your article. You are encouraged to prepare figures that are clear, easy to read and of the best possible quality and resolution.

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Keywords: term, term, term

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5.2. Artigo

New Methodology for Estimating Occupational Exposure in Interventional Radiology

Abstract

Interventional Radiology is an area of medicine that uses ionizing radiation as a guide to interventions. The dose values the interventionists are exposed to are difficult to standardize.

This presents an assessment of the occupational: coronary angiography, coronary angioplasty, cerebral angiography, borderline angiography and borderline angioplasty. This was addressed in 2 steps.

The first stage was characterized by occupational exposure, through Optically Stimulated Luminescence (OSL) dosimetry in different parts of the body: thyroid, lens, abdomen, feet and hands. It was performed in three different modalities of interventional radiology procedures: coronary, cerebral and peripheral.

In the second step, an effective dose was determined through dosimetry, using the conversion of 6 regions with surface dose in lead aprons to 26 internal regions. Through routine parameters, the effectiveness was estimated through the Product through Kerma Area (KPA) performed through fluoroscopic equipment, where a factor calculation is performed for each modality. As the effective doses, through the combination of the two methods and calculated by KPAi, were projected through alternative methods of agreement between the two methods. The use of experimental factors to estimate the effective dose is proposed to help the radioprotection program.

The highest equivalent doses were total abdominal and hands for coronary and peripheral modalities, crystalline and for modern modalities. The dose cannot as representative for the whole body underestimate other doses such as abdomen, limits and lens.

The coronary and cerebral modalities showed a bias between -1 and 0 µSv, where the estimate through KPA infers effective dose values close to those calculated by dosimeters. Peripheral modalities showed a bias between -11 and -7 µSv, underestimating the effective dose, where the proximity of the interventionist implies higher levels of scattered radiation exposure in contrast to lower KPA values, due to the extremity regions.

Keywords: Interventional Radiology, Dosimetry, Kerma Area Product, Optically Stimulated Dosimeter.

Introduction

Interventional radiology (IR) is an area of medicine that uses ionizing radiation as a guide for interventions [10]. These interventions are performed for diagnostic and therapeutic purposes, using percutaneous accesses, and are guided by fluoroscopic images. These procedures are slightly invasive when compared to other surgical procedures. Where they promote recovery quickly with greater benefits for patients[1, 2, 11].

During the IR procedures, interventionists are positioned close to the patient, where he receives the primary beam of ionizing radiation [12]. Therefore, due to the proximity of interventionists to the primary beam, this area of medicine is responsible for the greatest occupational exposures to the medical team [10, 13, 14].

Dose estimation through dosimeters is the gold standard method in occupational dosimetry, but this method is more efficient in cases of homogeneous radiation beam [10, 13, 14]. For the doses received by the team in IR, the estimate presents complications due to the beam not being homogeneous [14]. But the dosimetric methods in interventional procedures are the same as those employed in other modalities of procedures [10]. Effective dose values change due to several factors such as exposure time, x-ray tube load, type of examination, intervention sites and patient anatomy [3, 10, 14, 15].

IR performs interventions in several areas of the body, such as coronary, cerebral and extremity modalities [16-18]. For each intervention area, specific protocols are used, delivering different levels of exposure to interventionists [16, 19]. This highlights the difficulty of creating methodologies that more effectively and accurately indicate the dose received by interventionists during IR procedures [2, 10, 14].

During technological advances, dosimetric parameters were implemented in fluoroscopic devices, allowing control through each procedure of the occupational exposure level [20]. Therefore parameters such as fluoroscopy time, Kerma and Kerma Product Area (KPA) were implemented

allowing monitoring [20]. Studies have shown the use of KPA as a representative factor for the dose [21-23]. Where the KPA has a greater representation of the dose distributed in relation to Kerma, because the distribution of the dose in area is taken into account [24].

The aim of this study was to perform a dosimetry assessment with greater efficacy and accuracy for IR procedures and to determine a new methodology for calculating effective dose that assists the radiological protection program. In dosimetry, exposure levels were evaluated for 6 different regions of the interventionist body and the exposure profile for different intervention protocols (coronary, cerebral and extremity). The new methodology of effective dose calculation was estimated by conversion factors multiplied by the KPA obtained provided by fluoroscopic equipment.

Materials and Methods

Fluoroscopy Equipment

The procedures were performed in two fluoroscopy equipment of the Hemodynamics Sector of the Hospital das Clínicas of the Botucatu Medical School. Coronary procedures were performed with the Innova IGS 520 equipment (GE Healthcare). Cerebral and extremity procedures were performed with artis zee equipment (Siemens). The two equipments are in accordance with all quality control tests required by RDC 330/2019 and Normative Instruction No. 91[5, 6]. Both equipment sits on lead-to-backs as part of stationary radiological protection. The saiotes are located a few centimeters below the table and end approximately 30 cm above the ground. The two equipment sits on transparent plumbiferous shields attached to the ceiling for the protection of professionals.

In coronary procedures, angiography and angioplasty use the same protocol. 60 kVp, 15 frames/s, "normal" noise level, 20 cm field of view, automatic current control (mA).

In cerebral angiography procedures, automatic control of kVp, 4 frames/s, "normal" noise level, 42 cm of field of view, automatic current control (mA) was used.

In extremity procedures, angiography and angioplasty differ in the protocol. Being the end angiography protocol: automatic control of kVp, 4 frames/s, "normal" noise level, 48 cm of field of view, automatic control of mA. End angioplasty protocol: automatic kVp control, 2 frames/s, "normal" noise

level, 48 cm field of view, automatic current control (mA).

Selection of Procedures

The protocols for the application of interventional radiology were divided by the areas of intervention, coronary, cerebral and peripheral. Therefore, the procedures chosen were: coronary angiography, coronary angioplasty, cerebral angiography, vascular angiography, vascular angioplasty and arterial aneurysm treatment.

The choices were made using the following criteria: total exposure time (fluoroscopy time); frequency of the procedure in the clinical routine and noise level or noise level, which is a parameter selected for each protocol and influences the current in the tube (mA) used.

Dosimetry of Professionals

From the choice of procedures, the dosimetry of the professionals was performed using Optically Stimulated Luminescence dosimeters (OSL). For greater accuracy of the level of exposure of the medical team, two interventionists were dyestered during each procedure. These were presented as the main interventionist (interventionist A) and secondary interventionist (interventionist B), according to the Figure 1.

(Figure 1 here)

Figure 1 - Outline of the position of interventionists during the vascular intervention procedure. During the procedures, a ceiling shield and plumbiferous skirt were used to protect the interventionists.

The performance profile of each interventionist is distinguished according to the intervention area. In coronary interventions interventionist A is an experienced interventionist physician coordinates the entire procedure. Interventionist B is the instrumentist where he assists the procedure.

In brain and peripheral interventions, professional A is an interventionist physician experienced in the area of intervention and professional B is a resident physician who assists the procedures (auxiliary physician).

Dosimetry was performed using dosimeters in the following regions: crystalline, thyroid, thorax, abdomen, hand and foot, represented by Figure 2.

Where the dosimeter was positioned on the plumbiferous protectors.

(Figure 2 here)

Figure 2 - Demonstration of the position of OSL dosimeters.

For all routine lysed procedures, the following parameters were recorded through the work center of each fluoroscopic equipment: exposure time, Air Kerma and KPA.

Equivalent Dose Calculation for each procedure

From the dosimetry, the accumulated dose per cycle of measurements was obtained. In this project, 3 cycles of measurements were carried out, the 1st with duration of 1 month, the 2nd with duration of 3 months and the 3rd with duration of 3 months. Therefore, this project had a total dosimetry period of 7 months. Knowing that the accumulated dose was estimated per measurement cycle, then the Equivalent Dose Rate (EDR) was calculated for each cycle, represented by Equation 1, through the ratio between the Accumulated Equivalent Dose (AED) in the dosimeter and Total Time (Tt) of exposure.

Equation 1

$$EDR = \frac{AED}{T_t}$$

With EDR, the Equivalent Dose (ED) was calculated by procedure, being the product of EDR and the Fluoroscopy Time (T_f) of each procedure for their respective cycles, defined in Equation 2. Thus, equivalent dose profiles were obtained per examination for the tradable regions in all procedure modalities.

Equation 2

$$ED = EDR * T_f$$

Effective Dose Calculation for each procedure

From the equivalent dose profile, the Effective Dose (E) was calculated for each examination following the following steps.

Conversion of equivalent dose from the 6 external regions to 26 internal regions using Conversion Factors (CF). The CFs were obtained in previous studies conducted by our research group, and are presented in Table 1 [21].

Calculate the Effective Dose using Equation 3.

Equation 3

$$Effective\ Dose\ (E) = \sum_{T}^{26} w_T * D_E$$

With these steps, the Effective Doses were obtained for each procedure.

Effective Dose Estimation through KPA

Through the effective doses and KPAs, a multiplicative f factor was calculated for each modality, estimating the effective dose from the KPA [22]. This factor f was calculated using the experimental values, in which f is demonstrated by Equation 4.

Equation 4

$$f = \frac{\bar{X}_E}{\bar{X}_{PKA}} \left(\frac{\mu Sv}{Gy.cm^2}\right)$$

Being XE, the average effective dose of each modality in μSv, and XKPA the average KPA of each modality in Gy.cm². With these data, an effective dose estimate was performed from the KPA values of each procedure.

Statistical Analysis

Statistical analyses were performed using software graphpad prism 8 (GraphPad, USA).

For the equivalent dose values calculated in topic 0, the values of the median dose for each region of the body were calculated to perform the Shapiro-Wilk normality test, comparing them with each other through the Kruskal-Wallis test and dunn's multiple comparison test. The null hypothesis confers that the dose values are not different in the different regions of the body of the same professional during procedures of the same modality.

For the estimation of Effective Dose calculated in topic 0, the agreement between the estimated values of the Effective Dose by factor f against the experimental values of the Effective Dose was analyzed using the Bland-Altman method.

(Table 1 here)

Table 1 - Conversion Factors (HR) from external to internal dose and their respective sensitivity factors (wt) [3, 31].

Results

Procedures from three different areas of intervention were chosen. Angiography and angioplasty in coronary and peripheral interventions. Angiography in brain interventions.

According to the choice of modalities of interest, dosimetry was performed, in which the number of procedures evaluated are presented in Table 2 below.

(Table 2 here)

Table 2 - Number of transferable exams for all modalities of procedures.

The equivalent dose profile in the regions of each modality is presented in the following figures: Coronary Angiography (Figure 3), Coronary Angioplasty (Figure 4), Cerebral Angiography (Figure 5), Extremity Angiography (Figure 6) and Extremity Angioplasty (Figure 7).

