WHITE PAPER

Optimal Breast Compression in Mammography

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Christina Robert, PhD
Clinical Marketing Specialist

Julian Marshall
Chief Knowledge Officer

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Introduction

Mammography is the gold standard for breast cancer screening, and the only method proven to reduce mortality in randomized controlled trials. More recently, breast tomosynthesis has been shown to improve clinical performance. It has demonstrated a reduction in recall rate and/or improved cancer detection, especially that of invasive cancers, in all but extremely dense breasts.[1,2] The success of any breast screening program, whether using mammography or tomosynthesis, hinges on sufficient levels of quality, clinical performance,[3] and client attendance.[4,5]

Screening program performance depends on a wide range of factors. Many, such as clinical performance indicators, are well understood; others, such as subject safety and comfort, must also be considered to maximize attendance.[6]

One key factor in both mammography and tomosynthesis is breast compression. These modalities compress the breast between a plastic paddle and the breast platform. This white paper summarizes how breast compression affects image quality, clinical performance, and the subject safety and comfort aspects of screening.

This white paper also addresses the impact of both over- and under-compression of the breast and describes the target range for proper breast compression. It describes how the Volpara® TruPressure™ clinical function and Volpara® Analytics™ software can help you track breast compression in your clinic and train your technologists to optimize breast compression.

Why Compress the Breast?

Breast compression is essential for optimizing mammography and tomosynthesis screening exams.

- Proper compression immobilizes the breast, which improves image quality by reducing motion blur. It reduces the thickness of the breast, which decreases the radiation dose to the subject and improves detectability of lesions by spreading out the overlapping tissue. It enhances clinical performance through improved lesion visualization and reduction of false positives.
- Improper compression, by contrast, may have undesirable effects: excessive compression may cause subjects discomfort, breast pain, and tearing of the skin, especially superior to the breast in older subjects; insufficient compression may allow involuntary subject movement to induce motion blur and decrease image quality; and both excessive and insufficient compression reduce clinical performance in terms of the sensitivity of mammography and positive predictive value (PPV).

Quantifying Breast Compression

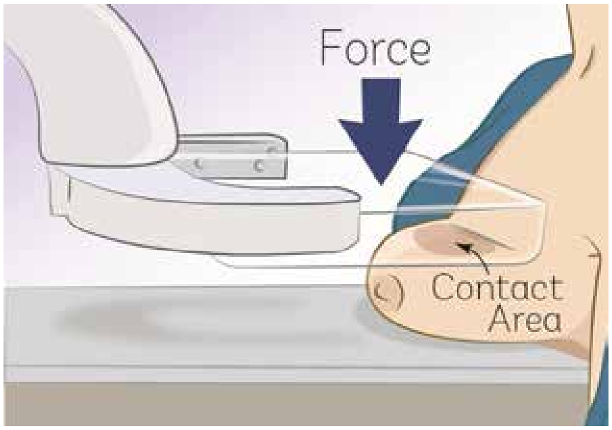
In the United States, mammographic quality assurance guidelines state that “compression shall be applied in a manner that minimizes the potential obscuring effect of overlying breast tissue and motion artifact,”[7] while European guidelines state that force should be “firm but tolerable,” with a maximum automatically applied compression of 130–200 N.[8]

However, significant variation exists in practice.[9] Technologists are often taught rules of thumb, such as to compress the breast until the “skin is taut” or “until the woman complains, then back off a bit,” and sometimes simply to compress to a specific force, such as 140 N.

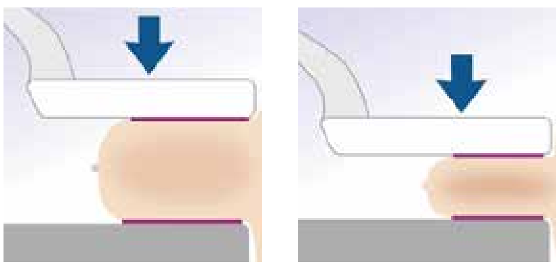
Unfortunately, force (recorded for each image by the x-ray machine) does not correlate well with subject discomfort since it does not account for differences in breast size (figure 1).[10]

A better approach is to consider the pressure applied to the breast,[11] which is calculated as:

$$\textit{Pressure} = \frac{\textit{Force}}{\textit{Contact area}}$$



Pressure is easily explained with a familiar example: It is far more painful to be stepped on by a high-heeled shoe than a flat one.



