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Original Article

Comparative Evaluation of Modern Medical Ultrasound Gels in the Sonographic Detection of Breast Microcalcifications: A Clinical Validation Study

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Abstract:

Background: The detection of breast microcalcifications (MCs) by ultrasound is challenging due to their size being near the resolution limit. While ultrasound gel is essential for acoustic coupling, whether advancements in gel technology translate to improved MC detection remains unclear.

Objective: To clinically evaluate whether three commercially available ultrasound gels, compliant with the current Chinese national standard YY0299-2016, yield differences in the detection and characterization of MCs in breast carcinoma.

Methods: In this retrospective self-controlled study, 165 patients with pathologically proven breast carcinoma and mammographically identified MCs were included. Each patient underwent preoperative breast ultrasonography using the same scanner and settings. Three different gels were applied sequentially to the same lesion. The visibility, number, and echo intensity of scattered, clustered, and isolated MCs (≤1 mm) were assessed by two blinded radiologists.

Results: No statistically significant differences were found among the three gels in the detection rates of patients with MCs, clustered MCs, or isolated MCs (Cochran's Q test, $P > 0.05$). The inter-observer agreement was excellent (kappa > 0.85). Minor variations in the subjective echo intensity of a few isolated MCs were not statistically significant.

Conclusion: Under the stringent requirements of the YY0299-2016 standard, modern ultrasound gels exhibit highly comparable acoustic performance. Their differences do not translate to clinically significant improvements in the sonographic detection of microcalcifications, suggesting a performance plateau has been reached for this specific diagnostic task.

Keywords: Breast carcinoma, Microcalcification, Ultrasound gel, Breast ultrasonography, Diagnostic performance

1. Introduction

Breast carcinoma (BC) remains a leading cause of cancer-related morbidity and mortality among

women worldwide [1]. Ultrasonography is a cornerstone imaging modality for breast lesion detection and characterization, valued for its real-time capability, safety, and cost-effectiveness. Key sonographic features of BC include hypoechoic texture, irregular margins, and the presence of microcalcifications (MCs) [2]. MCs, typically defined as calcified foci less than 1 mm in diameter, present as punctate hyperechoic spots with or without acoustic shadowing. They are a critical diagnostic clue, identified in 60-80% of BC cases upon histology, and are often associated with early-stage disease [3, 4].

However, the sonographic detection of MCs is technically demanding because their size is close to or even below the wavelength of high-frequency ultrasound, approaching the fundamental resolution limit of the imaging system [5]. Consequently, strategies to optimize MC visualization have primarily focused on enhancing ultrasound hardware resolution and operator skill. The role of the ultrasound gel (couplant), a critical interface medium that eliminates air between the probe and skin to facilitate acoustic energy transmission, has received comparatively less attention.

A foundational study by Poltawski and Watson in 2007 suggested that commonly used gels in the UK exhibited only minor differences in ultrasonic transmission, with negligible clinical impact [6]. In the intervening years, gel formulations have evolved, with advancements in hydrogel technology leading to claims of improved acoustic properties, such as more optimal acoustic impedance matching and reduced attenuation [7－8]. The introduction of the Chinese mandatory standard YY0299-2016, which specifies strict parameters for key acoustic properties like ultrasonic velocity, acoustic impedance, and attenuation, represents a significant step towards product standardization [9]. This raises a pivotal clinical question: in the era of standardized, modern gels, do the purported technological advancements between products translate to any measurable difference in detecting the most challenging targets, such as MCs?

This study aims to answer this question by conducting a rigorous, blinded, and self-controlled clinical comparison of three YY0299-2016 compliant ultrasound gels, including a historically recognized "gold standard." We test the hypothesis that the performance of these modern gels has converged, yielding no clinically relevant difference in the detection and characterization of breast microcalcifications.

