Title

Mean glandular dose coefficients (DgN) for x-ray spectra used in contemporary breast imaging systems

Permalink
https://escholarship.org/uc/item/640722dj

Journal
Physics in Medicine and Biology, 60(18)

ISSN
0031-9155

Authors
Nosratieh, Anita
Hernandez, Andrew
Shen, Sam Z
et al.

Publication Date
2015-09-21

DOI
10.1088/0031-9155/60/18/7179

Peer reviewed

HHS Public Access
Author manuscript
Phys Med Biol. Author manuscript; available in PMC 2016 September 21.

Published in final edited form as:
Phys Med Biol. 2015 September 21; 60(18): 7179–7190. doi:10.1088/0031-9155/60/18/7179.

Mean Glandular dose coefficients (D_{gN}) for x-ray spectra used in contemporary breast imaging systems

Anita Nosratieh,
Department of Radiology, Biomedical Engineering Graduate Group, University of California Davis

Andrew Hernandez,
Department of Radiology, Biomedical Engineering Graduate Group, University of California Davis

Sam Z. Shen,
Sunnybrook Research Institute, University of Toronto

Martin J. Yaffe,
Sunnybrook Research Institute, University of Toronto

J. Anthony Seibert, and
Department of Radiology, University of California Davis

John M. Boone
Department of Radiology, Department of Biomedical Engineering, University of California Davis

Abstract

Purpose—To develop tables of normalized glandular dose coefficients D_{gN} for a range of anode–filter combinations and tube voltages used in contemporary breast imaging systems.

Methods—Previously published mono-energetic D_{gN} values were used with various spectra to mathematically compute D_{gN} coefficients. The tungsten anode spectra from TASMICS were used; Molybdenum and Rhodium anode-spectra were generated using MCNPx Monte Carlo code. The spectra were filtered with various thicknesses of Al, Rh, Mo or Cu. An initial HVL calculation was made using the anode and filter material. A range of the HVL values was produced with the addition of small thicknesses of polymethyl methacrylate (PMMA) as a surrogate for the breast compression paddle, to produce a range of HVL values at each tube voltage. Using a spectral weighting method, D_{gN} coefficients for the generated spectra were calculated for breast glandular densities of 0%, 12.5%, 25%, 37.5%, 50% and 100% for a range of compressed breast thicknesses from 3 to 8 cm.

Results—Eleven tables of normalized glandular dose (D_{gN}) coefficients were produced for the following anode/filter combinations: W + 50 μm Ag, W + 500 μm Al, W + 700 μm Al, W + 200 μm Cu, W + 300 μm Cu, W + 50 μm Rh, Mo + 400 μm Cu, Mo + 30 μm Mo, Mo + 25 μm Rh, Rh + 400 μm Cu and Rh + 25 μm Rh. Where possible, these results were compared to previously published D_{gN} values and were found to be on average less than 2% different than previously reported values.

Conclusion—Over 200-pages of D_{gN} coefficients were computed for modeled x-ray system spectra that are used in a number of new breast imaging applications. The reported values were found to be in excellent agreement when compared to published values.

1. Introduction

Breast tissue has been determined to be more sensitive to radiation than previously thought during the days of screen-film mammography as evidenced by the increase in tissue-weighting coefficients (from 0.05 to 0.12) published by ICRP 103. (Mountford and Temperton 1992;Valentin 2007) Of the two prominent tissue types found within the breast (glandular and adipose tissue), glandular tissue is the radiosensitive tissue at risk. Accurate radiation dosimetry to the breast is a challenge given the large variability in quantity and distribution of glandular tissue amongst individuals. Consequently the average of the overall glandular dose is reported as the Mean Glandular Dose (MGD) as described by Hammerstein. (Richard Hammerstein et al. 1979)

The dose to the breast is given by $D_g = D_{gN} \times k$ where k (mGy) is the incident air kerma at the entrance surface of the breast. k is measured using an ion chamber free-in-air (no backscatter) and positioned along the central ray of the x-ray source for a given kV, mAs, source-to-chamber distance and beam quality. (Bushberg and Boone 2011) D_{gN} (mGy/mGy) is the normalized glandular dose coefficient and has been studied by several investigators. (Boone et al. 2004;Boone et al. 2005;Dance 1990;Sechopoulos et al. 2007;Sobol and Wu 1997;Thacker and Glick 2004;Vedantham et al. 2012;Wu et al. 1991;Wu et al. 1994) The D_{gN} value is dependent on the quality of the radiation beam (x-ray tube voltage, half value layer, x-ray tube target and filter material) and breast characteristics (breast composition and breast thickness).