Large breast—180cm^2 contact area

- 180 N force
- **10 kPa pressure**
- Less pain

Small breast—110cm^2 contact area

- 180 N force
- **16 kPa pressure**
- Greater pain

Figure 1. Example of compression pressure and discomfort in different-sized breasts.

Volpara TruPressure, available as a component in Volpara Analytics, is a tool that determines the contact area from mammographic images. It retrospectively calculates the compression pressure that was actually applied to the breast. The contact area measured by TruPressure is equivalent to planimetry and has been validated with a capacitive skin-contact measurement device.[12]

Compression and Clinical Performance

How compression pressure affects cancer detection rate and positive predictive value

A recent Dutch study (n=113,464) showed that the cancer detection rate peaks at a pressure of ~10 kPa (figure 2).[13] A similar peak was observed in positive predictive value (PPV). This is the first study that relates pressure to clinical performance in a breast screening program.

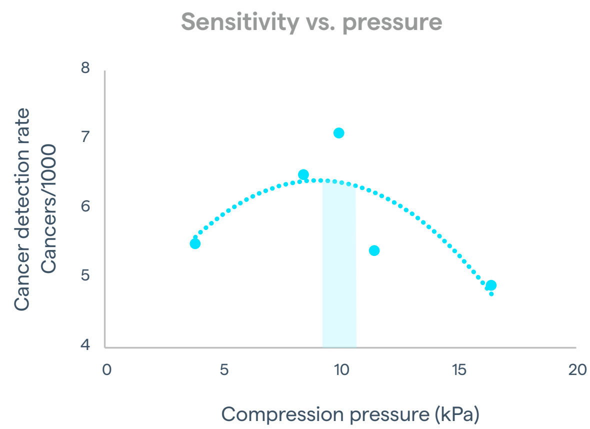


Figure 2. Cancer detection rate peaks at ~ 10 kPa compression pressure.

The study also showed that clinical performance decreases both above and below the ~10 kPa pressure level, suggesting that clinicians could optimize clinical performance if they trained their technologists to deliver compression within a target pressure range centered on ~10 kPa.

The graph in figure 2 clearly illustrates that both under-compression and over-compression affect clinical performance of screening. In addition, improper compression has clinical impacts beyond those described in the Dutch study. This paper discusses in detail how under-compression and over-compression affect breast screening.

Under-Compression of the Breast

Under-compression is the result of insufficient compression force being applied to the breast. It has several negative effects on the diagnostic value of the mammogram.

How Under-compression Affects Clinical Performance

As described earlier, under-compression reduces clinical performance in screening (figure 3).[13]

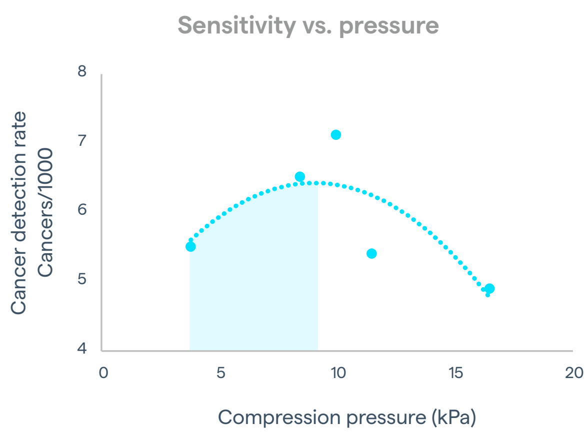


Figure 3. Cancer detection rate drops significantly with compression pressure lower than 10 kPa.

Adequate breast compression spreads out overlapping tissue. Under-compression reduces sensitivity (increases false negatives), in part because overlapping normal breast tissue masks lesions (figure 4),[14] as mass lesions and dense tissue have similar x-ray absorption characteristics.[15]

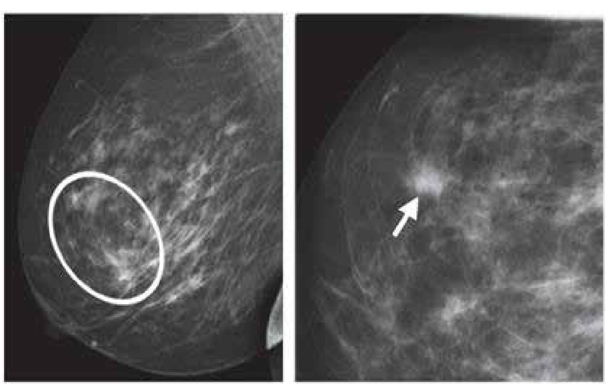


Figure 4. Indistinct fibroglandular tissue (circled) contains a small invasive ductal cancer (arrow) under spot compression.