(Figure 3 herre)

Figure 3 - Equivalent doses received by interventionists A (white boxplot) and B (boxplot grays) in the coronary angiography modality for the regions: crystalline (ALS and ELB), thyroid (TA and TB), thorax (AC and CB), abdomen (AA and AB), hands (HA and HB) and feet (AF and FB). Each boxplot represents the following statistical values: the lower and upper bounds of the box indicate the 25th and 75th percentiles. The solid horizontal line in the box establishes the median. The sum symbol represents the average value, and the error bars above and below the box represent the standard deviation. All doses were estimated on the individual plumbiferous protections.

For coronary angiography, shown in Figure 3 below, the dose values showed statistical differences between the regions. For interventionist A, there was no significant difference between lens and thorax. The other regions when compared showed statistical difference ($\alpha<0.05$). For interventionist B, all regions presented statistical differences ($\alpha<0.05$). For interventionist A, the highest doses were found in the abdomen and hand region (medians: 32.64 and 40.56 μSv). For interventionist B, the highest doses were measured in the lens and hand (medians: 4.16 and 2.64 μSv).

(Figure 4 here)

Figure 4 - Equivalent doses received by interventionists A (white boxplot) and B (boxplot cinzas) in the coronary angioplasty modality for the regions: crystalline (ALS and ELB), thyroid (At TA and TB), thorax (AC and CB), abdomen (AA and AB), hands (HA and HB) and feet (AF and FB). Each boxplot represents the following statistical values: the lower and upper bounds of the box indicate the 25th and 75th percentiles. The solid horizontal

line in the box swells the median. The sum symbol represents the average value, and the error bars above and below the box represent the standard deviation. All doses were estimated on the individual plumbiferous protections.

For coronary angioplasty, shown in Figure 4, a profile similar to coronary angiography was observed, which has approximately three times longer time, shown in Figure 8 (medians: 2.4 and 7.6 minutes). For interventionist A, the abdomen demonstrates a higher level of exposure than the hand (medians: 124.28 and 106.05 μSv), but the two regions presented the highest exposure levels when compared to the other regions. The regions of the lens and foot presented high rates of exposure in angioplasty (medians: 44.60 and 33.62 μSv) when compared with angiography (medians: 8.30 and 2.66 μSv). When analyzing the levels of statistical difference between the regions for interventionist A, statistical differences were obtained when comparing crystalline with abdomen and hand, thyroid with abdomen and hand ($\alpha<0.05$). For interventionist B, there were statistical differences when comparing crystalline with the thorax, and thorax with abdomen, in addition to the hand and foot ($\alpha<0.05$).

(Figure 5 here)

Figure 5 - Equivalent doses received by interventionists A (white boxplot) and B (gray boxplot) in the cerebral angiography modality for the regions: crystalline (ALS and ELB), thyroid (TA and TB), thorax (AC and CB), abdomen (AA and AB), hands (HA and HB) and feet (AF and FB). Each boxplot represents the following statistical values: the lower and upper bounds of the box indicate the 25th and 75th percentiles. The solid horizontal line in the box swells the median. The sum symbol represents the average value, and the error bars above and below the box represent the standard deviation. All doses were estimated on the individual plumbiferous protections.

In Figure 5, the highest doses presented for interventionist A and B were for the lens (medians: 58.24 and 63.03 μSv) and hands (medians: 122.04 and 65.13 μSv), and the lens in interventionist B received a higher level of exposure when compared to interventionist A. Interventionist A presented the highest exposure levels in

the lens, thorax and hand regions (medians: 58.24, 47.95 and 122.04 μSv). Interventionist B presented the highest exposure levels in the crystalline and hand regions (medians: 63.03 and 65.13 μSv). For interventionist A, there were statistical differences ($\alpha<0.05$) when comparing crystalline with thyroid, abdomen and foot, thyroid with thorax and hand, chest with abdomen and hand, abdomen with hand and hand with foot. For interventionist B there were statistical differences ($\alpha<0.05$) when comparing crystalline with thyroid and foot, thyroid with thorax and hand.

(Figure 6 here)

Figure 6 - Equivalent doses received by interventionists A (white boxplot) and B (boxplot ash) in peripheral angiography mode for the regions: crystalline (ALS and ELB), thyroid (TA and TB), thorax (AC and CB), abdomen (AA and AB), hands (HA and HB) and feet (AF and FB). Each boxplot represents the following statistical values: the lower and upper bounds of the box indicate the 25th and 75th percentiles. The solid horizontal line in the box swells the median. The sum symbol represents the average value, and the error bars above and below the box represent the standard deviation. All doses were estimated on the individual plumbiferous protections.

In Figure 6, interventionist A presented the highest exposures in the regions of the lens, abdomen and hand (medians: 167.22, 285.51 and 459.48 μSv). Interventionist B presented the highest exposure levels in the regions of the lens, thorax and hand (medians: 137.68, 114.22 and 173 μSv). For interventionist A, comparing crystalline with thyroid, thyroid with abdomen, thyroid with hand and hand with foot there was statistical difference ($\alpha<0.05$). Interventionist B also presented statistical differences ($\alpha<0.05$) comparing crystalline with thyroid and thyroid with hand.

(Figure 7 here)

Figure 7 - Equivalent doses received by interventionists A (white boxplot) and B (gray boxplot) in peripheral angioplasty modality for regions: crystalline (ALS and ELB), thyroid (At TA and TB), thorax (AC and CB), abdomen (AA and AB), hands (HA and HB) and feet (AF and FB). Each boxplot represents the following statistical values: the lower and upper bounds of the box indicate the 25th and

75th percentiles. The solid horizontal line in the box swells the median. The sum symbol represents the average value, and the error bars above and below the box represent the standard deviation. All doses were estimated on the individual plumbiferous protections.

In Figure 7, interventionist A presented the highest exposure levels in the regions of the lens, abdomen, hand and foot (medians: 159, 183.10, 183.30 and 149.42 μSv). Interventionist B presented the highest exposure levels in the crystalline, abdomen and hand regions (medians: 77.77, 106 and 125.44 μSv). The statistical differences ($\alpha<0.05$) for the regions of interventionist A, occurred between crystalline with thyroid, thyroid with foot, thyroid with abdomen and hand and chest with abdomen and hand. For interventionist B, he presented statistical differences ($\alpha<0.05$) in thyroid comparations with abdomen, thyroid with hand, chest with hand and hand with foot.

The Figure 8 represents the exposure time profile for the evaluated procedures of each modality.

(Figure 8 here)

Figure 8 - Exposure time profile for the procedures evaluated in each modality: coronary angiography (Coronary AG), coronary angioplasty (Coronary AP), cerebral angiography (Cerebral AG), peripheral angiography (Peripheral AG) and peripheral angioplasty (Peripheral AG). Each boxplot represents the following statistical values: the lower and upper bounds of the box indicate the 25th and 75th percentiles. The solid horizontal line in the box swells the median. The sum symbol represents the average value, and the error bars above and below the box represent the standard deviation.

In the metered procedures, kerma and kerma area (KPA) values of each procedure were obtained through the work center of each fluoroscopic equipment, in Figure 9. The total Kerma profile per procedure for each modality is presented in Figure 9.A. The KPA profile per procedure for each modality is presented in Figure 9.B.

(Figure 9(a) and Figure 9(b) here)

Figure 9 - Profile of the parameters of each dosimetry performed

for coronary angiography (Coronary AG), coronary angioplasty (Coronary AP), cerebral angiography (Cerebral AG), extremity angiography (Peripheral AG) and extremity angioplasty (Peripheral AP). Figure 9.A - Total kerma obtained from fluoroscopic equipment for the procedures with haditons. Figure 9.B - Kerma Product Area obtained from fluoroscopic equipment for transferedos procedures. Each boxplot represents the following statistical values: the lower and upper bounds of the box indicate the 25th and 75th percentiles. The solid horizontal line in the box swells the median. The sum symbol represents the average value, and the error bars above and below the box represent the standard deviation.

Through the equivalent doses of the metered procedures, the profile of the effective doses was stipulated for Interventionist A presented in **Erro! F onte de referência não encontrada.** and Interventionist B presented in Figure 11, demonstrating the doses for each modality. The effective doses presented by the white boxplots, in the two figures, were calculated by the method presented topic "0 Effective Dose Calculation for each procedure". The gray boxplots represent the effective reference dose, calculated through the use of a single representative dosimeter used in the chest region multiplied by the apron transmission factor. This reference dose is stipulated as the European model where the dosimeter is used inside the apron as a value[14, 32].

(Figure 10 here)

Figure 10 - Effective doses calculated for interventionists A (white boxplot) and reference doses (R) using a single dosimeter in the chest (boxplot cinzas) for the metered-dose modalities: coronary angiography (CoAG A and CoAG R), coronary angioplasty (CoAP A and CoAP R), cerebral angiography (CeAG A and CeAG R), peripheral angiography (PeAG A and PeAG R) and coronary angioplasty (PeAP A and PeAP R). Each boxplot represents the following statistical values: the lower and upper bounds of the box indicate the 25th and 75th percentiles. The solid horizontal line in the box swells the median. The sum symbol represents the average value, and the error bars above and below the box represent the standard deviation.

(Figure 11 here)

Figure 11 - Effective doses calculated for interventionists B (white boxplot) and reference doses (R) using a single chest dosimeter (gray boxplot) for the metered-dose modalities: coronary angiography (CoAG A and CoAG R), coronary angioplasty (CoAP A and CoAP R), cerebral angiography (CeAG A and CeAG R), peripheral angiography (PeAG A and PeAG R) and coronary angioplasty (PeAP A and PeAP R). Each boxplot represents the following statistical values: the lower and upper bounds of the box indicate the 25th and 75th percentiles. The solid horizontal line in the box swells the median. The sum symbol represents the average value, and the error bars above and below the box represent the standard deviation.

Para a estimativa de dose efetiva através do KPA, foi utilizado o fator f. Estes fatores são apresentados na Tabela 3, onde existe um fator para cada modalidade e intervencionista.

(Table 3 here)

Table 3 - Table with multiplicative factors (mean and standard deviation) for Effective Dose Estimation through KPA.

To estimate the effective dose through KPA, multiplicative factors (f) were determined to achieve an effective dose estimate from the KPA. These factors were obtained through Equation 4, and expressed in Table 3.

To evaluate the difference between the effective dose estimated by factor f and the effective dose estimated by dosimeters, the Bland Altman method was performed, which indicates the degree of agreement between the methods. Figure 12 presents bland-altman's graphs for interventionist A in all modalities. Figure 13 presents bland-altman's graphs for interventionist B in all modalities.