While there are many sources of D_{gN} values for conventional mammography applications (Dance 1990;Sobol & Wu 1997;Wu, Barnes, & Tucker 1991;Wu, Gingold, Barnes, & Tucker 1994) new breast imaging applications such as multi – energy imaging, tomosynthesis and scanning slit mammography have made use of a wide range of spectra for which there are no tabulated D_{gN} values available. For example, the Hologic Selenia dual mammography and digital breast tomosynthesis unit uses anode/filter combinations of tungsten (W)/rhodium (Rh) or W/silver (Ag) in mammography mode and W/aluminum (Al) for digital tomosynthesis. Hologic has also developed a dual energy breast imaging system where images are acquired at higher tube voltages (45–49 kV) using a W/copper (Cu) anode/filter combination. The spectral properties are very different in comparison to the GE SenoClaire which utilizes molybdenum (Mo)/Cu or Mo/Rh target/filter combinations. The (dual energy) GE SenoBright Contrast system uses the same anode and filter combinations as the GE SenoClaire system for the low energy exposure and Cu filtration at high energies. The Philips MicroDose system uses a W-anode with 0.5 mm of Al filtration and the Siemens Mammomat system uses a W/Rh anode/filter combination. Lastly, IMS Giotto Tomo uses a W-anode with either Rh or Ag filtration. Given these new breast imaging applications, which use relatively exotic x-ray spectra compared to the days of screen film mammography, D_{gN} coefficients are needed to enable accurate estimation of MGD.

Previously reported D_{gN} values have primarily been for molybdenum (Mo) and rhodium (Rh) anodes with Mo and Rh filtration. (Boone 1999;Dance 1990;Sobol & Wu 1997;Wu, Barnes, & Tucker 1991;Wu, Gingold, Barnes, & Tucker 1994) Some compilations of D_{gN} coefficients extend to tungsten (W) anodes, however differences in half value layer (HVL) of the spectra are not addressed (Sechopoulos, Suryanarayanan, Vedantham, & Karellas 2007;Sechopoulos et al. 2014) as with traditional tables of D_{gN} values. Furthermore, there is a recent focus on breast imaging applications where x-ray tube voltages are substantially higher than with mammography or digital breast tomosynthesis.

Investigators in the United States and Europe have developed coefficients that correct for the geometric differences of dose distribution in digital breast tomosynthesis compared to mammography. Sechopolous et al use a *relative glandular dose* (RGD) metric that enables calculation of breast dose as a function of projection angle, breast size and thickness for various x-ray spectra. (Sechopoulos, Suryanarayanan, Vedantham, & Karellas 2007;Sechopoulos, Sabol, Berglund, Bolch, Brateman, Christodoulou, Flynn, Geiser, Goodsitt, & Jones 2014) Dance et al have developed mean glandular dose conversion factors that are a combination of physical measurements, calculations and Monte Carlo simulations to determine MGD for a variety of x-ray spectra. (Dance et al. 2009;Dance et al. 2011;Sechopoulos, Suryanarayanan, Vedantham, & Karellas 2007) However, medical physicists in the United States still rely on traditional D_{gN} coefficients to calculate MGD and thus there is a need to expand on these traditional methods.

The motivation for this work was to develop tables of D_{gN} coefficients that extend the tube voltage and HVL range for Mo, Rh and W anodes and also to include additional filter materials. In collaboration with investigators currently working on these new systems D_{gN} tables were developed for a broad range of x-ray tube voltages, anode/filter combinations and half value layer (HVL) values for breast thicknesses ranging from 3–8 cm for 0%, 12.5%, 25%, 37.5%, 50% and 100% breast composition. This work defines breast glandular density to be the mass per volume of glandular tissue with respect to the total breast tissue as described by Hammerstein et al. (Richard Hammerstein, Miller, White, Ellen Masterson, Woodard, & Laughlin 1979) The D_{gN} coefficients reported here are based on calculations made as a function of photon energy ($D_{gN}(E)$). (Boone 2002)

2. Methods

2A. Spectral modeling

The <u>t</u>ungsten <u>a</u>node <u>s</u>pectral <u>m</u>odel using <u>i</u>nterpolating <u>c</u>ubic <u>s</u>plines (TASMICS) (Hernandez and Boone 2014) was employed in this study to generate W anode spectra for the tube voltage of interest. This spectral model is based on Monte Carlo simulations (MCNPx 2.6.0) and uses cubic spline interpolation to generate minimally-filtered (0.8 mm Be) W anode spectra between 20 and 640 kV with an anode angle of 12 degrees and 1 keV energy resolution. Rh and Mo minimally-filtered (0.8 mm Be) spectra were also simulated in MCNPx using an identical fluence tally, source definition, and energy binning as in TASMICS, but with a 24 degree “effective” anode angle as is typical in breast imaging, tube voltages from 20 kV to 60 kV, and anode compositions of high purity Rh and Mo. The Rh and Mo x-ray spectra were simulated using the same methods utilized in TASMICS for 20 kV to 60 kV. (Hernandez & Boone 2014)

The TASMICS spectral model was used to generate W spectra which were filtered using energy dependent elemental attenuation coefficients from the NIST XCOM: Photon Cross Sections Database. (Berger et al. 1998) The Rh and Mo spectra were also filtered using the same approach. The following lists the anode and filter combinations generated for this study: Mo + 400 μm Cu[I], Rh + 400 μm Cu[II], Mo + 30 μm Mo[III], Mo + 25 μm Rh[IV], Rh + 25 μm Rh[V], W + 50 μm Ag[VI], W + 500 μm Al[VII], W + 700 μm Al[VIII], W + 200 μm Cu[IX], W + 300 μm Cu[X] and W + 50 μm Rh[XI].