2. Materials and Methods

2.1. Study Population and Design

This retrospective study was approved by the Institutional Review Board of Zhuzhou Central Hospital, and the requirement for informed consent was waived. We reviewed the clinical data of 165 female patients (age ≥ 18 years) with pathologically confirmed BC who were admitted between March 2021 and March 2023. The inclusion criteria were: (1) preoperative mammography confirming the presence of MCs within a breast mass; (2) preoperative breast ultrasonography performed using all three investigated ultrasound gels on the same lesion.

2.2. Ultrasound Gels

The following three commercially available, YY0299-2016 compliant medical ultrasound gels were evaluated:

Gel A (Experimental 1): Medical sterilizing ultrasonic couplant (Shandong Bolian Biotechnology Co., Ltd.). A hydrogel composed of carbomer, triethanolamine, propylene glycol, glycerol, and trichlorohydroxyphenyl ether.

Gel B (Experimental 2): Medical ultrasonography couplant (Tianjin Chengxin Medical Auxiliary Materials Factory). A hydrogel composed of carbomer, potassium hydroxide, Casson, and purified water.

Gel C (Control): Aquasonic 100 ultrasound gel

(Parker Laboratories, Inc., USA). This gel was selected as a reference due to its long-standing and widespread international use.

2.3. Ultrasound Examination

All examinations were performed using a Mindray Resona R9 color Doppler ultrasound system equipped with a 5-14 MHz linear array probe. The same preset for breast imaging was used for all patients. An experienced sonographer (with >5 years in breast US) performed a comprehensive scan. For each patient, the three gels were applied sequentially to the identical lesion site. The gel was spread evenly to form a layer of approximately 1 mm in thickness. Multiple static images and cine clips of the lesion and its surrounding tissue were acquired for each gel application and stored in the Picture Archiving and Communication System (PACS).

2.4. Image Analysis and Blinding Procedure

To eliminate assessment bias, all stored images were de-identified, randomized, and independently reviewed by two radiologists (Reader 1 and Reader 2, each with over 8 years of experience in breast imaging) who were blinded to the gel type and patient identity. The readers assessed the images for:

1. The presence or absence of MCs.
2. The classification of MCs as scattered or clustered.
3. The number and subjective echo intensity (rated as equivalent, slightly weaker, or significantly weaker relative to the surrounding parenchyma) of all isolated MCs, defined as well-defined, punctate echoes ≤1 mm in diameter with minimal peripheral interference.

Any discrepancies between the two readers were resolved by a joint consensus review.

2.5. Statistical Analysis

Statistical analyses were performed using SPSS Statistics (Version 26.0, IBM Corp.). The detection rates of MCs (patient-based and lesion-based) across the three gels were compared using the Cochran's Q test for related samples. Post-hoc pairwise comparisons were conducted with the McNemar's test with Bonferroni correction. Inter-observer agreement for the categorical detection of MCs was evaluated using Cohen's kappa coefficient; a kappa value of >0.8 was considered excellent agreement. A two-tailed P-value of <0.05 was considered statistically significant.

3. Results

3.1. Patient and Microcalcification Characteristics

A total of 165 female BC patients with a mean age of 52.4 ± 10.7 years were included in the final analysis. All patients had MCs confirmed by mammography.

3.2. Gel Microstructure and Acoustic Properties

While all three gels complied with the YY0299-2016 standard (acoustic parameters summarized in Table 1), their underlying microstructures, as revealed by scanning electron microscopy, exhibited distinct morphological variations (Figure 2).

Table 1. Key Acoustic Parameters as Specified by the National Mandatory Standard YY0299-2016.

Parameter	Ultrasonic Velocity (35°C)	Acoustic Impedance (35°C)	Acoustic Attenuation (35°C)
Unit	m/s	Pa·s/m³ (or Rayls)	dB/(cm·MHz)
YY0299-2016 Requirement	1520 - 1620	1.5×10^6 - 1.7×10^6	≤ 0.05

Despite this shared acoustic compliance, scanning electron microscopy revealed distinct morphological differences in their underlying microstructure (Figure 2).