(Figure 12(a), Figure 12(b), Figure 12(c), Figure 12(d) and Figure 12(e) here)

Figure 12 - Estimates of equivalent dose through KPA in agreement with the Effective Dose calculated for Interventionist A. Figure 12-A Bland-Altman for the coronary angiography procedures of interventionist A. Figure 12-B Bland-Altman for the angioplasty coronary procedures of interventionist A. Figure 12-C Bland-Altman for the cerebral angiography procedures of

interventionist A. Figure 12-D Bland-Altman for end angiography procedures for end angiography procedures interventionist A. Figure 12-E Bland-Altman for the end angioplasty procedures of interventionist A.

(Figure 13(a), Figure 13(b), Figure 13(c), Figure 13(d) and Figure 13(e) here)

Figure 13 - Equivalent dose estimates using the KPA in accordance with the Effective Dose calculated for Interventionist B. Figure 13-A Bland-Altman for the angiography procedures of interventionist B. Figure 13-B Bland-Altman for the angioplasty coronary procedures of interventionist B. Figure 13-C Bland-Altman for the cerebral angiography procedures of interventionist B. Figure 13-D Bland-Altman for end angiography procedures for end angiography procedures interventionist B. Figure 13-E Bland-Altman for interventionist end angioplasty procedures B.

For coronary angiography procedures, interventionist A (Figure 12.A) demonstrated a bias of -0.21 μSv, lower limit of -2.64 μSv and upper limit of 2.21 μSv. For interventionist B (Figure 13.A), a bias of 0, lower limit of -0.13 μSv and upper limit of 0.13 μSv. In coronary angioplasty procedures, was observed. interventionist A (Figure 12.B) presented a bias of -0.6 μSv, lower limit of -5.64 μSv and upper limit of 4.45 μSv. Interventionist B (Figure 13.B), presented a bias of 0.14 μSv, lower limit of -0.62 and upper limit of 0.34 μSv.

In cerebral angiography procedures, when comparing the methods, interventionist A (Figure 12.C) presented a bias of -0.36 μSv, lower limit of -3.54 μSv and upper limit of 2.83 μSv. Interventionist B (Figure 13.C) presented a bias of -1.58 μSv, lower limit of -6.27 μSv and upper limit of 3.12 μSv. The values present a good agreement between the methods.

In the end angiography procedures, interventionist A (Figure 12.D) presented a bias of 11.37 μSv, lower limit of -7.61 μSv and upper limit of 30.35 μSv. Interventionist B (Figure 13.D), a bias of 11.5 μSv, lower limit of -29.56 μSv and upper limit of 52.55 μSv. The Endpoint Angioplasty procedure was obtained for interventionist A (Figure 12.E) a bias of 3.57 μSv, lower limit of -14.55 and upper limit 21.73 μSv. For interventionist B (Figure 13.E), bias of 3.87 μSv, lower limit of -25.53 μSv and upper limit of 33.26 μSv.

Discussion

The procedures chosen for the present study were those with higher dose potential for the medical team, presented in Table 2.

The statistical differences presented in Figure 3 occurred because the beam was not homogeneous, where the exposure presents different intensities for the different regions. For interventionist B, the exposure levels were lower due to the distance from the professional to the X-ray tube, where interventionist A is located approximately 0.5 m while B is at 1.0 m. The exposure profile of interventionist B differs from interventionist A, because it is located behind it, making the crystalline the region with the highest exposure to scattered radiation.

The higher levels of exposure occurred in coronary angioplasty, in Figure 4, where the X-ray tube performs a greater number of exposures in the left anterior oblique projection. This position of the X-ray tube causes interventionists to position themselves frontally to the primary beam.

In Figure 5, both interventionists, the chest region (medians: 47.95 and 16.15 μSv) presented a higher dose when compared to the abdomen (medians: 5.76 and 6.49 μSv). This is because the protocols are different, where there is a higher occurrence of exposures with right anterior oblique projection with angles close to 90º, the chest region presented higher doses [33].

For extremity angiography shown in Figure 6, interventionist B is also a resident physician. The patient presented an exposure profile similar to interventionist A, differing only in the abdomen regions (medians: 285.51 and 110 μSv) and hand (medians: 459.48 and 173 μSv). Interventionist B presented a higher dose in the foot when compared to interventionist A (medians: 117 and 80.36 μSv).

The end angioplasty presented in Figure 7 is a modality similar to extremity angiography where interventionist B is a resident physician. However, due to the adversities of the procedure, interventionist B has lower contributions, acting for the purpose of assistance. Soon in some regions presents exposure profiles similar to interventionist A, but lower medians when compared to A. As the ends of angioplasty are at the end of the table, this implies similar exposure levels of the abdomen and hand in interventionist A (medians: 183.10 and 183.30 μSv).

This is because the tube is positioned so that the main beam is located in the region that will receive the angioplasty, in these cases at the end of the table, near the abdomen.

When analyzing the figures 3-7, it is possible to notice statistical differences in the exposure levels of the different regions for interventionists A and B. This shows the lack of singularity between the doses received in the different regions during the same procedure.

The fluoroscopy time for the different modalities of procedures, presented in Figure 8, did not represent a direct relationship with the other quantities: Kerma, KPA and effective dose, being presented respectively in Figures 9-11. When comparing procedures with different protocols and exposure times, only exposure time does not imply the dose value received by the medical team. The cerebral angiography procedure, compared with coronary angioplasty, has longer exposure time (medians: 13.4 and 7.6 minutes) and KPA (medians: 175.41 and 58.84 Gy.cm2). However when evaluating Kerma (medians: 729.9 and 1074 mGy), effective dose for interventionist A (medians: 4.32 and 1.97 μSv) and interventionist B (medians: 0.43 and 2.16 μSv) the dose levels per procedure are higher in coronary angioplasty, which is a procedure of shorter exposure time.

The exposure region of the coronary angioplasty procedure is the patient's chest while the region of cerebral angiography is the skull. Therefore, the source-detector distance (DFD) for coronary angioplasty is greater than the DFD of cerebral angiography, resulting in a smaller KPA in coronary angioplasty, as there is a greater dose distribution. However, since the thorax is thicker than the skull, the energy needed to go through the DFD and result in a feasible image, Kerma and the effective dose in coronary angioplasty are higher. Another factor that implies lower KPA in coronary angioplasty and a kerma and higher effective dose when compared with cerebral angiography is the difference in frame rate used in each protocol, 15 frames/s and 4 frames/s. When comparing extremity angiography and extremity angioplasty, the procedure of longer exposure did not result in a higher dose to the professional by procedure. When comparing the times between angiography and angioplasty of the extremities (median: 9.85 and 25.60 minutes), angioplasty presented

approximately one time 2.5 times longer than angiography. However, extremity angiography presents Kerma (medians: 174.60 and 61.90 mGy), KPA (medians: 48.86 and 15.54 Gy.cm2) and effective dose (medians: interventionist A – 13.36 and 7.72 μSv / interventionist B – 5.95 and 5.34 μSv) higher than angioplasty. This greater exposure in angiography is also observed when comparing Figure 6 and Figure 7, where the medians of the regions of the lens, thyroid, thorax, abdomen and hand for interventionist A, were higher in angiography when compared with end angioplasty. The following doses are: crystalline (medians: 167.22 and 159 μSv), thyroid (medians: 41.76 and 36.71 μSv), thorax (medians: 15 2.30 and 91.93 μSv), abdomen (median: 285.52 and 183.10 μSv), hand (medians: 459.48 and 183.30 μSv). Due to the physical parameter of the procedure, the frame rate per second (SPF), where on extremity angiography is on average 4 Fps and angioplasty is 2 SPF, there is influence of a higher dose on angiography. Another factor that influences a higher dose level in angiography is the case study, where angiography there is a need to evaluate the circulatory system and all involvements that are compromising the patient. Soon there is a higher occurrence of exposure in the pelvic region, which infers a higher level of scattered radiation when compared to angioplasty, where there is a predominance of exposures in the extremities, where there is less scattered radiation. Therefore, the number of frames per second and the level of scattered radiation infer so far dose in the end angiography.

When analyzing Figure 10 and Figure 11, the interquartile intervals for interventionist A and B are different between the modalities of procedures. In coronary procedures, interventionist B is positioned where the distance between him and the source is greater than interventionist A, shown in Figure 1. Therefore, in coronary procedures the dose is lower in interventionist B, about 4 times. In the brain procedure, the dose had similar interquartile intervals between interventionists A and B, due to B being a resident physician, but A presents greater dose variation. In extremity procedures, interventionist B is also a resident physician. However, doses in the chest and abdomen would differ greatly in interventionist A, with higher medians. This generates major changes in the calculated effective dose, as the organs of this region are more radiosensitive. Therefore, for extremity procedures the effective dose differed greatly among interventionists A and B.

When analyzing the level of exposure by regions, both interventionists present similar profiles for most regions, differing in the abdomen for angiography, and thorax for angioplasty.

These factors where they were determined from representative values for KPA data, obtained from the equipment, and effective dose, obtained through dosimetry [22, 34]. In coronary procedures where interventionist A has higher doses, the factors also presented higher values. In this work, when compared with the values presented in the article Delichas, Psarrakos [34], interventionist A presented higher doses and procedures with lower KPA, so the factors are higher, but close. For brain and extremity procedures, due to interventional procedures A and B having similar exposure profiles, multiplicative factors were also similar, obtaining smaller differences when compared to coronary procedures. The end angioplasty procedure presented the highest effective dose estimation factor. This occurred because this procedure has one of the highest effective doses (median: interventionist A – 7.72 μSv / interventionist B - 5.34 μSv) and the lowest KPA value (median: 15.54 $Gy.cm^2$). As the beam is directed to the extremities, it requires a smaller Kerma to perform the procedure, but due to the proximity of the interventionist to the beam entails one of the greatest exposures to the interventionist. Unlike extremity angiography, where there is a need for investigation as already commented, therefore the KPA is higher in this modality, inferring a lower estimation factor than angioplasty.

To obtain the factors presented above, the effective dose obtained from dosimeters and from KPA is used. The effective dose and KPA are intrinsic factors of the hospital sector of this research, dependent on parameters such as fluoroscopic equipment, positioning of professionals and protocols used. Therefore, the methodology for obtaining these factors can be used in any environment of use of fluoroscopic equipment, but the factors are specific to each service.

To obtain the factors presented above, the effective dose obtained from dosimeters and from KPA is used. The effective dose and KPA are intrinsic factors of the hospital sector of this research, dependent on parameters such as fluoroscopic equipment, positioning of professionals and protocols used. Therefore, the methodology for obtaining these factors can be used in any environment of use of fluoroscopic

equipment, but the factors are specific to each servisse.