Matlab (7.14, The MathWorks Inc., 105 Natick, MA, 2012a) code was written to calculate the HVL of the filtered spectra, this value served as the starting HVL value. In order to obtain a range in HVL, the x-ray beam was filtered with various thicknesses of PMMA as a surrogate for the breast compression paddle.

2B. D_{gN} Calculations

The breast model used was a cylinder of semi-circular cross section and radius of 8.5 cm, skin thickness of 4 mm under a 3 mm polystyrene compression paddle.(Boone 2002) For each x-ray tube voltage and HVL value, the polyenergetic normalized glandular dose coefficients $p\,D_{gN}$ were calculated using:

$$pD_{gN}=\frac{\sum_{E=Emin}^{Emax}\Phi(\mathrm{E})\vartheta(E)DgN(E)\Delta E}{\sum_{E=Emin}^{Emax}\Phi(E)\vartheta(E)\,\Delta E}$$

where $\Phi(E)$ (units of photons/mm^2) represent the unnormalized spectra, $\vartheta(E)$ (units of mGy per photons/mm^2) is the photon fluence to air kerma conversion factor and $D_{gN}(E)$ (units of mGy/mGy). (Boone 2002) $D_{gN}(E)$ was calculated using the parameterisations given in Appendix A–C of the work by Boone (Boone 2002) for 0%, 50% and 100% glandular density.[XII]

The intermediate glandular densities (12.5%, 25% and 37.5%) were calculated by weighing the $D_{gN}(E)$ coefficients for 0%, 50% and 100% by the volume glandular fraction V_g (Equation 1) from Boone. (Boone 1999)

[I]General System
[II]General System
[III]GE Essential
[IV]GE SenoBright
[V]GE Essential
[VI]IMS Giotto
[VII]Philips MicroDose
[VIII]Hologic Dimensions
[IX]Hologic Contrast
[X]Hologic Contrast
[XI]Siemens Mammomat
[XII]Note that in Appendix D (Boone 2002) the equation for exposure per photon/mm^2 is incorrect. The x-ray quanta per unit exposure (photons/mm^{2}mR) was calculated using Eq. 2 described in Boone (Boone and Seibert 1997) as derived by Johns. (Johns and Cunningham 1974)

$$V_g = \left[\frac{(1-f_g)}{f_g} \frac{\rho_g}{\rho_a} + 1 \right]^{-1}$$

where f_g is the weight fraction of glandular tissue, ρ_g is the density of 100% glandular tissue and ρ_a is the density of 100% adipose tissue (ρ_g = 1.04 g/cm^3 and ρ_a = 0.93 g/cm^3 from Hammerstein et al.) (Richard Hammerstein, Miller, White, Ellen Masterson, Woodard, & Laughlin 1979)

3. Results

3A. X-ray Spectra

The x-ray tube voltage, target/filter combinations and HVL range for this study are summarized in Table 1.

A sample of x-ray spectra for the lowest, middle and highest tube voltage (kV) are displayed in Figure 1.

3B. D_{gN} Values

The comprehensive set of D_{gN} values is quite large (over 200 pages) and therefore a sampling of the results are shown here in Tables 2–12. The D_{gN} coefficients for breast glandular density of 0%, 12.5%, 25%, 37.5%, 50% and 100% for compressed breast thickness of 3–8 cm as a function of kV and HVL are in D_{gN} Tables 2–12 which are available by email request to: jmboone@ucdavis.edu.

3C. Comparison to previous publications

Comparisons to the D_{gN} values of Boone (Boone 1999) were made for 0% and 100% glandular breast density for the following anode/filter combinations: W/Rh, W/Ag, Mo/Mo, Mo/Rh and Rh/Rh (Figure 2). A linear fit of the D_{gN} values as a function of HVL from this work was used for interpolation in order to compare the D_{gN} values reported here to the same HVL reported in Boone's work. The y-axis in Figure 2 is the reported D_{gN} value from Boone (Boone 1999) and the x-axis is the interpolated D_{gN} value for the same HVL for this work. The individual points represent a single D_{gN} value for a given kV and breast thickness (3–8 cm). The maximum differences between D_{gN} coefficients produced in this work to that of Boone for a specific anode/filter material and breast composition were 3%, 6%, 2%, 3%, 8%, 6%, 4%, 4%, 4%, and 3% for W/Rh – 0%, W/Rh -100%, W/Ag – 0%, W/Ag – 100%, Mo/Mo – 0%, Mo/Mo – 100%, Mo/Rh – 0%, Mo/Rh – 100%, Rh/Rh – 0% and Rh/Rh – 100%, respectively.