This same under-compression also increases the possibility of overlapping normal tissue masquerading as a lesion. This is a common source of false-positive recalls (figure 5).[16]

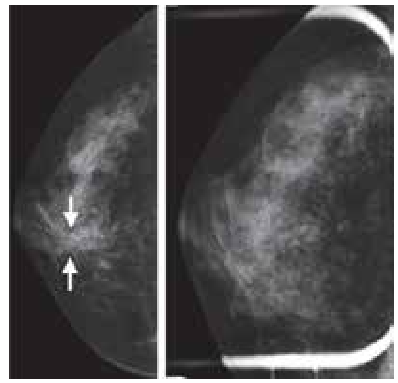


Figure 5. An apparent distortion (arrows) that disappears with spot compression.

How Under-Compression Affects Motion Blur

All mammography and tomosynthesis imaging systems turn the x-ray tube on for finite periods of time, during which an image is captured by the x-ray detector. Any subject motion during that period will result in motion blur in the image, making it more difficult for the clinician to observe small structures (figure 6).[16]

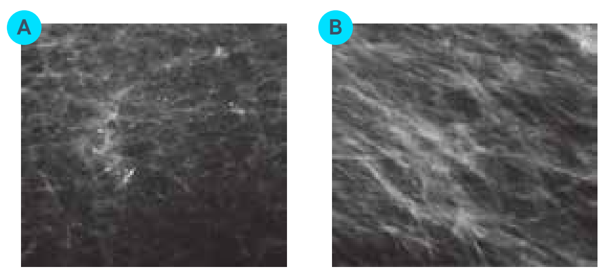


Figure 6. Linear calcifications (A) suggest malignancy, not observed in contralateral view (B).

Good compression and positioning, with clear instructions to the subject about holding still and controlling her respiration, can reduce motion blur and contribute to optimal image quality.

How Under-Compression Affects X-ray Scatter and Lesion Visibility

Under-compression of the breast means that a greater thickness increases both the total tissue attenuation and the relative amount of scattered radiation when compared to a breast under full compression.[17]

To limit the radiation dose to thicker breasts while maintaining similar image signal levels, the automatic exposure control (AEC) selects a more transmissive x-ray beam; together with the increased scattered radiation, this lowers the image contrast compared to that of a thinner breast.[18] Lesion detection performance in digital mammography images acquired under AEC has been shown to be reduced in thicker breasts compared to thinner breasts, suggesting that increased compression would improve lesion visibility (figure 7).[19]

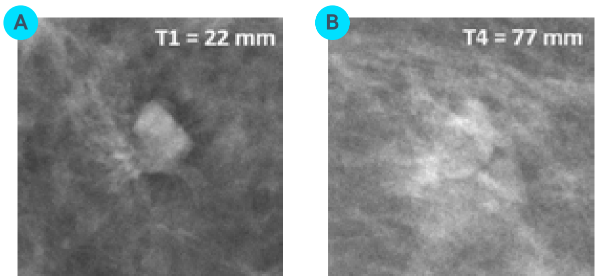


Figure 7. A simulated mass lesion is clearly visible in a thin breast (A) but less visible in a thick one (B).

How Under-Compression Affects Radiation Exposure

The dose calculations methods of Dance,[20] both for 2D projection mammography[21] and 3D breast tomosynthesis,[22] have a strong dependence on the compressed thickness of the breast—the lower the thickness, the lower the dose.[23,24,25] Under-compression, which increases the thickness of the breast, should be avoided as it has a strong negative impact on ionizing radiation exposure and thus does not support the "As Low As Reasonably Achievable" (ALARA) principle.

Over-Compression of the Breast

Over-compression has several negative effects on screening mammography.