Analyzing the Bland-Altman graphs presented in Figure 12 and Figure 13, there is an excellent degree of agreement between the effective dose and the effective dose estimated through the KPA.

For coronary procedures (Figure 12 - A and B; Figure 13 - A and B) an excellent degree of agreement was obtained, as there were minimal/zero differences between the methods of obtaining the effective dose, dosimetry (gold standard) and estimation through the KPA (new method).

In the cerebral procedure (Figure 12 - C; Figure 13 - C), interventionists present a greater difference in relation to the estimated effective dose due to the interquartile interval of their exposure. Both interventionists presented similar medians, A: 1.97 μSv and B: 2.16 μSv, but interventionist B presents a higher interquartile range when compared to A. This infers in a greater difference between the comparison methods.

In the extremity procedures, there was no good degree of agreement between the methods because the proximity of the interventionists to the exposure beam (lateral end of the table) infers a higher dose, but due to the low thickness of the attenuating region the KPA is low.

When comparing the effective doses obtained through the different methods (dosimetry and KPA estimation), for coronary and cerebral interventions, there were good degrees of agreement with low dispersions. The estimation of effective dose by KPA tends to overestimate the effective dose, which brings a more conservative estimate regarding the safety of the interventionist.

When comparing the effective doses obtained by the different methods for peripheral interventions, using KPA does not indicate a good factor to represent the actual dose obtained by the interventionist. This occurs, as already commented, because the region of exposure is close to the blateral of the table, causing the interventionist to be close to the primary beam, so that it receives higher levels of exposure when compared to the other modalities. However, the region of the intervention (usually leg) has a smaller thickness than the other modalities, generating a lower KPA value. Therefore, KPA cannot represent the actual level of exposure due

to the proximity of the interventionist to the primary beam.

Conclusion

The dosimetry performed in ir procedures demonstrated great variability in body exposures. It is noted that for all modalities of transferable procedures, they presented great statistical difference between the regions. The single dosimeter in the chest underestimates exposure levels when comparing equivalent doses of regions such as abdomen and hand. In the calculations of effective doses, in the different modalities using the thorax as representative, the dose is overestimated where the contribution of the other regions is not considered. The different modalities showed great differences in interquartile intervals of body exposure. Cerebral procedure present higher doses in the hand and lens of the interventionist, while in the other procedures, the region of the hand and abdomen was the one with the highest exposure. It was very common for the interventionists' hand to receive the highest dose due to the proximity of the primary beam. The dose difference between crystalline and abdomen demonstrates that different protocols should have different decision-making in relation to radiological protection.

The estimation of effective dose through KPA showed excellent levels of agreement with the effective dose dosetrada. Being a methodology of application soon after the end of each procedure with the purpose of assisting the radiological protection program.

Interventions in the extremities presented lower KPA, and in these procedures, the interventionist positioning is close to the interventional region, closer to the primary beam. The metered dose modalities demonstrated that the scattered radiation has the greatest contribution in the dose received by the team. The exception was in the interventions of extremities, in which the primary beam has a great contribution.

Ethical Statement

This research was developed in the Laboratory of Physics Applied to Radiodiagnosis (LAFAR), duly approved by the Research Ethics Committee (CEP) under protocol: CAAE 16932513.5.0000.5411.

Figuras

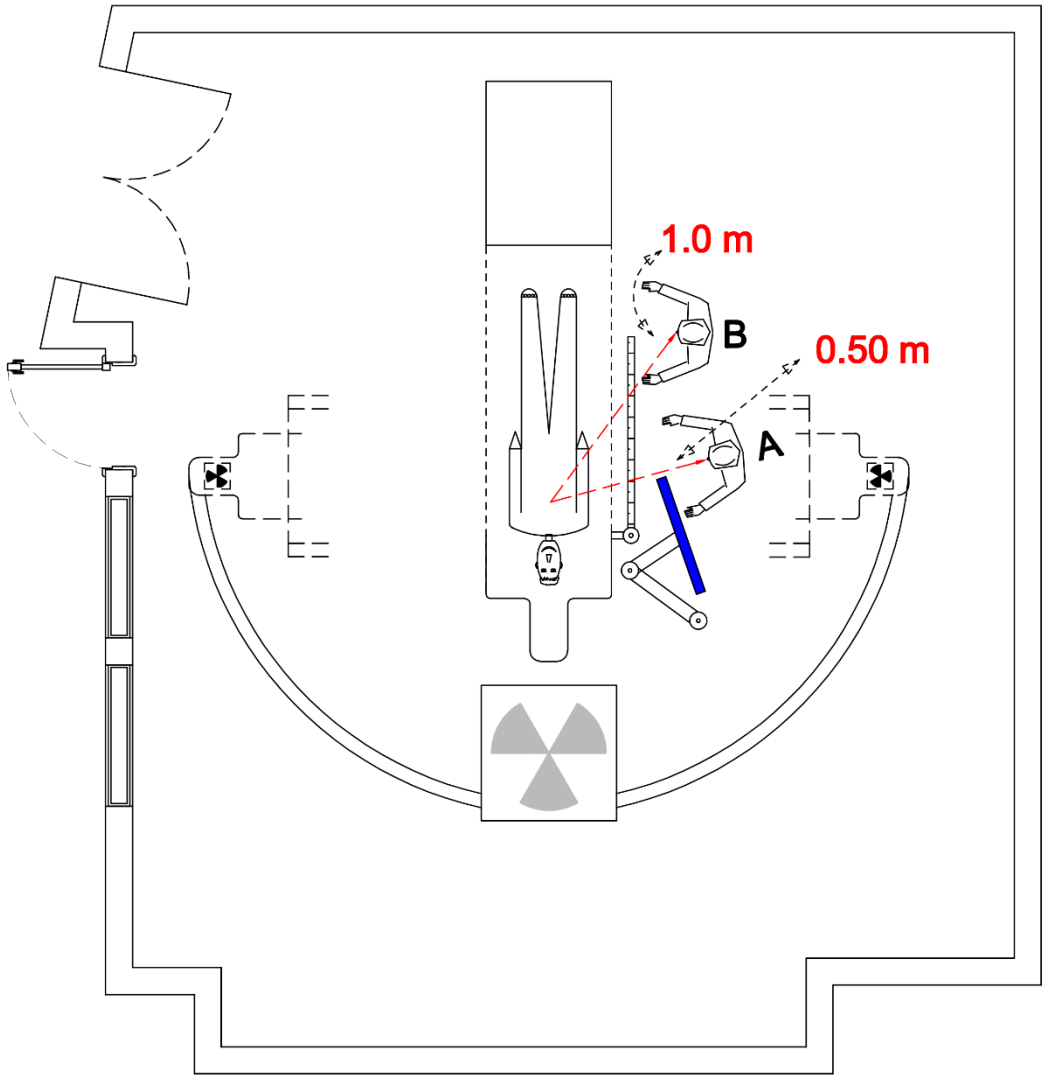

Figure 1

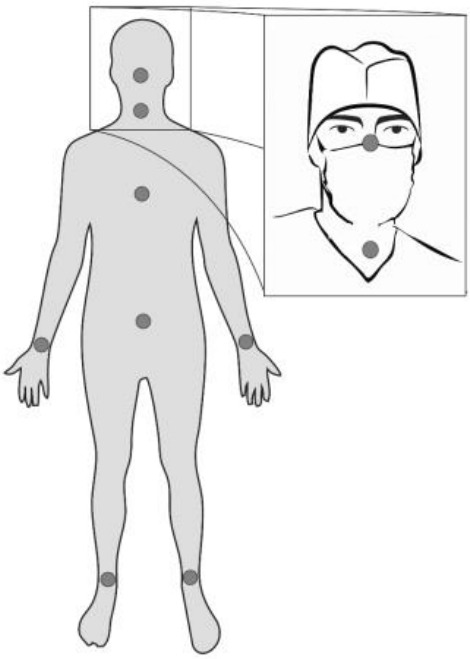

Figure 2

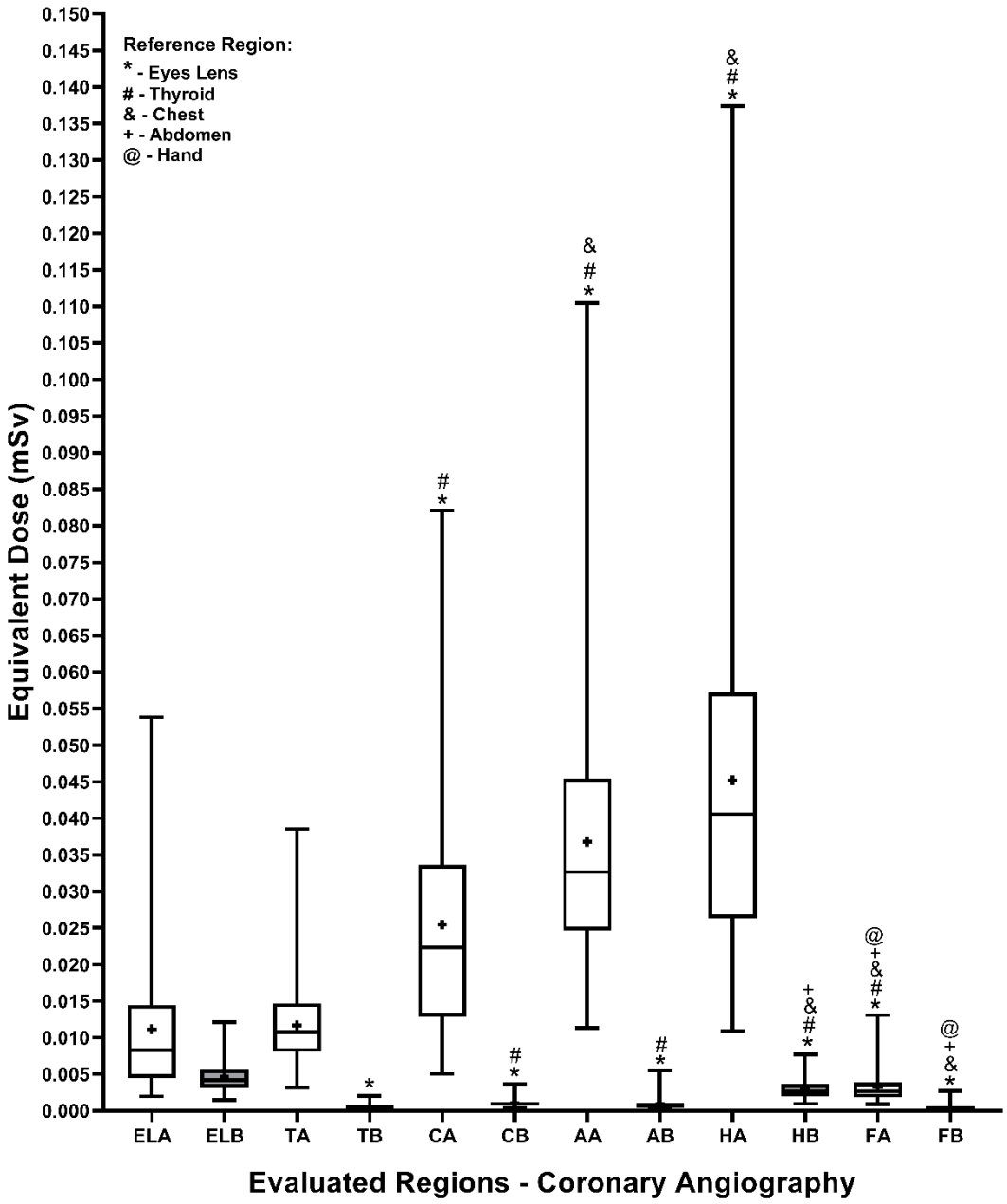
Reference Region:
* - Eyes Lens
# - Thyroid
& - Chest
+ - Abdomen
@ - Hand
Equivalent Dose (mSv)
0.150
0.145
0.140
0.135
0.130
0.125
0.120
0.115
0.110
0.105
0.100
0.095
0.090
0.085
0.080
0.075
0.070
0.065
0.060
0.055
0.050
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
ELA
ELB
TA
TB
CA
CB
AA
AB
HA
HB
FA
FB
Evaluated Regions - Coronary Angiography

