Volpara HEALTH

WHITE PAPER

Patient-Based Radiation Dose Estimation in Breast Cancer Screening

Keeping Patients Safe and Informed
2018

Ralph Highnam, PhD
Chief Scientist

White Paper: Patient-Based Radiation Dose Estimation in Breast Cancer Screening

Keeping Patients Safe and Informed

Introduction

Each year millions of women are screened using mammography and/or tomosynthesis to detect breast cancer at an early stage. Because the breast is one of the most radiation-sensitive organs,[1] and although the doses used are relatively low,[2] constant vigilance is necessary to ensure that the dose is as low as reasonably achievable (the ALARA principle). Despite the efforts of x-ray vendors and regulatory bodies, patients and clinicians are often concerned about exposure to radiation. For some women, the concern is sufficient to reduce adherence to screening programs or deter them from undergoing breast screening altogether.[3]

Imaging of phantoms in periodic quality control checks has been the primary form of dose monitoring in mammography. However, a new technology now enables more accurate reporting of patient-based doses. This paper explains the scientific background and rationale behind the Volpara® TruRadDose™ clinical function and its application in monitoring system performance in near real time.

Mean Glandular Dose Estimation Today

Mean glandular dose (MGD), used synonymously with average glandular dose (AGD), is widely accepted as the most appropriate measurement for predicting the risk of radiation-induced cancer. MGD is the focus of national and international mammographic dose regulations and quality assurance guidelines.

The US Food and Drug Administration stipulates: "The average glandular dose delivered during a single cranio-caudal view of an FDA-accepted phantom simulating a standard breast shall not exceed 3.0 milligray (mGy) (0.3 rad) per exposure. The dose shall be determined with technique factors and conditions used clinically for a standard breast."[4] EU guidelines also recommend maximum dose levels according to phantom exposures (see table 1).[5]

Although every x-ray manufacturer provides an estimate of the MGD applied for each image, the vendors do not all necessarily use the same algorithm for estimating MGD. In addition, because dose is dependent on breast density, each manufacturer makes simplistic estimations of density to be able to calculate the MGD. Manufacturers insert their computed dose values into the DICOM images sent to workstations and PACS, and the radiologist or technologist can view the MGD estimates.

A maximum average glandular dose is set per PMMA thickness:

Thickness of PMMA	Equivalent breast thickness	Maximum average glandular does to equivalent breasts	
		Acceptable level	Achievable level
[cm]	[cm]	[mGy]	[mGy]
2.0	2.1	< 1.0	< 0.6
3.0	3.2	< 1.5	< 1.0
4.0	4.5	< 2.0	< 1.6
4.5	5.3	< 2.5	< 2.0
5.0	6.0	< 3.0	< 2.4
6.0	7.5	< 4.5	< 3.6
7.0	9.0	< 6.5	< 5.1

Table 1. European guidelines for acceptable and achievable AGD, according to breast thickness of a polymethylmethacrylate (PMMA; also known under the trade names Lucite, Plexiglas, or Perspex) phantom.[5]

Unlike the manufacturers' methods, the Volpara TruRadDose clinical function relies on a sophisticated 3D density form of volumetric breast composition from the Volpara® TruDensity™ clinical function, which uses the entire image to compute breast density. It provides objective and consistent breast density estimation across a wide range of manufacturers and models of x-ray equipment.

Dance's MGD Algorithm

X-ray manufacturers generally use MGD estimation algorithms derived from the models of Wu[6,7,8] and Dance.[9,10,11,12] Additional models exist, such as those from the FDA[13] and Boone.[14] Wu's algorithm allows adjustment for breast-specific density, but it is unclear how manufacturer implementations of Wu estimate breast density, if at all. The Dance algorithm also allows for consideration of breast density in the MGD estimate, but it uses a simplistic estimate of density derived solely from compressed breast thickness.

Volpara TruRadDose is based on Dance's model for estimation of MGD because it is widely accepted and is now available in most mammography and tomosynthesis equipment. Furthermore, comparisons with Wu and Boone indicate high correlations between the various models. Dance's model is outlined in table 2.