4. Discussion

The dramatic differences in spectral distribution between varying anode and filter combinations are apparent in Figure 1. Depending upon the imaging modality, using one anode/filter combination over another may yield better images with less radiation dose to the breast. In the case of digital tomosynthesis, harder beams are typically used since the exposures are distributed over a number of projection images. Whereas in dual-energy mammography, a high tube voltage projection image is subtracted from a low tube voltage acquisition with different filtration, enabling differences in the spectral distribution to enhance the presence of iodine contrast agent in lesions of interest.

This work was accomplished by combining previously published Monte Carlo x-ray spectra with published mathematical equations describing monoenergetic values of D_{gN}. With knowledge of a system's tube voltage, HVL, anode/filter combination and entrance kerma, breast thickness and composition, the coefficients in $\mathrm{D_{gN}}$ Tables 2–12 can be used to estimate the MGD for a wide assortment of breast imaging applications. Please note that Tables 2–12 are samples of the data set, for entire set of tables please contact the corresponding author. For D_{gN} coefficients that were previously published, comparisons were made to this work as shown in Figure 2.

The percent difference between this work and Boone (Boone 1999) is based on a maximum difference in a single Dgn value (note that over 700-Dgn values were compared). This difference ranged from 2–8%. Although the exact cause of this difference unknown it may have been a result of interpolating the HVL of this work to match the HVL values reported by Boone (Boone 1999).

The range of glandular densities (0–50%) reported here reflect the "Myth of the 50–50 breast," where 95% of over 2500 women in that study had volume glandular densities less than 45%. (Yaffe et al. 2009) Thus to accurately represent the screening population, the data presented here were computed with realistic glandular densities of 0%, 12.5%, 25%, 37.5% and 50%. Tables for 100% breast composition are also available and used comparison to previous publications.

Conclusion

The aim of this work was to address the need for D_{gN} cofficients for systems that employ new x-ray spectra. Tables of D_{gN} coefficients for varying anode/filter combinations as a function of kV, HVL, breast composition and thickness were presented. Results presented compared well to previously published values. Comprehensive (over 200 pages) of D_{gN} tables were generated in this study and are available by request to the corresponding author jmboone@ucdavis.edu.

Acknowledgments

We would like to thank Drs. Loren Niklason and Berry Ren from Hologic and Dr. Serge Muller from General Electric for providing beam characteristics specific to commercial systems. This research was supported in part by a grant from the National Institute of Biomedical Imaging and Bioengineering R01 EB002138

References

Berger MJ, Hubbell JH, Seltzer SM, Chang J, Coursey JS, Sukumar R, Zucker DS, Olsen K. XCOM: photon cross sections database. NIST Standard reference database. 1998; 8(1):3587–3597.

Boone JM, Shah N, Nelson TR. A comprehensive analysis of DgNCT coefficients for pendant-geometry cone-beam breast computed tomography. Medical physics. 2004; 31(2):226–235. [PubMed: 15000608]

Boone JM. Glandular breast dose for monoenergetic and high-energy x-ray beams: Monte Carlo assessment 1. Radiology. 1999; 213(1):23–37. [PubMed: 10540637]

Boone JM. Normalized glandular dose (DgN) coefficients for arbitrary x-ray spectra in mammography: Computer-fit values of Monte Carlo derived data. Medical physics. 2002; 29(5): 869–875. [PubMed: 12033583]

Boone JM, Kwan AL, Seibert JA, Shah N, Lindfors KK, Nelson TR. Technique factors and their relationship to radiation dose in pendant geometry breast CT. Medical physics. 2005; 32(12):3767–3776. [PubMed: 16475776]

Boone JM, Seibert JA. An accurate method for computer-generating tungsten anode x-ray spectra from 30 to 140 kV. Medical physics. 1997; 24(11):1661–1670. [PubMed: 9394272]

Bushberg, JT.; Boone, JM. The essential physics of medical imaging. Lippincott Williams & Wilkins; 2011.