Figure 3

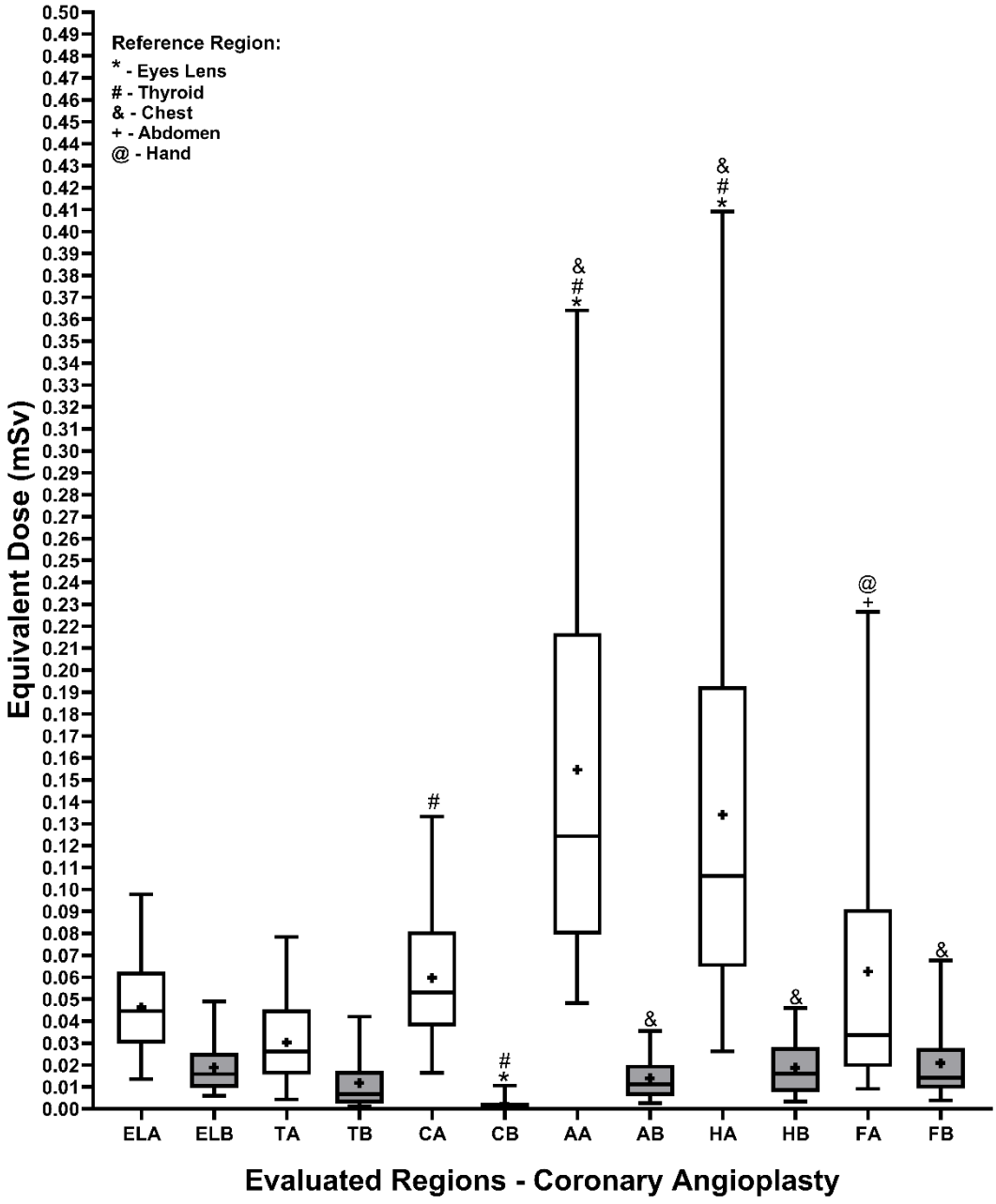
Reference Region:
* - Eyes Lens
# - Thyroid
& - Chest
+ - Abdomen
@ - Hand
Equivalent Dose (mSv)
0.50
0.49
0.48
0.47
0.46
0.45
0.44
0.43
0.42
0.41
0.40
0.39
0.38
0.37
0.36
0.35
0.34
0.33
0.32
0.31
0.30
0.29
0.28
0.27
0.26
0.25
0.24
0.23
0.22
0.21
0.20
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
ELA
ELB
TA
TB
CA
CB
AA
AB
HA
HB
FA
FB
Evaluated Regions - Coronary Angioplasty

Figure 4

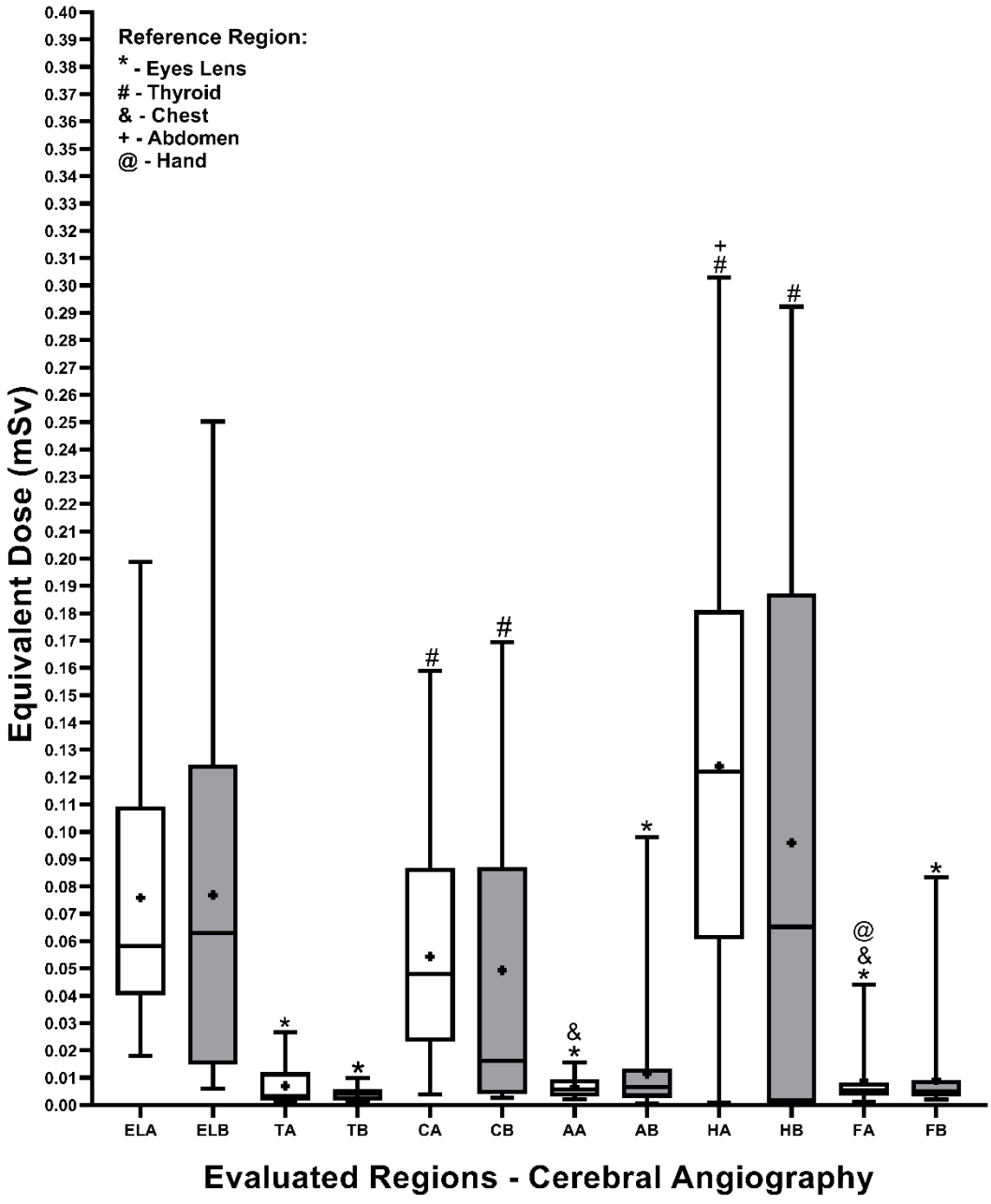
Reference Region:
* - Eyes Lens
# - Thyroid
& - Chest
+ - Abdomen
@ - Hand
Equivalent Dose (mSv)
0.40
0.39
0.38
0.37
0.36
0.35
0.34
0.33
0.32
0.31
0.30
0.29
0.28
0.27
0.26
0.25
0.24
0.23
0.22
0.21
0.20
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
ELA
ELB
TA
TB
CA
CB
AA
AB
HA
HB
FA
FB
Evaluated Regions - Cerebral Angiography