MGD = K g c s

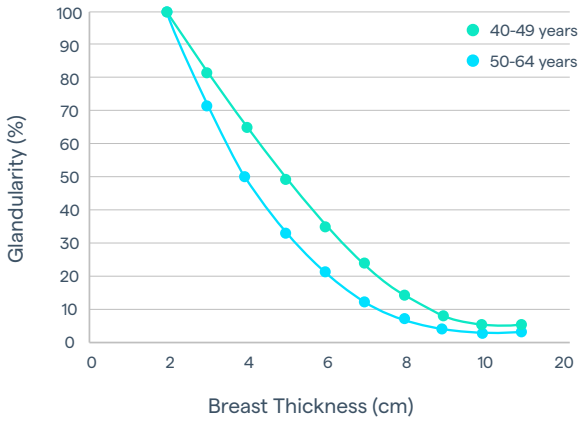
K (mGy)	The incident air kerma (i.e., the "Entrance Dose" at the surface of the breast)
g	A conversion factor describing the fraction of "K" that is absorbed by the glandular tissue in the breast, assuming a breast of 50% adiposity and 50% glandularity
c	The correction factor for breast composition (i.e., corrects for any difference in glandularity from 50%)
s	The correction factor for x-ray spectrum that corrects for differences in the x-ray spectrum when a target/filter combination other than Molybdenum/Molybdenum is used, a correction that is independent of the HVL

Table 2. Dance's model for estimation of Mean Glandular Dose (MGD).

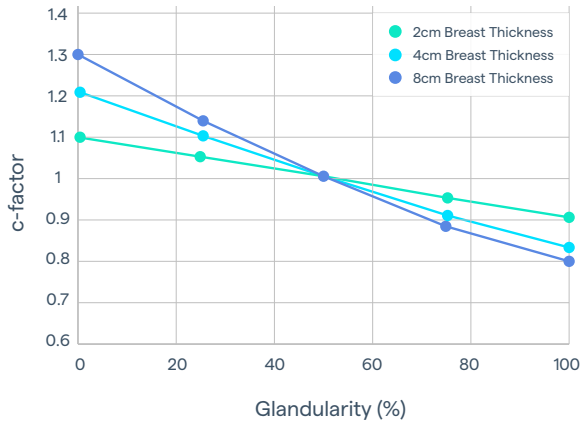
The entrance dose K is provided by either the local physicist's site survey in the x-ray machine calibration file or in the DICOM header of each image. Dance provides a range of s-factors for correcting various target/filter combinations, and g-factors for converting combinations of breast thickness and half-value layer (HVL) based on the assumption of 50% breast glandularity.

To correct for glandularity differences (c-factors), Dance makes a simple estimate of glandularity based on breast thickness and age group (see graph 1). Dance then provides a table of c-factors for various combinations of HVL, breast thickness, and glandularity. Graph 2 illustrates how c-factors vary by glandularity at a fixed HVL, and for several breast thicknesses.

As an example, Dance estimates that a 40-year-old woman with 2-cm breast thickness would have 100% glandularity (see graph 1), giving a c-factor of 0.9—the assumption of a 50% glandularity breast would have led to 10% overestimation of MGD. Similarly, a 40-year-old woman with 8-cm breast thickness would have 14% breast glandularity and a c-factor of 1.2—MGD would be underestimated by 20%.



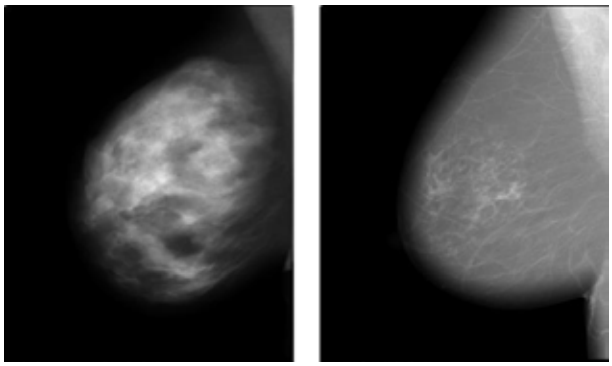
Graph 1. Dance's estimation of glandularity for women aged 40–49 years and 50–64 years, based on breast thickness, originally derived from measurements on a small number of women in the United Kingdom. Reproduced from Dance et al.[10]



Graph 2. Variation of Dance's "c" correction factor according to glandularity, at a fixed HVL (0.45 mm) and 2-, 4-, or 8-cm breast thicknesses. Reproduced from Dance et al.[9]

Volpara TruRadDose Patient-Based Glandularity

Accurate dose estimation depends on accurate assessment of glandularity. Although Dance's breast thickness approach might work on average, it does not differentiate between two women with the same breast thickness but with very different amounts of glandular tissue (see figure 1).