How Over-Compression Affects Clinical Performance

As described earlier, over-compression has recently been shown to reduce clinical performance (figure 8).[13] The Dutch study shows that performance decreases with increased pressure. For many this was an unexpected result, because it was not the generally held belief, as the aforementioned training practices show.

In figure 8, note that there appears to be a fairly sharp drop in the cancer detection rate just above 10 kPa.

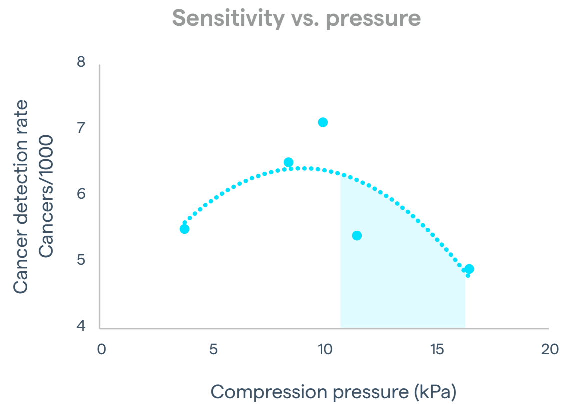


Figure 8. Cancer detection rate drops significantly with compression pressure high than 10 kPa.

While the Dutch study is novel for screening mammography, results from previous diagnostic mammography studies may explain the performance reduction with over-compression. Those studies demonstrated that some lesions exhibit compromised visibility in spot compression views, which have high localized compression, resulting in a subset of cancers essentially being "pressed away" (figure 9).[26,27,28]

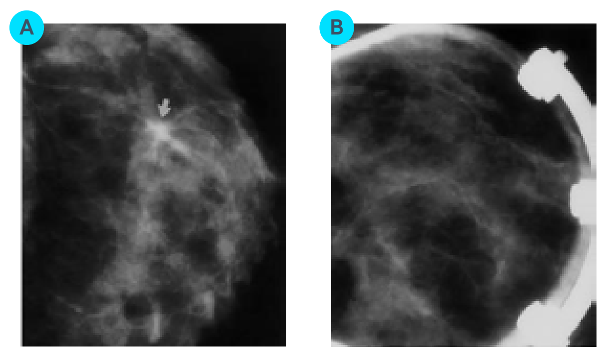


Figure 9. Invasive ductal carcinoma (A) was not detected in spot compression (B), resulting in delayed diagnosis.

How Over-Compression Affects Pain and Discomfort

The breast is often a sensitive organ. For many women, breast compression may result in discomfort or pain. The compression experience of women during mammography can affect their willingness to participate in future mammography exams.[29]

Historically, technologists were taught to apply significant force to the breast to improve the quality and dose performance of imaging. However, for some, that force causes pain, which is discussed as one of the "harms of mammography".[30]

Studies that have shown that women who experience greater compression pressure have greater odds of experiencing severe pain (figure 10).[31] Whelehan showed that 25 to 46% of women who fail to re-attend screening cite pain as the primary reason.[29]

By examining re-attendance rates in the Breast Screening Programme in England for women who were screened during the period 2009 to 2015, one can infer that 3 to 6% of the invited population would fail to re-attend due to pain.[32]

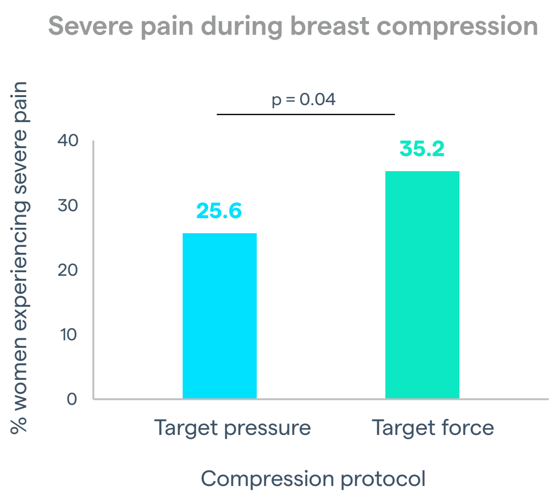


Figure 10. Compression protocol based on pressure reduces severe pain compared to a protocol based on force.

A study by de Groot showed that a compression protocol with a target pressure of 10 kPa achieved a significant reduction in severe pain, without increasing the number of image retakes, compared to a force-standardized protocol.[33] A further study in a diagnostic population indicated that a pressure-guided protocol provided non-inferior visibility, sharpness, and contrast compared to a force-guided protocol when it came to lesion examination.[34]

Thus, a compression protocol based on pressure can minimize subject discomfort without adversely affecting clinical performance of mammography.