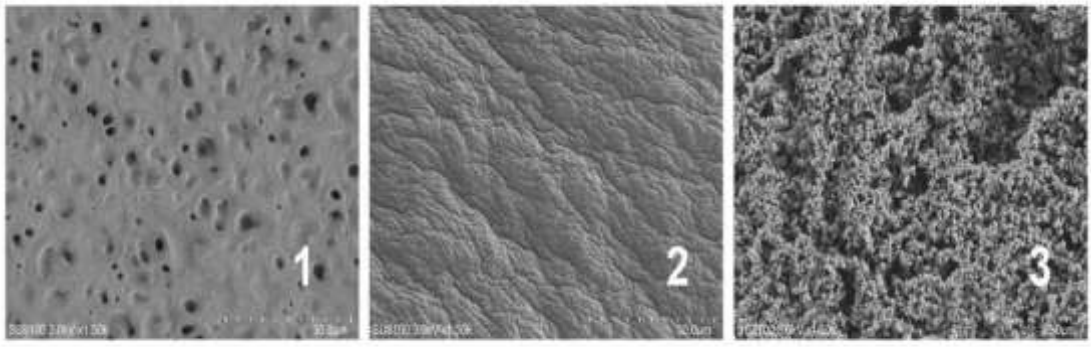

Figure 2. Scanning Electron Microscopy images of the three ultrasound gels. (A) Gel A (Shandong Bolian), (B) Gel B (Tianjin Chengxin), (C) Gel C (Parker's Aquasonic 100). Scale bars represent 100μm.

3.3. Detection of Microcalcifications

The detection rates of microcalcifications across the three gels are summarized in Table 2 (patient-based data) and Table 3 (lesion-based data). Cochran's Q test revealed no statistically significant differences among Gels A, B, and C in the detection of patients with any MCs (P = 0.854) or clustered MCs (P = 1.000). Similarly, the total count of isolated microcalcifications was nearly identical across all three groups (P = 0.654).

Table 2. Comparison of Microcalcification Detection Rates Across Three Ultrasound Gels

Microcalcification Category	Gel A (n=165)	Gel B (n=165)	Gel C (n=165)	*P*-Value
Patients with any MCs, n (%)	131 (79.4%)	131 (79.4%)	130 (78.8%)	0.854
Patients with clustered MCs, n (%)	115 (69.7%)	115 (69.7%)	115 (69.7%)	1.000

Table 3. Comparison of Isolated Microcalcification Counts Across Three Ultrasound Gels

Microcalcification Category	Gel A	Gel B	Gel C	*P*-Value
Total isolated MCs counted	204	204	203	0.654

Note: Table 2 presents patient-based detection rates. Table 3 presents the total counts of individual microcalcifications identified. P-values were derived from Cochran's Q test for comparing three related groups.

Representative ultrasound images demonstrating the comparable visualization of the same cluster of microcalcifications using the three different gels are shown in Figure 3.