Right MLO VBD: 21.7% Right MLO VBD: 2.8%

Figure 1. Right mediolateral oblique (MLO) mammograms for different women with the same breast thickness but varying breast density.

Volpara TruRadDose uses a patient-based glandularity measure derived from Volpara TruDensity's volumetric breast density (VBD) to compute a patient-based dose. Typical VBDs range from 0 to 35%, whereas Dance's glandularity ranges from 3 to 100%. While both methods include the breast density of the central portion of the breast, only VBD also incorporates both the subcutaneous and retroglandular fat into the overall glandularity percentage.

Figure 2 illustrates the region (shaded blue) of the breast volume that Dance uses to determine glandularity (%). Dance excludes the subcutaneous fat layer and the fatty breast edge, where the breast is thinner (not compressed). Volpara TruDensity uses a different model that excludes only the skin in its density estimation.

Another distinction is that Volpara TruRadDose considers glandularity as a proportion of volume, while Dance's method treats glandularity by weight.

Volpara TruRadDose adapts VBD to Dance's glandularity by performing these steps:

- Removes the subcutaneous fat from the volume of breast (may raise the density by 20+%);
- Removes the uncompressed breast edge from the volume of breast (may raise the density by 3 to 8%);
- Uses the known densities of fibroglandular and fatty tissue to change the density from volume to weight (may raise the density by ~6%).[15]

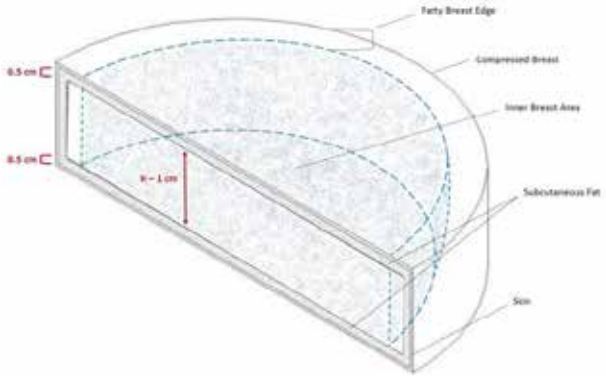
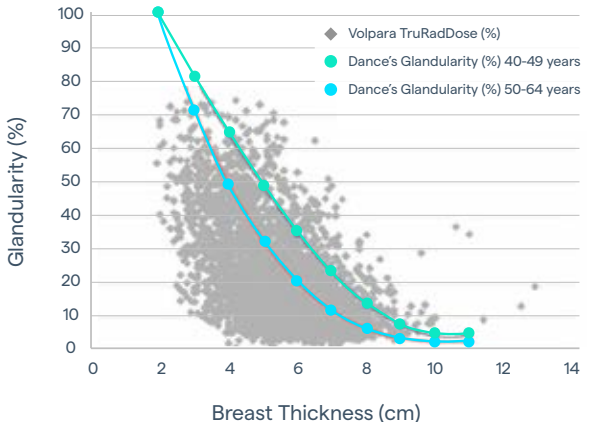


Figure 2. Diagram of a compressed breast and the regions important for glandularity estimations in Dance's model.

The Volpara TruRadDose conversion makes the range of glandularity values more comparable to those of Dance (graph 3). The distribution of points shown for Volpara TruRadDose glandularity better reflects the diversity of breast composition in women of similar breast thickness. As the Volpara TruRadDose data in graph 3 is primarily from women aged 50+ years, it more closely matches Dance's data for 50–64-year-olds.



Graph 3. Dance glandularity based on breast thickness as a function of age group, overlaid on Volpara TruRadDose glandularity for 1000 patients.[10]

Work is currently underway to better determine the location of dense tissue in 3D, as taking the distribution of glandular tissue into consideration can further improve dose estimation.[16]

Local Calibration of Volpara TruRadDose[a]

Imaging system-specific factors, such as x-ray tube output photon fluence and spectrum HVL, also influence the MGD. Changes that occur with normal system wear, and slight manufacturing variations, can make these factors vary between otherwise equivalent systems.