Figure 5

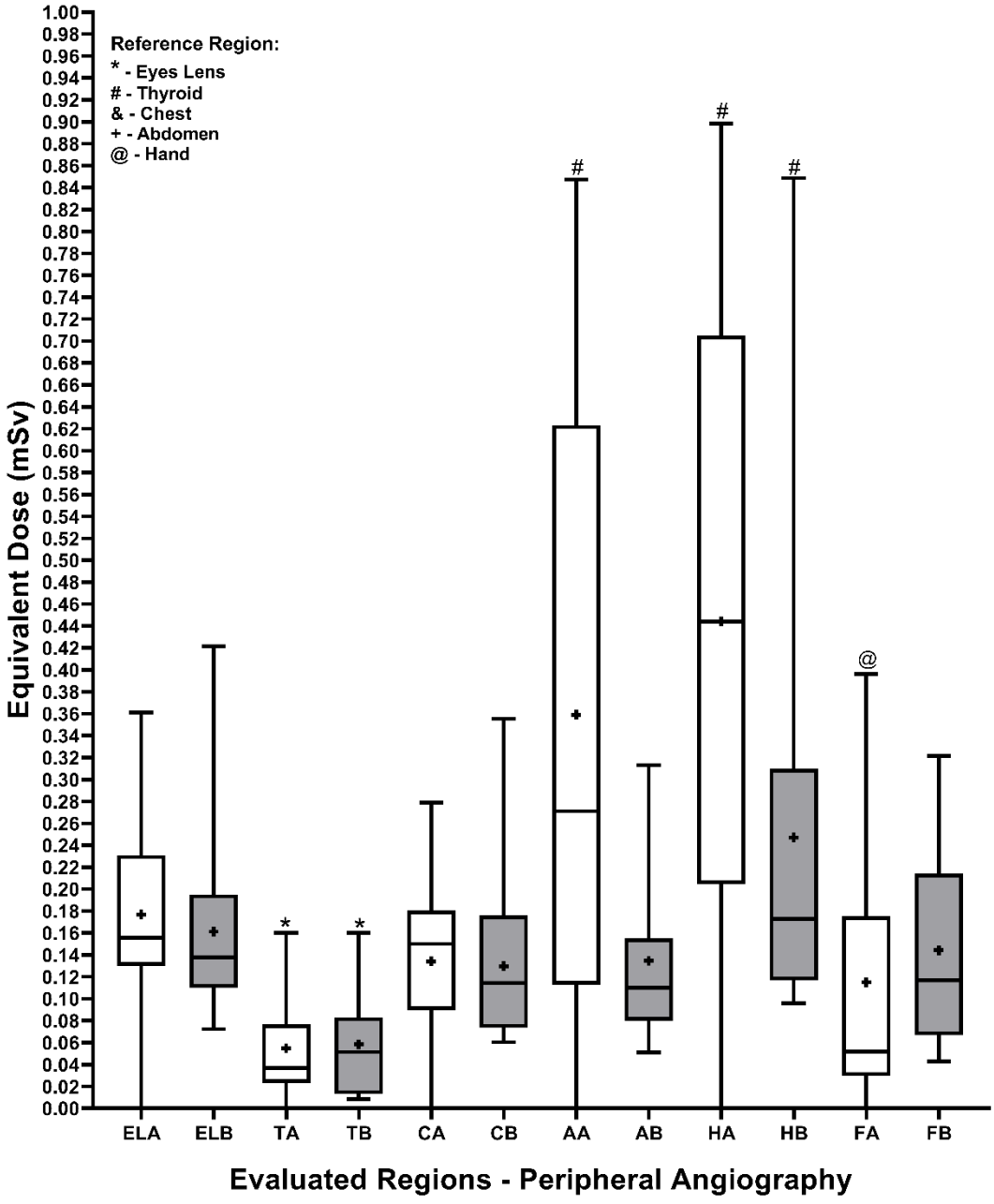
Reference Region:
* - Eyes Lens
# - Thyroid
& - Chest
+ - Abdomen
@ - Hand
Equivalent Dose (mSv)
1.00
0.98
0.96
0.94
0.92
0.90
0.88
0.86
0.84
0.82
0.80
0.78
0.76
0.74
0.72
0.70
0.68
0.66
0.64
0.62
0.60
0.58
0.56
0.54
0.52
0.50
0.48
0.46
0.44
0.42
0.40
0.38
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
ELA
ELB
TA
TB
CA
CB
AA
AB
HA
HB
FA
FB
Evaluated Regions - Peripheral Angiography

Figure 6

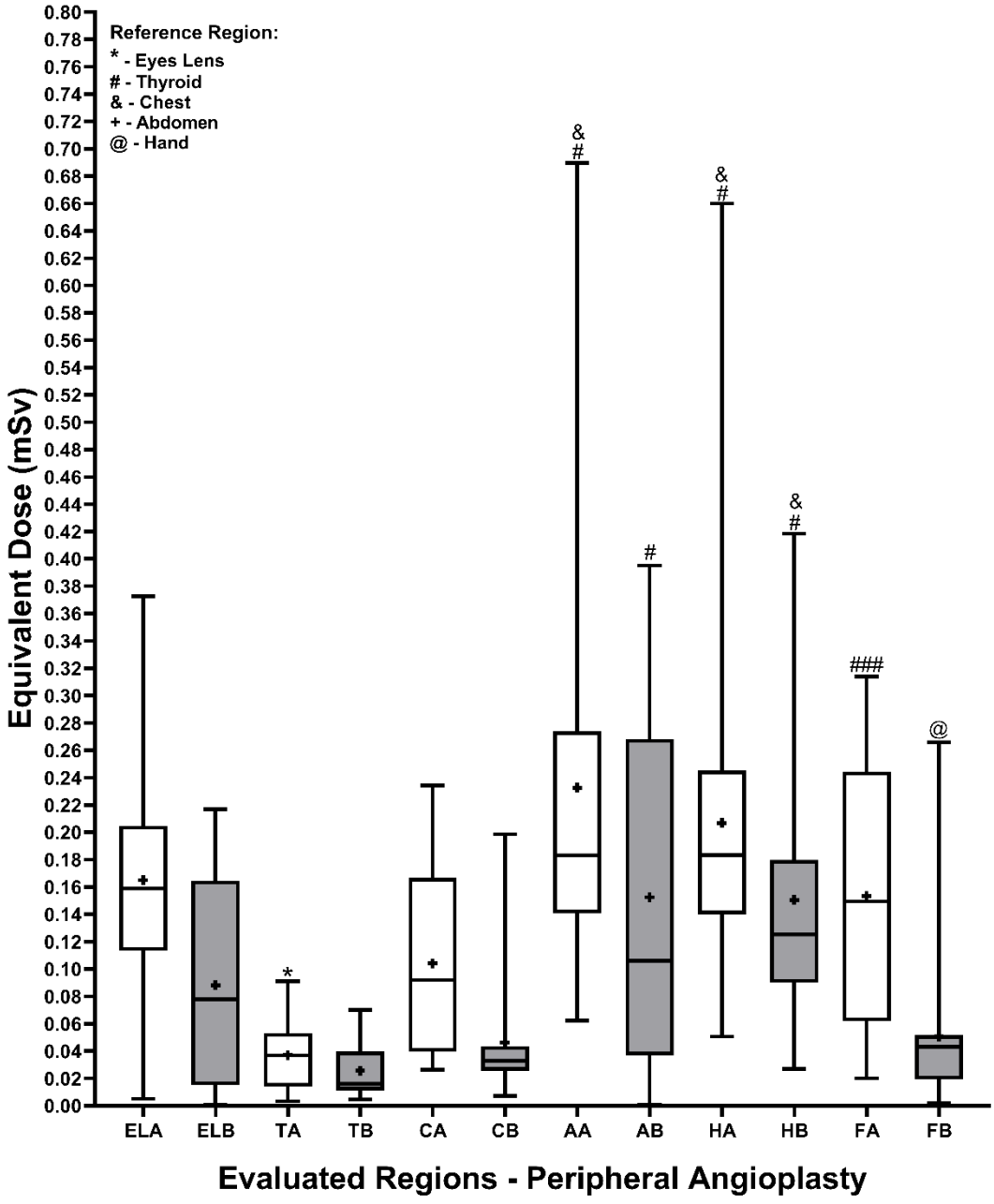
Reference Region:
* - Eyes Lens
# - Thyroid
& - Chest
+ - Abdomen
@ - Hand
Equivalent Dose (mSv)
0.80
0.78
0.76
0.74
0.72
0.70
0.68
0.66
0.64
0.62
0.60
0.58
0.56
0.54
0.52
0.50
0.48
0.46
0.44
0.42
0.40
0.38
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
&
#
&
#
#
&
#
###
@
*
ELA
ELB
TA
TB
CA
CB
AA
AB
HA
HB
FA
FB
Evaluated Regions - Peripheral Angioplasty

Figure 7

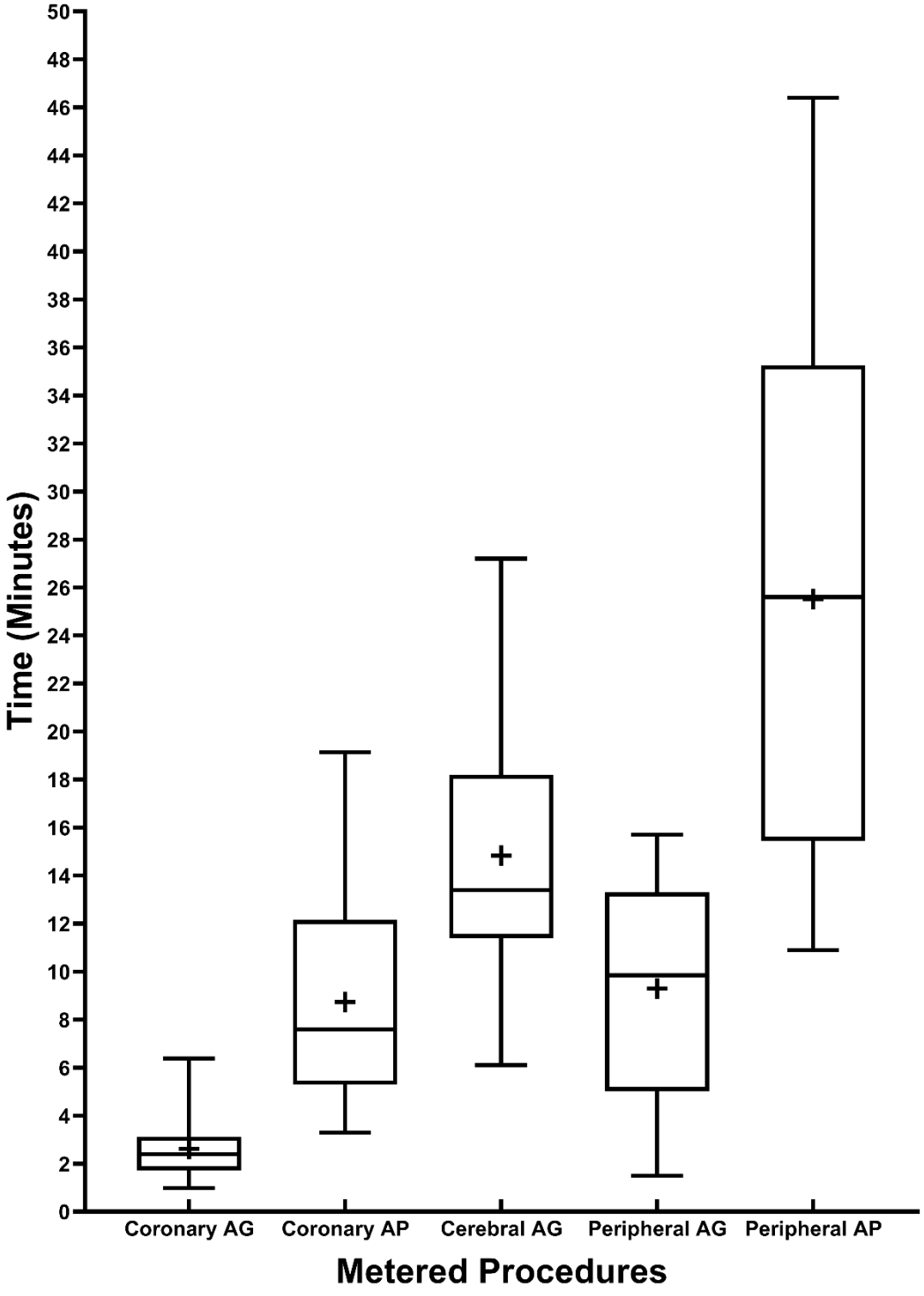
Time (Minutes)
50
48
46
44
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
Coronary AG
Coronary AP
Cerebral AG
Peripheral AG
Peripheral AP
Metered Procedures