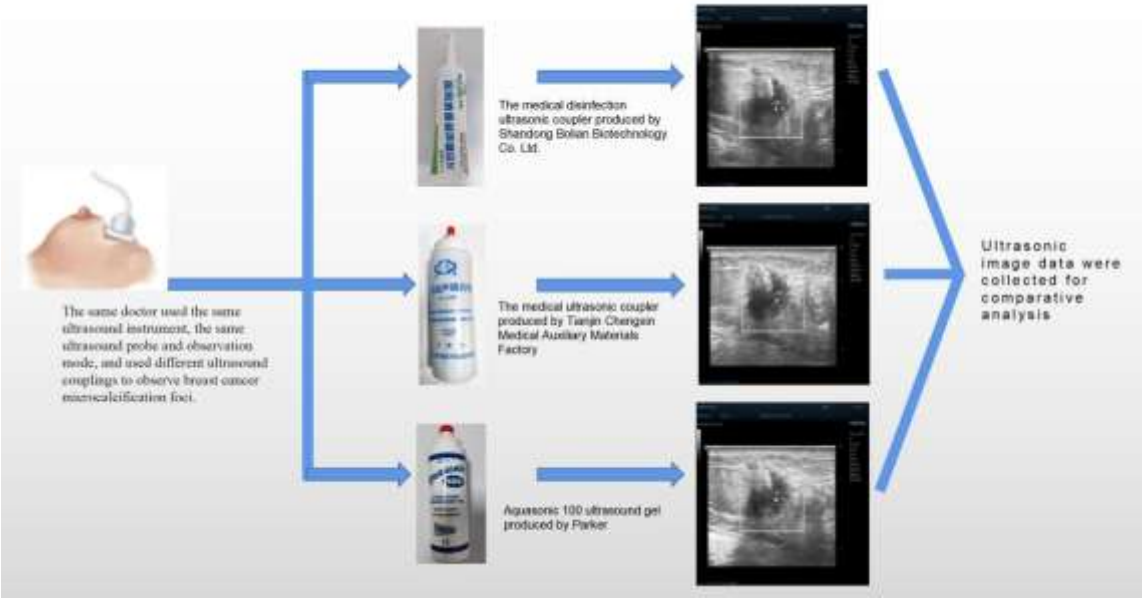

Figure 3. Representative ultrasound images of the same cluster of microcalcifications. No appreciable difference in visibility or echo intensity is observed.

3.4. Analysis of Isolated Microcalcifications and Physical Principle

A total of 204 isolated MCs were identified in the consensus review for Gels A and B. For Gel C, 203 isolated MCs were identified. One MC was not visualized with Gel C, and three others were subjectively rated as having slightly weaker echo intensity compared to their appearance with Gel A. However, these minor variations were not statistically significant. The physical principle of ultrasound interaction with microcalcifications near the resolution limit, which underlies the challenge of their detection, is schematized in Figure 4.