Radiation protection regulations often require periodic measurement of x-ray tube output and HVL to ensure that the physical imaging system and protocols fall within reference dose limits. Despite routine acquisition of high-quality dosimetry data, the survey measurements may not be used to update the imaging system. The system-stored parameters may be factory-loaded values, or values from service calibration. Inaccuracies in the manufacturer-reported MGD may occur if these parameters are outdated.

Volpara TruRadDose allows dosimetry measurements to override outdated machine values in the DICOM header and uses those values to improve dose calculation accuracy. The calibration files from each on-site dosimetry survey are imported into Volpara TruRadDose and can include any number of x-ray tube photon output and HVL measurements that the physicist makes. The software uses optimized interpolation and extrapolation methods, with strict limits to ensure accuracy, to provide the most accurate dose possible for each woman. To ensure accuracy, the software both matches the DICOM header Device ID to the calibration file and uses the DICOM header Study Date to select the appropriate calibration. If no site survey calibration is available, the software adapts to using the DICOM header tube output and HVL values.

Volpara TruRadDose vs. Manufacturer MGD

The MGD estimated by Volpara TruRadDose correlates well with the manufacturer MGD in the DICOM header. The variance in both the glandularity estimates and dose models used by each manufacturer becomes clear when MGD is stratified by breast density. Separating cases by Volpara® Density Grade™ (VDG®) or BI-RADS®[b] reveals that manufacturers make assumptions about the density across all breasts. Figure 3, for Manufacturer A, shows strong correspondence between MGD and Volpara TruRadDose in VDG 1, but divergence in VDG 4; whereas figure 4, for Manufacturer B, shows strong correspondence between MGD and Volpara TruRadDose in VDG 4, but divergence in VDG 1.

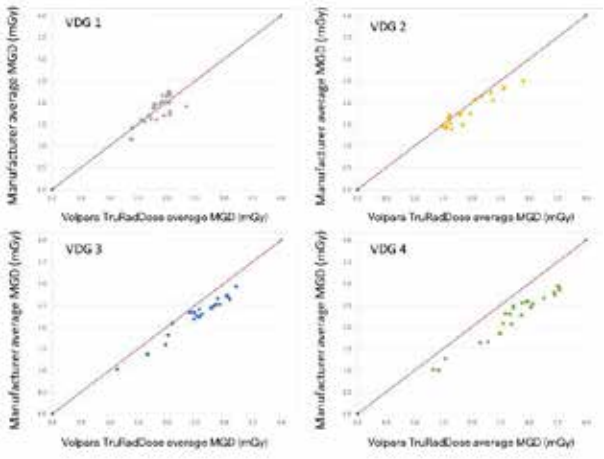


Figure 3. Comparison of Manufacturer A and Volpara TruRadDose estimates of average MGD according to VDG breast density categories.

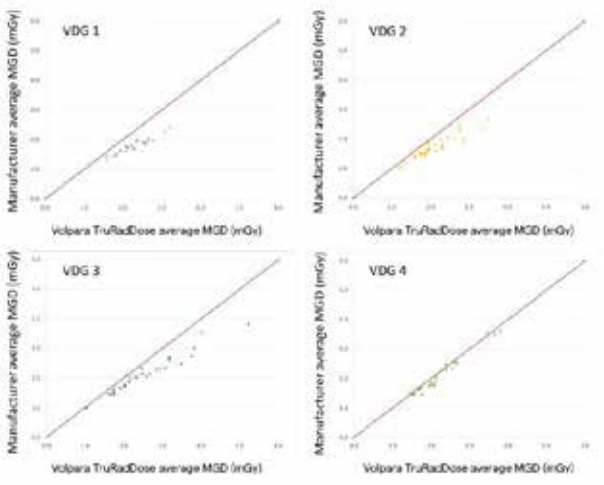


Figure 4. Comparison of Manufacturer B and Volpara TruRadDose estimates of average MGD according to VDG breast density categories.

[a] This section applies only to the VolparaServer platform. Volpara's new architecture does not support dose calibration files.

[b] American College of Radiology Breast Imaging Reporting and Data System.

An example of the difference between manufacturers' MGD is shown in table 3, which compares two different x-ray machines that imaged similar patient populations. The manufacturer dose delivered by system Y is lower than that delivered by system X by 0.2 mGy (12%). However, the Volpara TruRadDose shows that system Y actually delivers a higher patient-based dose than system X by 0.4 mGy (20%). Also, both manufacturers appear to underestimate the radiation dose for this population, as system X and Y manufacturer doses are 0.3 mGy (15%) and 0.9 mGy (38%) lower than their respective Volpara TruRadDose values. This highlights the benefit of a dose metric based on true patient breast density, and the advantage of a consistent dose metric for comparison of x-ray dose between systems.