How Over-Compression Affects Radiation Exposure and Image Quality

Increasing breast compression makes sense: it reduces the required radiation, and it reduces scatter, increasing image quality. But if breast compression causes women to not re-attend screening, then screening does not occur, and cancers are not detected.

Thus, simply increasing breast compression is not the answer. A balance must be struck between the degree of compression employed, the quality of the image, the radiation dose applied, and the comfort of the woman. In the end, subject comfort leads to attendance at screening and is fundamental to achieving clinical outcomes.

From Force to Pressure

During subject positioning, mammography systems measure the force applied to the breast and display it to the technologist. However, as mentioned before, pressure takes into account the size of the breast, whereas force does not.

TruPressure calculates the compression pressure for each standard mammographic view and provides the result in the Volpara® Scorecard™ image or within the dashboards of Volpara Analytics.

Training Technologists on Pressure

Technologists can easily adapt to feedback on their compression performance. Volpara Analytics makes them aware of the average pressure they are applying, which helps them understand how well they are adjusting to breast size variation.

This feedback helps optimize their pressure performance in upcoming exams. For example, if a woman with small breasts presents for screening, the technologist can remember to use less force.

Managers can use Volpara Analytics to assess the ability of each technologist to conform to compression guidelines within a range around 10 kPa.

Real-World Examples

Volpara software tools can help identify a variety of breast compression issues:

- TruPressure revealed that the average breast thickness on one machine was 2 mm greater than the breast thickness on other units, although breast volumes were similar. An investigation proved that it was providing insufficient compression because of an incorrect automated compression setting. While this is a small difference, it could in fact have led to an increase in radiation dose being delivered to those subjects (figure 11).

Median values over 4 weeks				
X-ray machine	Breast thickness mm	Breast Volume cm^3	Force N	Pressure kPa
2	61	804	86	8.0
3	59	808	105	9.9
4	59	835	109	9.9
5	59	811	103	9.6

Figure 11. Compression parameters at four x-ray machines.

- TruPressure provided analytic data for comparing compression characteristics in Malay women versus Dutch and US women (figure 12).[35] Compression forces were lowest in the US, intermediate in Malaysia, and highest in the Netherlands. Because Malay women had significantly smaller contact area than the other groups, they experienced the highest compression pressure.

	Malaysia	Netherlands	USA
Compression force (daN)	12.2 ± 3.4	13.8 ± 2.7	7.4 ± 3.1
Contact area (dm^2)	0.87 ± 0.46	1.18 ± 0.50	1.06 ±0.51
Compression pressure (kPa)	17.8 ± 10.5	13.7 ± 5.9	8.1 ± 4.1
Max compression pressure (kPa)	131.7	73.9	44.7

Figure 12. Compression parameters in three populations.

Though the real outcome is unknown, it is conceivable that the excessive compression pressure resulted in discomfort for Malaysian women, adversely affected screening re-attendance, and reduced the visualization of breast tumors.

- By applying compression pressures up to 40% higher than her peers, one operator consistently applied excessive pressure, leading to subject complaints (figure 13).

Median values	Op 1	Op 2	Op 3
Breast Volume cm3	919	829	818
Breast thickness mm	71	59	69
Compression force (N)	62	129	61
Compression pressure (kPa)	7.9	13.5	8.5

Figure 13. Compression behaviors of three operators.

Conclusion

Breast compression is a critical part of mammography. As we have demonstrated from the literature, inappropriate compression is detrimental to clinical performance, image quality, and subject safety and comfort.

- Insufficient compression leads to high radiation dose, poor image quality, and poor lesion visualization—factors which can put subjects at risk.
- Excessive compression leads to lower cancer detection rates and increased subject discomfort, adversely affecting subsequent attendance at screening.

The lack of consistent breast compression guidelines can result in confusion for technologists and trainers, inconsistent screening practice, and varied performance.

Volpara TruPressure provides objective assessment of compression pressure, which is the basis for improving mammographic image quality, clinical outcomes, and subject experience.

Volpara Analytics enables managers to review technologist performance and guide the training of technologists.

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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
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