Dance DR. Monte-Carlo calculation of conversion factors for the estimation of mean glandular breast dose. Physics in medicine and biology. 1990; 35(9):1211. [PubMed: 2236205]

Dance DR, Young KC, Van Engen RE. Further factors for the estimation of mean glandular dose using the United Kingdom, European and IAEA breast dosimetry protocols. Physics in medicine and biology. 2009; 54(14):4361. [PubMed: 19550001]

Dance DR, Young KC, Van Engen RE. Estimation of mean glandular dose for breast tomosynthesis: factors for use with the UK, European and IAEA breast dosimetry protocols. Physics in medicine and biology. 2011; 56(2):453. [PubMed: 21191150]

Hernandez AM, Boone JM. Tungsten anode spectral model using interpolating cubic splines: Unfiltered x-ray spectra from 20 kV to 640 kV. Medical physics. 2014; 41(4):042101. [PubMed: 24694149]

Johns, HE.; Cunningham, JR. In The Physics of Radiology. Charles C. Thomas Publ; Springfield, IL: 1974. The combination of radiation fields for clinical use; p. 373-374.

Mountford PJ, Temperton DH. Recommendations of the international commission on radiological protection (ICRP) 1990. European Journal of Nuclear Medicine and Molecular Imaging. 1992; 19(2):77–79.

Richard Hammerstein G, Miller DW, White DR, Ellen Masterson M, Woodard HQ, Laughlin JS. Absorbed Radiation Dose in Mammography 1. Radiology. 1979; 130(2):485–491. [PubMed: 760167]

Sechopoulos I, Sabol JM, Berglund J, Bolch WE, Brateman L, Christodoulou E, Flynn M, Geiser W, Goodsitt M, Jones AK. Radiation dosimetry in digital breast tomosynthesis: Report of AAPM Tomosynthesis Subcommittee Task Group 223. Medical physics. 2014; 41(9):091501. [PubMed: 25186375]

Sechopoulos I, Suryanarayanan S, Vedantham SC, Karellas A. Computation of the glandular radiation dose in digital tomosynthesis of the breast. Medical physics. 2007; 34(1):221–232. [PubMed: 17278508]

Sobol WT, Wu X. Parametrization of mammography normalized average glandular dose tables. Medical physics. 1997; 24(4):547–554. [PubMed: 9127307]

Thacker SC, Glick SJ. Normalized glandular dose (DgN) coefficients for flat-panel CT breast imaging. Physics in medicine and biology. 2004; 49(24):5433. [PubMed: 15724534]

Valentin, J. The 2007 recommendations of the international commission on radiological protection. Elsevier Oxford; 2007.

Vedantham S, Shi L, Karellas A, Noo F. Dedicated breast CT: radiation dose for circle-plus-line trajectory. Medical physics. 2012; 39(3):1530–1541. [PubMed: 22380385]

Wu X, Barnes GT, Tucker DM. Spectral dependence of glandular tissue dose in screen-film mammography. Radiology. 1991; 179(1):143–148. [PubMed: 2006265]

Wu X, Gingold EL, Barnes GT, Tucker DM. Normalized average glandular dose in molybdenum target-rhodium filter and rhodium target-rhodium filter mammography. Radiology. 1994; 193(1): 83–89. [PubMed: 8090926]

Yaffe MJ, Boone JM, Packard N, Alonzo-Proulx O, Huang SY, Peressotti CL, Al-Mayah A, Brock K. The myth of the 50–50 breast. Medical physics. 2009; 36(12):5437–5443. [PubMed: 20095256]

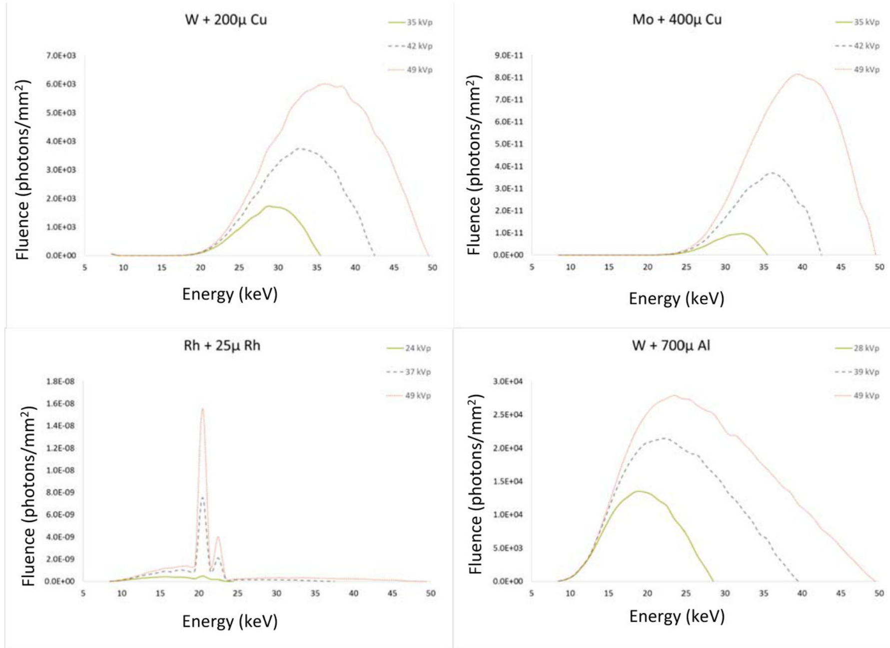

Figure 1.