Manufacturer/System	X	Y
Number of images	64	308
Number of studies	16	77
Volumetric breast density %	9.0	9.2
Glandularity %	17.3	19.2
Compressed breast thickness mm	56.0	57.0
Manufacturer dose mGy	1.7	1.5
Volpara TruRadDose mGy	2.0	2.4

Table 3. Volpara TruRadDose results for two systems from different manufacturers at one US site. The populations screened had similar volumetric breast density and compressed breast thickness. All breast and dose data are reported as medians.

Accessing Volpara TruRadDose Results

There are several easy ways to access Volpara TruRadDose results in a clinical setting:

Volpara® Analytics™ software, a quality control system for breast imaging, includes the Volpara TruRadDose clinical function as a standard component. Each case sent to Volpara Analytics is processed with the Volpara TruRadDose algorithm. The dose results are included in the Volpara® Scorecard™ Secondary Capture Image (see figure 5) and sent to the technologist and radiologist for review. In addition, Volpara Analytics graphs such as those shown in figure 6 and figure 7 help physicists track machine performance in the clinical environment, instead of only during physics surveys. The Volpara TruRadDose results are also available to dose aggregation systems through a DICOM Radiation Dose Structured Report.

Additionally, the minimum, median, and maximum Volpara TruRadDose values can be viewed for each mammography unit and operator. These values can also be directly compared to the manufacturer-reported MGD values.

Volpara Scorecard software displays the Volpara TruRadDose clinical function. As with Volpara Analytics, Volpara TruDensity adds Volpara TruRadDose values to the Volpara Scorecard.

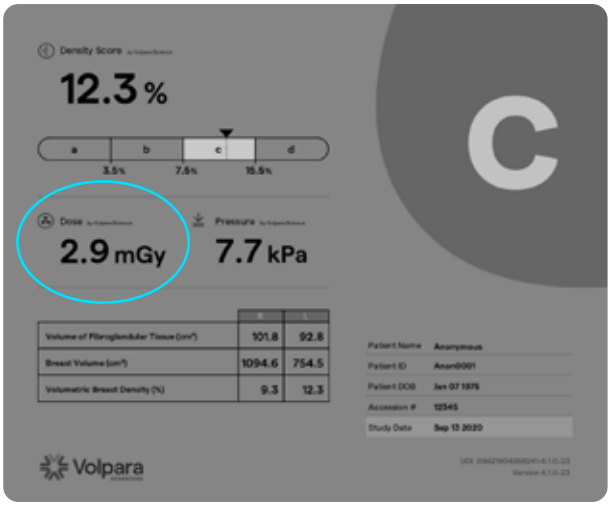


Figure 5. Volpara TruRadDose adds personalized dose to the Volpara Scorecard.

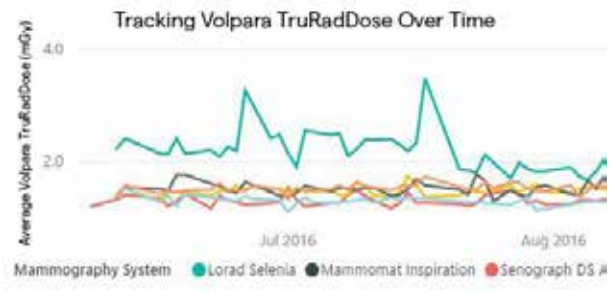


Figure 6. Volpara Analytics enables physicists to track Volpara TruRadDose by mammography system over time.

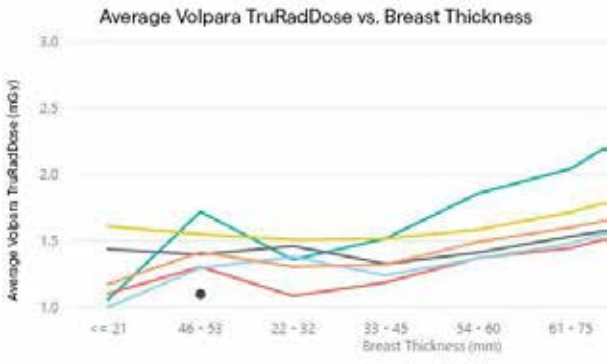


Figure 7. Physicists can track many other metrics in Volpara Analytics, such as average Volpara TruRadDose by breast thickness.