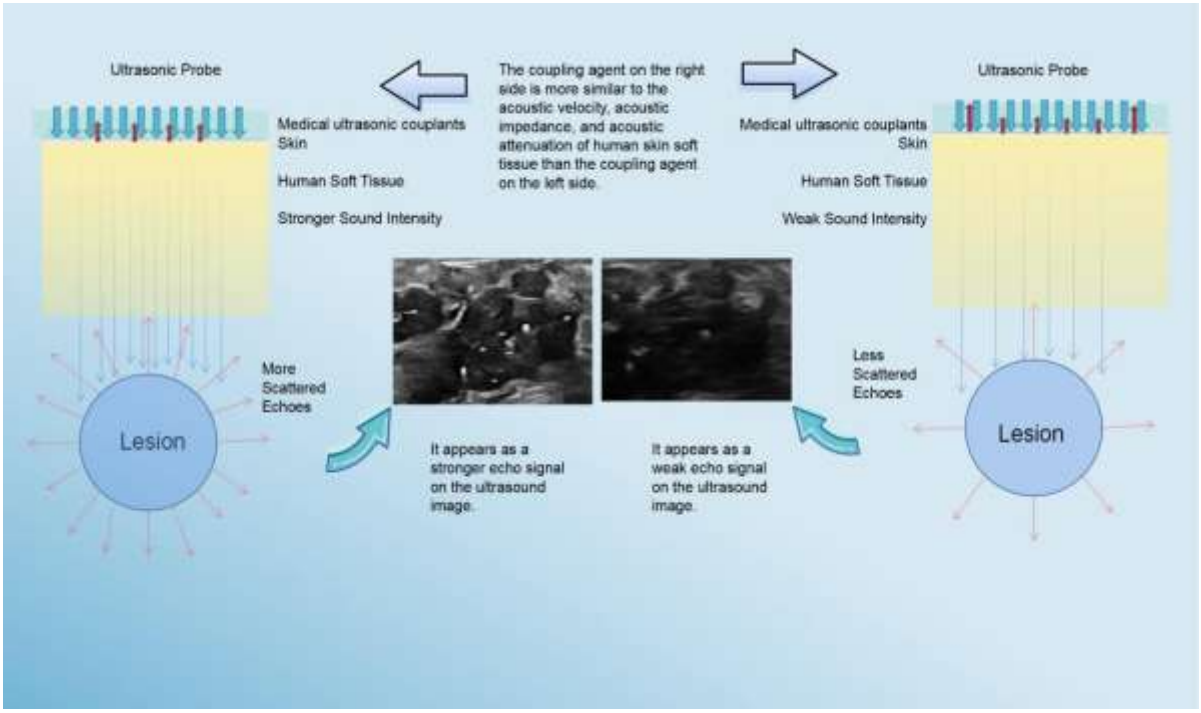

Figure 4. Schematic diagram illustrating the principle of ultrasound transmission and scattering.

4. Discussion

Our study provides robust clinical evidence that three commercially available ultrasound gels, compliant with the modern YY0299-2016 standard, perform indistinguishably in the critical task of detecting breast microcalcifications. This finding holds significant implications for clinical practice and technology assessment.

The core function of an ultrasound gel is to minimize the acoustic impedance mismatch between the transducer and the skin, thereby maximizing the transmission of ultrasonic energy into the body [10－11]. The YY0299-2016 standard effectively enforces a high baseline of performance by stipulating narrow, optimal ranges for key acoustic properties such as acoustic impedance (1.5-1.7 × 10^6 Rayls). Our results empirically demonstrate that once this high baseline is met, further formulation differences, evident in the electron micrograph morphology, do not yield measurable clinical benefits in resolving targets at the resolution limit. The theoretical energy losses due to absorption and interface reflection [12－14] appear to be effectively and equally minimized by all three compliant gels.

The slight numerical difference in the count of isolated MCs (204 vs. 203) and the minor subjective variations in echo intensity are both statistically and clinically negligible. This reinforces the concept that the primary limiting factor in visualizing sub-millimeter MCs is the intrinsic spatial resolution of the ultrasound system itself, rather than the coupling medium, provided a high-quality, standardized gel is used.

Our findings strongly support and extend the earlier work of Poltawski and Watson [6] into the modern era of regulated gel technology. We confirm that a "performance plateau" has been reached for this specific diagnostic application. Consequently, clinician and institutional choice of ultrasound gel can be confidently based on non-diagnostic factors such as cost, sterility, skin feel, viscosity, and environmental considerations, without concern for compromising diagnostic efficacy in the detection of microcalcifications.

4.1. Limitations

This study has several limitations. First, it was a single-center, retrospective study. Second, while the gels were compliant with a strong national standard, we did not perform independent, precise measurements of their acoustic physical properties (e.g., precise impedance value, attenuation coefficient) in our own lab, which could have provided a more direct structure-function correlation. Future studies could incorporate such detailed physical measurements. Finally, the evaluation of echo intensity was subjective; future work could employ quantitative ultrasound (QUS) parameters for a more objective assessment.

5. Conclusion

In conclusion, this rigorous clinical validation demonstrates that modern medical ultrasound gels adhering to the YY0299-2016 standard perform equivalently in the sonographic detection of breast microcalcifications. This indicates that the technology for this application has matured. Efforts to improve breast MC detection should therefore focus on advancements in ultrasound hardware and image processing algorithms, rather than on further refinements of the coupling gel.

Acknowledgements: Not applicable.

Ethical Compliance: This study was approved by the Ethical Committee of Zhuzhou Central Hospital Affiliated to Xiangya School of Medicine, Central South University (Approval No: ZZCHEC2023023-01), and was conducted in accordance with the Declaration of Helsinki.

Conflicts of Interests: The authors declare no conflicts of interest.

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