Sample of the spectra for the specified target and filter combinations shown in Table 1.

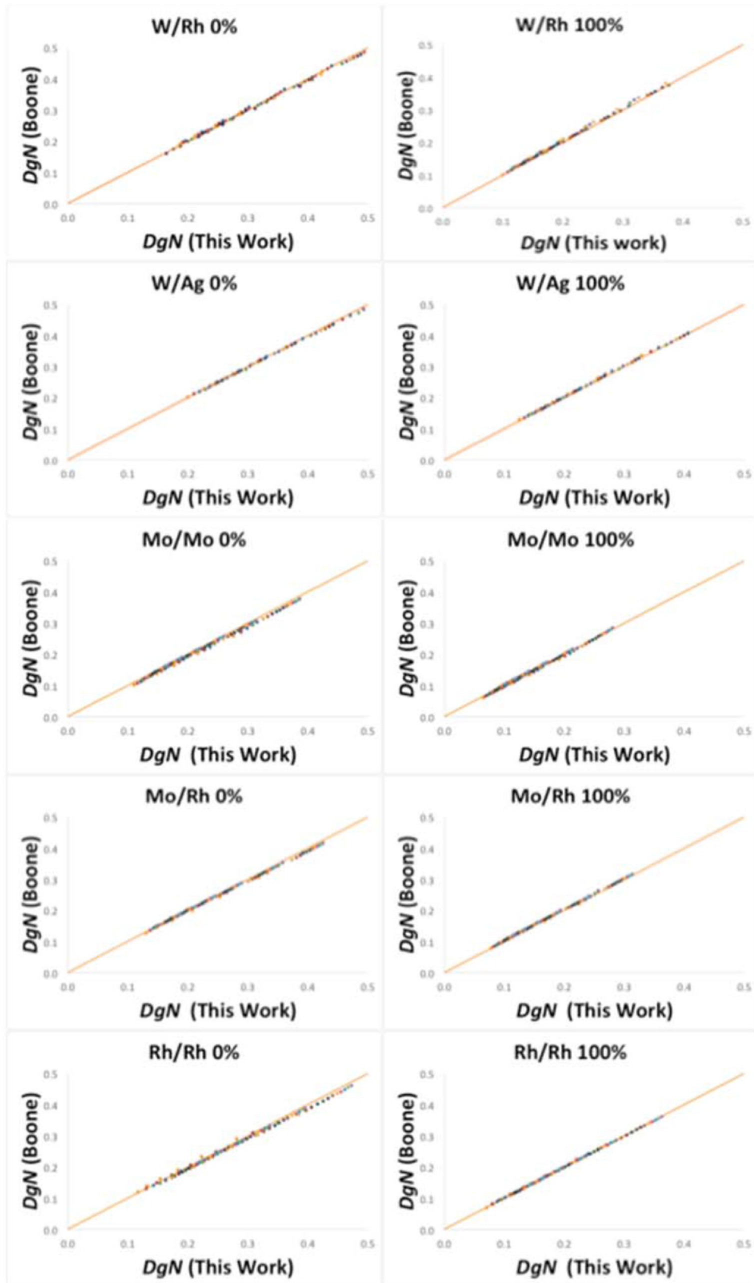

Figure 2.
Comparison of this work to Boone (Boone 1999) for a given Anode/Filter combination and breast composition (%). The D_{gN} units are mGy/mGy. The solid line, y = x, represents perfect agreement between the D_{gN} coefficients. Each point represents a single D_{gN} value for a given kV and breast thickness (3–8 cm).

Table 1

Summary of modeled spectra

Voltage (kV)	Target + Filter	HVL range mm Al	DgN Table #	Manufacturer
35–49	Mo + 400μ Cu	2.24 – 3.80	2	General System
35–49	Rh + 400μ Cu	2.21 – 3.79	3	General System
24–49	Mo + 30μ Mo	0.28 – 0.52	4	GE Essential
24–49	Mo + 25μ Rh	0.330 – 0.56	5	GE SenoBright Low Energy
24–49	Rh + 25μ Rh	0.28 – 0.65	6	GE Essential GE SenoBright Low Energy
26–34	W + 50μ Ag	0.48 – 0.69	7	Hologic Dimensions IMS Giotto TOMO
26–38	W + 500μ Al	0.34 – 0.61	8	Philips MicroDose
28–49	W + 700μ Al	0.46 – 0.92	9	Hologic Dimensions
35–49	W + 200μ Cu	1.68 – 2.89	10	Hologic Contrast
35–49	W + 300μ Cu	2.04 – 3.45	11	Hologic Contrast
23–35	W + 50μ Rh	0.41 – 0.64	12	Siemens Mammomat Hologic Dimensions IMS Giotto TOMO