Figure 8

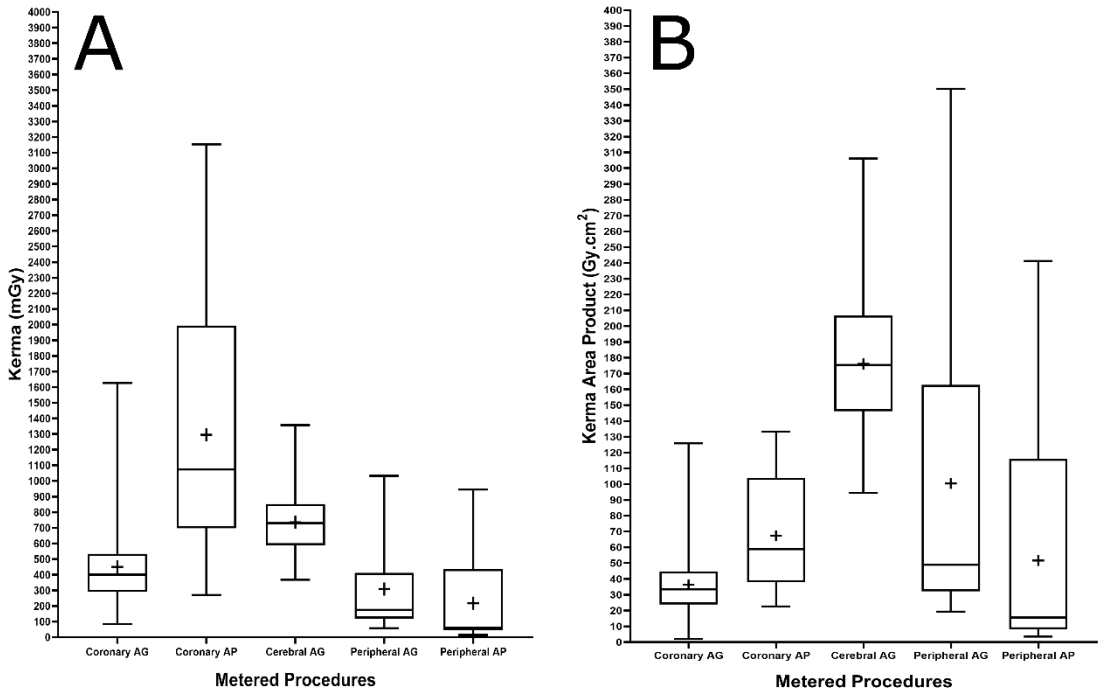

Figure 9

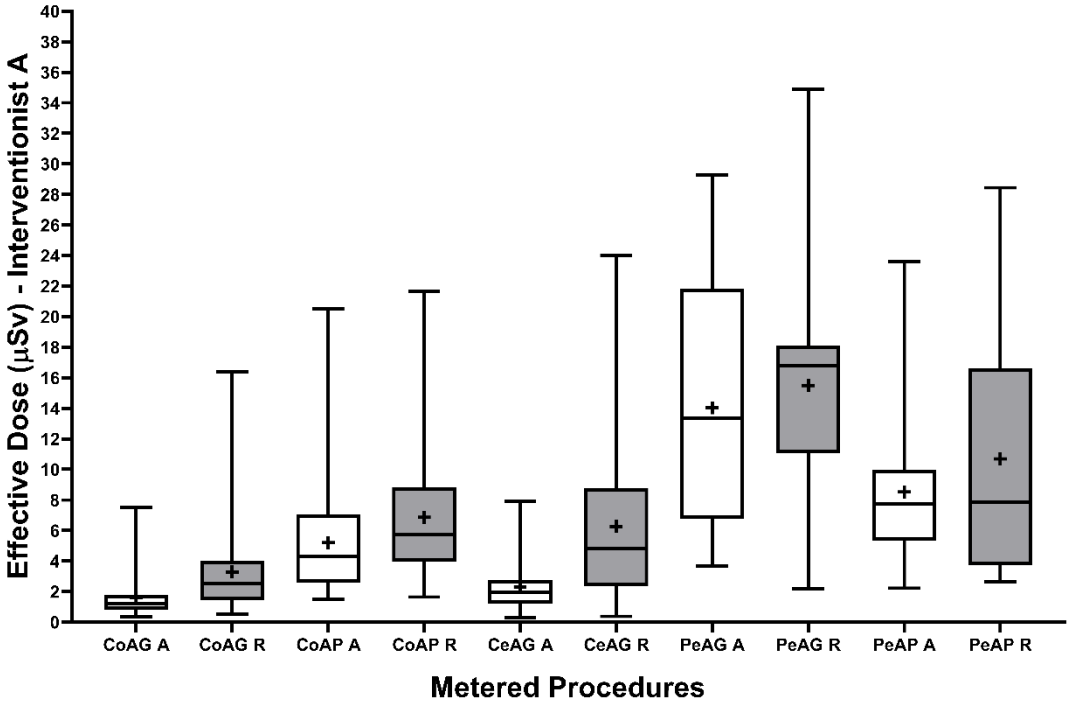

Figure 10

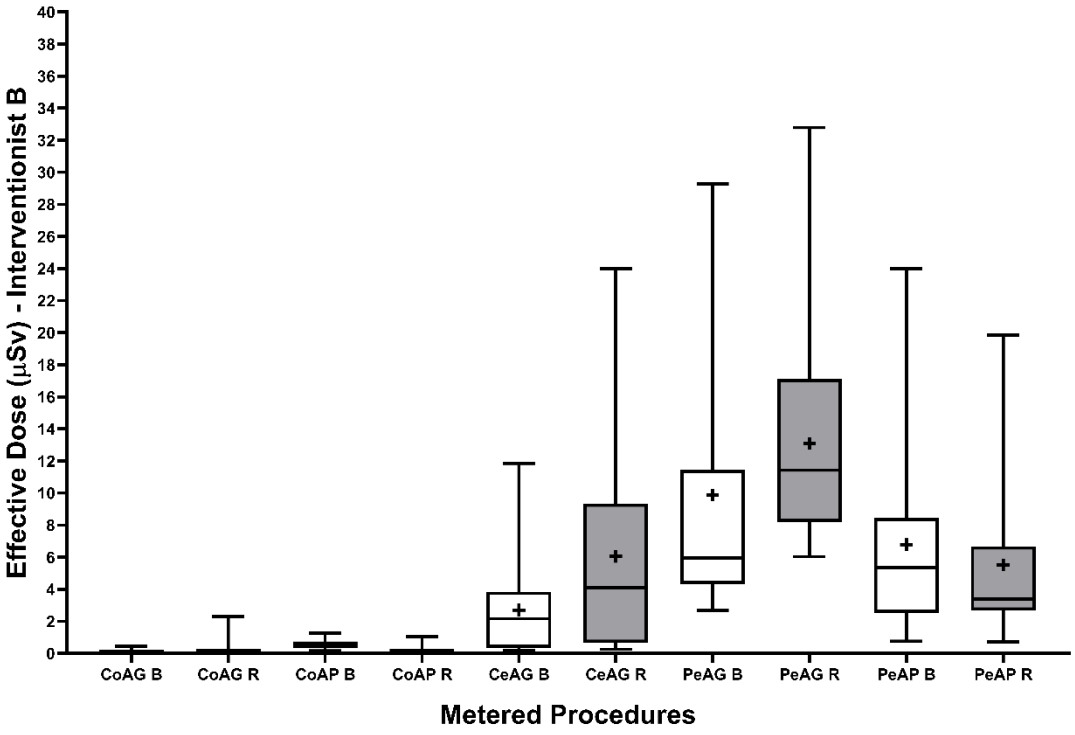
Effective Dose (μSv) - Interventionist B
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
CoAG B
CoAG R
CoAP B
CoAP R
CeAG B
CeAG R
PeAG B
PeAG R
PeAP B
PeAP R
Metered Procedures