The Volpara Scorecard is designed to inform clinicians about breast composition, dose, and compression—it is not intended to be given to the patient. The values in the Scorecard are available in standard DICOM interoperable form; if desired, subsets of the information can be included in patient letters.

Conclusion

The ability to include local site calibration parameters allows radiation protection staff to fulfill their medical physics obligations. Standardized dose estimations also help identify opportunities for improving quality control and enable meaningful comparisons of radiation doses between machines. Now that patient-based dose reporting is possible, more accurate dose information can be provided to women.

Please contact Volpara Health if you have questions about this paper or about implementing Volpara TruRadDose at your facility.

[1] Wrixon, A. D. "New ICRP Recommendations," *J. Radiol. Prot.*, vol. 28, no. 2, pp. 161–8, Jun. 2008.

[2] Yaffe, M. J. and Mainprize, J. G. "Risk of Radiation-induced Breast Cancer from Mammographic Screening," Jan. 2011.

[3] Ahmed, N. U. et al., "Breast cancer knowledge and barriers to mammography in a low-income managed care population," J. *Cancer Educ.*, vol. 24, no. 4, pp. 261–6, Jan. 2009.

[4] Department of Health and Human Services, Food and Drug Administration web site. Mammography Quality Standards Act Regulations. 21 CFR Chapter I, Subchapter B, 900.12. http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?fr=900.12. Revised as of April 01, 2013. Accessed May 27, 2014.

[5] Perry, N. et al., *European guidelines for quality assurance in breast cancer screening and diagnosis, Fourth Edition*, 2006, pp. 83.

[6] Wu, X. et al., "Normalized average glandular dose in molybdenum target-rhodium filter and rhodium target-rhodium filter mammography," *Radiology*, vol. 193, no. 1, pp. 83–89, 1994.

[7] Wu, X. et al., "Spectral dependence of glandular tissue dose in screen-film mammography," *Radiology*, vol. 179, no. 1, pp. 143–148, 1991.

[8] Sobol, W. T., Wu, T., "Parametrization of mammography normalized average glandular dose tables," *Med Phys*, vol. 24, no. 4, pp. 547–554, 1997.

[9] Dance, D.R., "Monte Carlo calculation of conversion factors for the estimation of mean glandular breast dose," *Phys Med Biol*, vol. 35, no. 9, pp. 1211–1219, 1990.

[10] Dance, D. R. et al., "Additional factors for the estimation of mean glandular breast dose using the UK mammography dosimetry protocol," *Phys. Med. Biol.*, vol. 45, no. 11, p. 3225, 2000.

[11] Dance, D. R., "Further factors for the estimation of mean glandular dose using the United Kingdom, European and IAEA breast dosimetry protocols," *Phys Med Biol.*, vol. 54, no. 14, pp. 4361–4372, 2009.

[12] Dance, D. R., et al., "Estimation of mean glandular dose for breast tomosynthesis: factors for use with the UK, European and IAEA breast dosimetry protocols.," *Phys. Med. Biol.*, vol. 56, no. 2, pp. 453–71, Jan. 2011.

[13] Rosenstein, M. et al., *Handbook of Glandular Tissue Doses in Mammography,* vol. 0. U.S. Department of Health and Human Services, Public Health Service, Food and Drug Administration, Center for Devices and Radiological Health, 1985, p. 16.

[14] Boone, J. M., "Glandular breast dose for monoenergetic and high-energy X-ray beams: Monte Carlo assessment," *Radiology*, vol. 213, no. 1, pp. 23–37, 1999.

[15] Hammerstein, G. R., et al., "Absorbed radiation dose in mammography," *Radiology*, vol. 130, pp. 485–91, 1979.

[16] Patel, V. et al., "Patient Specific Average Glandular Dose in Mammography," in *55th Annual Meeting of the American Association of Physicists in Medicine (AAPM),* 2.

Contact

info@volparahealth.com
support@volparahealth.com
volparahealth.com

US +1 855 607 0478
AUS 1800 370 623
NZ 0800 444 148

Europe +44 203 051 1029
Global +64 4 499 6029

Connect

@VolparaHealth @volpara Volpara Health

Copyright © 2021 Volpara Health Technologies Ltd. All rights reserved.