Table 2

Sample of D_{gN} values for Mo – 400 μm Cu Anode-Filter Combination

Dgn Values Mo-Cu Anode-Filter 0% Glandular Breast (mGy/mGy)							
		Breast Thickness (cm)					
Energy (kV)	**HVL**	**3**	**4**	**5**	**6**	**7**	**8**
35	2.335	0.960	0.897	0.831	0.766	0.706	0.650
	2.360	0.962	0.900	0.834	0.769	0.708	0.653
Dgn Values Mo-Cu Anode-Filter 50% Glandular Breast (mGy/mGy)							
Energy (kV)		Breast Thickness (cm)					
	HVL	**3**	**4**	**5**	**6**	**7**	**8**
35	2.335	0.924	0.848	0.773	0.703	0.641	0.585
	2.360	0.926	0.850	0.775	0.706	0.644	0.588

Table 3

Sample of D_{gN} values for Rh – 400 μm Cu Anode-Filter Combination

Dgn Values Rh-Cu Anode-Filter 0% Glandular Breast (mGy/mGy)							
		Breast Thickness (cm)					
Energy (kV)	**HVL**	**3**	**4**	**5**	**6**	**7**	**8**
35	2.206	0.956	0.893	0.826	0.761	0.701	0.646
	2.231	0.958	0.895	0.829	0.764	0.704	0.648
Dgn Values Rh-Cu Anode-Filter 50% Glandular Breast (mGy/mGy)							
Energy (kV)		Breast Thickness (cm)					
	HVL	**3**	**4**	**5**	**6**	**7**	**8**
35	2.206	0.919	0.843	0.768	0.698	0.636	0.581
	2.231	0.921	0.845	0.770	0.701	0.639	0.583

Table 4

Sample of D_{gN} values for Mo - 30 μm Mo Anode-Filter Combination

Table 3: Dgn Values Mo - Mo Anode-Filter 0% Glandular Breast (mGy/mGy)

		Breast Thickness (cm)					
Energy (kV)	**HVL**	**3**	**4**	**5**	**6**	**7**	**8**
35	0.368	0.352	0.283	0.233	0.197	0.169	0.148
	0.393	0.370	0.298	0.246	0.207	0.178	0.156

Table 3**: Dgn Values Mo - Mo Anode-Filter 50% Glandular Breast (mGy/mGy)**

Energy (kV)		**Breast Thickness (cm)**					
	HVL	**3**	**4**	**5**	**6**	**7**	**8**
35	0.368	0.305	0.239	0.194	0.162	0.138	0.121
	0.393	0.321	0.252	0.205	0.171	0.146	0.128

Table 5

Sample of D_{gN} values for Mo – 25 μm Rh Anode-Filter Combination

Dgn Values Mo - Rh Anode-Filter 0% Glandular Breast (mGy/mGy)							
		Breast Thickness (cm)					
Energy (kV)	**HVL**	**3**	**4**	**5**	**6**	**7**	**8**
35	0.418	0.391	0.317	0.262	0.222	0.191	0.168
	0.443	0.409	0.332	0.276	0.234	0.202	0.177
Dgn Values Mo - Rh Anode-Filter 50% Glandular Breast (mGy/mGy)							
Energy (kV)		**Breast Thickness (cm)**					
	HVL	**3**	**4**	**5**	**6**	**7**	**8**
35	0.418	0.340	0.269	0.219	0.184	0.157	0.138
	0.443	0.357	0.283	0.231	0.194	0.166	0.145

Table 6

Sample of D_{gN} values for Rh – 25 μm Rh Anode-Filter Combination

Dgn Values Rh-Rh Anode-Filter 0% Glandular Breast (mGy/mGy)							
		Breast Thickness (cm)					
Energy (kV)	**HVL**	**3**	**4**	**5**	**6**	**7**	**8**
35	0.450	0.431	0.358	0.303	0.260	0.227	0.200
	0.475	0.448	0.373	0.316	0.272	0.237	0.209
Dgn Values Rh-Rh Anode-Filter 50% Glandular Breast (mGy/mGy)							
Energy (kV)		**Breast Thickness (cm)**					
	HVL	**3**	**4**	**5**	**6**	**7**	**8**
35	0.450	0.381	0.310	0.258	0.219	0.189	0.166
	0.475	0.397	0.323	0.269	0.229	0.198	0.174