Figure 11

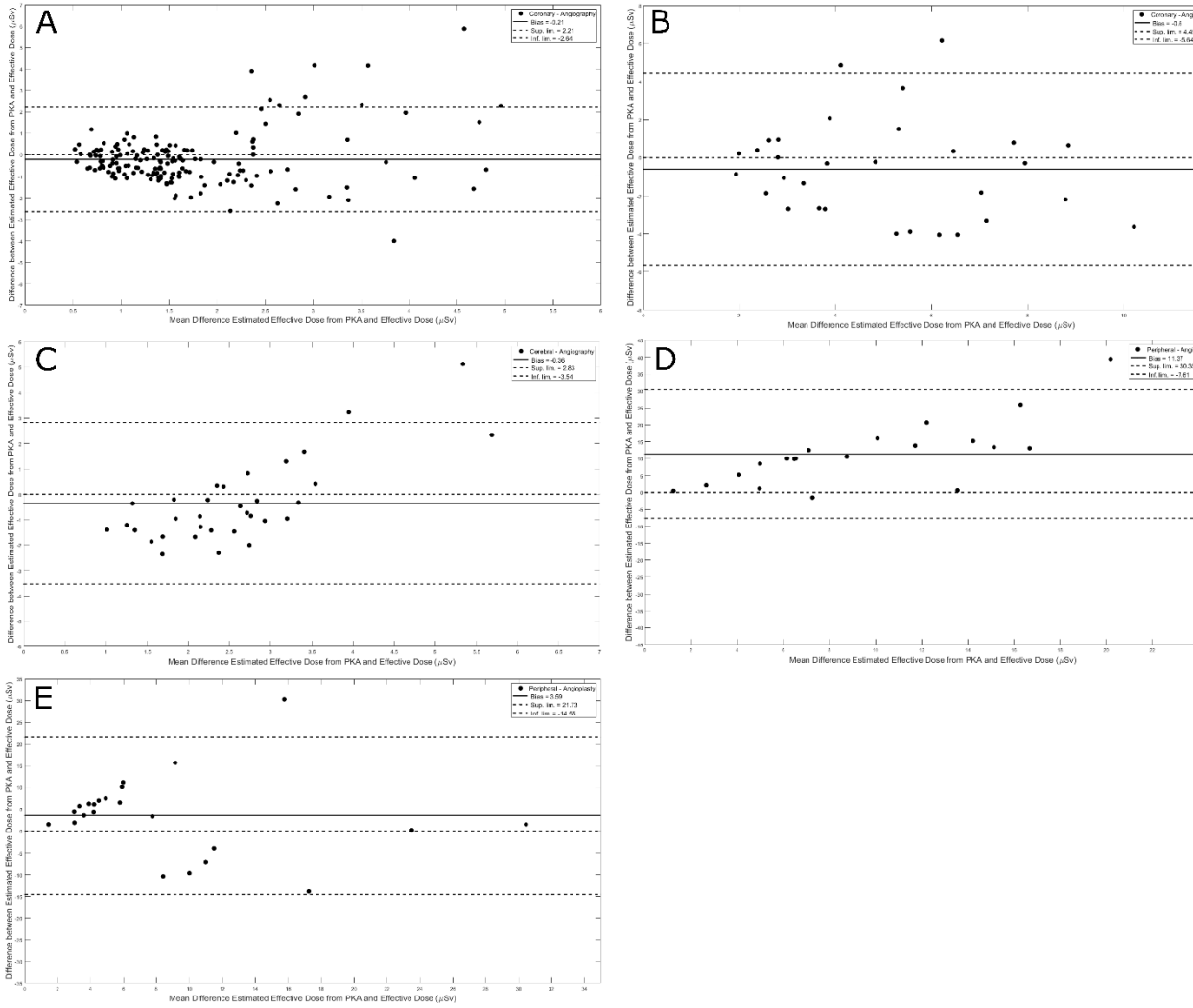
A
Coronary - Angiography
Bias = -0.21
Sup. lim. = 2.21
Inf. lim. = -2.64
Difference between Estimated Effective Dose from PKA and Effective Dose (μSv)
Mean Difference Estimated Effective Dose from PKA and Effective Dose (μSv)
B
Difference between Estimated Effective Dose from PKA and Effective Dose (μSv)
Mean Difference Estimated Effective Dose from PKA and Effective Dose (μSv)
C
Cerebral - Angiography
Bias = -0.36
Sup. lim. = 2.83
Inf. lim. = -3.54
Difference between Estimated Effective Dose from PKA and Effective Dose (μSv)
Mean Difference Estimated Effective Dose from PKA and Effective Dose (μSv)
D
Difference between Estimated Effective Dose from PKA and Effective Dose (μSv)
Mean Difference Estimated Effective Dose from PKA and Effective Dose (μSv)
E
Peripheral - Angioplasty
Bias = 3.59
Sup. lim. = 21.73
Inf. lim. = -14.55
Difference between Estimated Effective Dose from PKA and Effective Dose (μSv)
Mean Difference Estimated Effective Dose from PKA and Effective Dose (μSv)

Figure 12

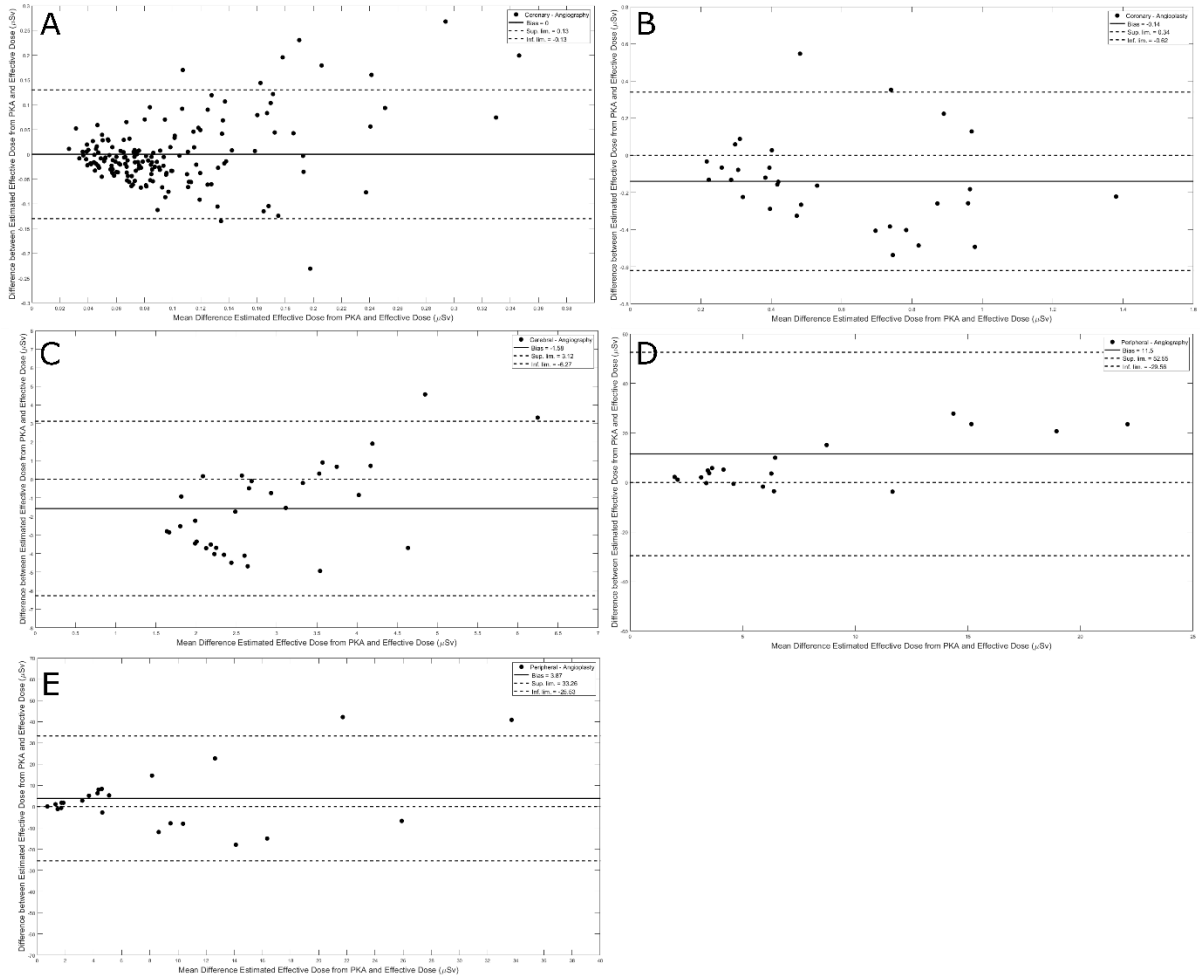
A
Coronary - Angiography
Bias = 0
Sup. lim. = 0.13
Inf. lim. = -0.13
Difference between Estimated Effective Dose from PKA and Effective Dose (μSv)
Mean Difference Estimated Effective Dose from PKA and Effective Dose (μSv)
B
Coronary - Angioplasty
Bias = -0.14
Sup. lim. = 0.34
Inf. lim. = -0.62
Difference between Estimated Effective Dose from PKA and Effective Dose (μSv)
Mean Difference Estimated Effective Dose from PKA and Effective Dose (μSv)
C
Cerebral - Angiography
Bias = -1.56
Sup. lim. = 3.12
Inf. lim. = -6.27
Difference between Estimated Effective Dose from PKA and Effective Dose (μSv)
Mean Difference Estimated Effective Dose from PKA and Effective Dose (μSv)
D
Peripheral - Angiography
Bias = 11.5
Sup. lim. = 62.05
Inf. lim. = -39.56
Difference between Estimated Effective Dose from PKA and Effective Dose (μSv)
Mean Difference Estimated Effective Dose from PKA and Effective Dose (μSv)
E
Peripheral - Angioplasty
Bias = 3.87
Sup. lim. = 33.26
Inf. lim. = -25.53
Difference between Estimated Effective Dose from PKA and Effective Dose (μSv)
Mean Difference Estimated Effective Dose from PKA and Effective Dose (μSv)

Figure 13

Tables

Table 1

External Region	Internal Region	w_t ($\sum w_t = 1$)	FC médio
Eye Lens	Brain	0.01	0.15
	Salivary glands	0.01	0.25
	Oral mucosa	0.01	0.26
Thyroid	Thyroid	0.04	0.03
Chest	Esophagus	0.04	0.014
	Thoracic Spine	0.12	0.013
	Ribs	0.01	0.032
	Sternum	0.01	0.035
	Lung	0.12	0.02
	Heart	0.01	0.021
	Breast	0.12	0.049
Abdomen	Colon	0.12	0.035
	Stomach	0.12	0.036
	Gonads	0.08	0.049
	Bladder	0.04	0.016
	Liver	0.04	0.021
	Extrathoracic Region	0.01	0.049
	Gallbladder	0.01	0.025
	Kidneys/Adrenals	0.01	0.011
	Pancreas	0.01	0.012
	Prostate	0.01	0.01
	Small Intestine	0.01	0.035
	Spleen	0.01	0.017
	Thymus	0.01	0.032
	Uterus	0.01	0.015
Hand	Skin	0.005	-
Feet	Skin	0.005	-

Table 2

	Angiography	Angioplasty
Coronary	166	33
Cerebral	39	-
Extremities	21	24

Table 3

	Effective Dose Estimation Factor by KPA (μSv/Gy.cm^2)	
Procedures	Interventionist A	Interventionist B
Coronary Angiography	0.0464	0.0025
Coronary Angioplasty	0.0742	0.0092
Cerebral Angiography	0.0159	0.0212
Extremity Angiography	0.0378	0.0386
Extremity Angioplasty	0.1002	0.0988

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