Table 7

Sample of D_{gN} values for W – 50 µm Ag Anode-Filter Combination

Dgn Values W-Ag Anode-Filter 0% Glandular Breast (mGy/mGy)							
		Breast Thickness (cm)					
Energy (kV)	**HVL**	**3**	**4**	**5**	**6**	**7**	**8**
30	0.549	0.490	0.411	0.349	0.301	0.264	0.233
	0.574	0.505	0.424	0.361	0.312	0.273	0.242
Dgn Values W-Ag Anode-Filter 50% Glandular Breast (mGy/mGy)							
Energy (kV)		Breast Thickness (cm)					
	HVL	**3**	**4**	**5**	**6**	**7**	**8**
30	0.549	0.436	0.357	0.298	0.255	0.221	0.194
	0.574	0.450	0.369	0.309	0.264	0.229	0.201

Table 8

Sample of D_{gN} values for W - 0.5 mm Al Anode-Filter Combination

Dgn Values W - 0.5 mm Al Anode-Filter 0% Glandular Breast (mGy/mGy)							
		Breast Thickness (cm)					
Energy (kV)	**HVL**	**3**	**4**	**5**	**6**	**7**	**8**
35	0.469	0.454	0.384	0.330	0.288	0.254	0.226
	0.494	0.469	0.398	0.343	0.299	0.264	0.235
Dgn Values W - 0.5 mm Al Anode-Filter 50% Glandular Breast (mGy/mGy)							
Energy (kV)		**Breast Thickness (cm)**					
	HVL	**3**	**4**	**5**	**6**	**7**	**8**
35	0.469	0.443	0.373	0.320	0.278	0.245	0.218
	0.494	0.458	0.387	0.332	0.289	0.254	0.227

Table 9

Sample of D_{gN} values for Mo - 0. 7 mm Al Anode-Filter Combination

Dgn Values W - 0.7 mm Al Anode-Filter 0% Glandular Breast (mGy/mGy)							
Energy (kV)		**Breast Thickness (cm)**					
	HVL	**3**	**4**	**5**	**6**	**7**	**8**
35	0.587	0.522	0.446	0.386	0.338	0.299	0.267
	0.612	0.536	0.459	0.398	0.349	0.309	0.276
Dgn Values W - 0.7 mm Al Anode-Filter 50% Glandular Breast (mGy/mGy)							
Energy (kV)		**Breast Thickness (cm)**					
	HVL	**3**	**4**	**5**	**6**	**7**	**8**
35	0.587	0.471	0.395	0.336	0.291	0.255	0.227
	0.612	0.484	0.406	0.347	0.300	0.264	0.234

Table 10

Sample of D_{gN} values for W- 0.2 mm Cu Anode-Filter Combination

Dgn Values W- 0.2 mm Cu Anode-Filter 0% Glandular Breast (mGy/mGy)							
Energy (kV)		**Breast Thickness (cm)**					
	HVL	**3**	**4**	**5**	**6**	**7**	**8**
35	1.678	0.862	0.792	0.724	0.660	0.603	0.551
	1.703	0.869	0.800	0.731	0.667	0.609	0.556
Dgn Values W- 0.2 mm Cu Anode-Filter 50% Glandular Breast (mGy/mGy)							
Energy (kV)		**Breast Thickness (cm)**					
	HVL	**3**	**4**	**5**	**6**	**7**	**8**
35	1.678	0.819	0.738	0.663	0.597	0.539	0.489
	1.703	0.826	0.745	0.670	0.603	0.544	0.494

Table 11

Sample of D_{gN} values for W- 0.3 mm Cu Anode-Filter Combination

Dgn Values W- 0.3 mm Cu Anode-Filter 0% Glandular Breast (mGy/mGy)							
Energy (kV)	**Breast Thickness (cm)**						
	HVL	**3**	**4**	**5**	**6**	**7**	**8**
35	2.036	0.932	0.866	0.798	0.733	0.673	0.618
	2.056	0.937	0.870	0.802	0.737	0.676	0.621
Dgn Values W- 0.3 mm Cu Anode-Filter 50% Glandular Breast (mGy/mGy)							
Energy (kV)	**Breast Thickness (cm)**						
	HVL	**3**	**4**	**5**	**6**	**7**	**8**
35	2.036	0.893	0.813	0.738	0.668	0.607	0.553
	2.056	0.897	0.818	0.742	0.672	0.611	0.556

Table 12

Sample of D_{gN} values for W - 50 μm Rh Anode-Filter Combination

Dgn Values W-Rh Anode-Filter 0% Glandular Breast (mGy/mGy)							
Energy (kV)		**Breast Thickness (cm)**					
	HVL	**3**	**4**	**5**	**6**	**7**	**8**
35	0.535	0.478	0.398	0.337	0.290	0.253	0.223
	0.560	0.494	0.412	0.349	0.301	0.263	0.232
Dgn Values W-Rh Anode-Filter 0% Glandular Breast (mGy/mGy)							
Energy (kV)		**Breast Thickness (cm)**					
	HVL	**3**	**4**	**5**	**6**	**7**	**8**
35	0.535	0.421	0.342	0.285	0.242	0.209	0.184
	0.560	0.436	0.355	0.296	0.252	0.218	0.192