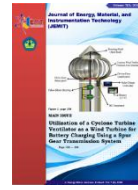




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## Evaluation of Physicochemical Properties and Image Quality of Commercial Ultrasound Transmission Gels Across Three Price Ranges

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### Abstract

Ultrasound coupling agents, commonly known as ultrasound transmission gels (USTG), play a crucial role in ultrasound diagnostics, particularly for pregnancy check-ups and practice sessions for medical professionals or biomedical engineering students. In Indonesia, USTG is widely available on e-commerce platforms, with prices ranging from very low to high for the same packaging size. Previous study mainly focused on comparing commercial USTG to a cheaper material or alternative USTG using different material and methods. This study addresses this gap by systematically comparing USTG from low, medium, and high price categories. Through characterization techniques such as Fourier Transform Infrared (FTIR) spectroscopy, UV-Visible spectroscopy, Thermogravimetric Analysis (TGA), density testing, pH testing, and image quality assessment, it was found that the three selected gels (low, medium, and high price ranges) did not show significant differences in performance. Based on image analysis of gel A, B, and C significance value is 0.33 ( $p > 0.05$ ) and this shows statistically not significant between each gel. This study provides valuable insights for individuals practicing ultrasound imaging techniques, helping them save costs without compromising quality.

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### Abstrak

Ultrasound coupling agents, yang umum dikenal sebagai ultrasound transmission gels (USTG), merupakan bagian penting dalam pemeriksaan diagnostik ultrasound, khususnya untuk pemeriksaan kehamilan dan sesi praktik bagi tenaga medis maupun mahasiswa teknik biomedis. Di Indonesia, USTG tersedia secara luas di platform e-commerce, dengan rentang harga yang sangat rendah hingga tinggi untuk ukuran kemasan yang sama. Penelitian ini mengevaluasi kualitas citra ultrasound yang dihasilkan oleh USTG dari berbagai rentang harga. Penelitian sebelumnya umumnya berfokus pada perbandingan USTG komersial dengan material alternatif yang lebih murah atau formulasi berbeda. Penelitian ini mengisi celah tersebut dengan melakukan perbandingan sistematis terhadap USTG dari kategori harga rendah, menengah, dan tinggi. Melalui teknik karakterisasi seperti Fourier Transform Infrared spectroscopy (FTIR), UV-Visible spectroscopy, Thermogravimetric Analysis (TGA), pengujian densitas, pengujian pH, serta penilaian kualitas citra, ditemukan bahwa tiga gel yang dipilih (rentang harga rendah, sedang, dan tinggi) tidak menunjukkan perbedaan performa yang signifikan. Berdasarkan analisis citra terhadap gel A, B, dan C, diperoleh nilai signifikansi sebesar 0,33 ( $p > 0,05$ ), yang menunjukkan tidak adanya perbedaan yang signifikan secara statistik antar gel. Studi ini memberikan wawasan yang bernilai bagi individu yang berlatih teknik

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*ultrasound imaging, sehingga dapat menghemat biaya tanpa mengorbankan kualitas.*

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## 1. Introduction

Biomaterials is a branch of biomedical engineering that deals with the use of natural and synthetic materials, as well as the analysis of material reactions to human tissues, for diagnostic and therapeutic purposes (Bhat & Kumar, 2013). One standard medical device utilizing biomaterials is ultrasound, also known as ultrasonography (USG). Ultrasonic devices have been widely used in the medical field for diagnostic and therapeutic purposes. They are considered safer than other radiological methods since they do not involve X-rays, particularly in pregnancy detection (Horcajadas et al., 2003).

A coupling agent, commonly known as ultrasound transmission gel (USTG), is required during an ultrasound examination. USTG has become a standard medium used in various medical procedures, including fetal condition examinations using ultrasound.

The quality of the echo from sound waves reflected by the ultrasound device depends on a parameter known as acoustic impedance ( $Z$ ), which determines how well energy is transferred between the transducer and body tissues (Susanti & Suprijanto, 2020). If two materials have significantly different impedance values (e.g., soft tissue and air), this causes strong reflections and results in unreadable signals, preventing the desired image from being produced. Therefore, USTG is necessary to minimize the impedance difference. Additionally, USTG provides lubrication to help healthcare professionals move the ultrasound probe more easily.

Currently, there are many variations in the types and brands of USTG available on the market, with a wide range of prices. Previous studies have primarily focused on the development of alternative gel formulations or comparisons between commercial and non-commercial materials (Milton et al., 2018; Myasar et al., 2019). However, there is a lack of systematic studies evaluating whether differences in price among commercially available USTG correspond to measurable differences in physicochemical properties and ultrasound imaging performance. This represents a gap, particularly in regions such as Indonesia where cost considerations play a major role in educational and clinical practice.

Three different commercial brands of ultrasound gels, the cheapest (IDR11.250,- or USD 0.69), medium (IDR56.500,- or USD 3.49), and most expensive (IDR135.000,- or USD 8.33) for the exact measurement of 250mL types that are available on Indonesian e-commerce were prepared and evaluated for their material properties through characterization. Further testing was conducted to determine the physicochemical characteristics of these gels, including density, pH, and viscosity. Human skin is naturally acidic, with a pH range of approximately 4-6 (Al-nima et al., 2019). Therefore, USTG formulations must ensure pH stability and avoid irritation when applied to the patients' skin (Medeiros Oliveira Ramos et al., 2017).

Therefore, the objective of this study is to evaluate whether price variations among commercially available USTG are associated with differences in material properties and ultrasound imaging performance, and to determine whether lower-cost alternatives can provide comparable effectiveness to higher-priced products.

## 2. Research Methods

The first method undertaken in this research was the exploration of commercially available ultrasound gels through Indonesia's e-commerce platform. From the initial investigation conducted during the early stages of the study, it was found that most ultrasound gel products are packaged in 250 mL containers with a wide range of prices. Subsequently, three types of gel were selected, representing the price range outlined in Table 1. Three different commercial brands of ultrasound gels are chosen as it represents the cheapest (IDR11.250,- or USD 0.69), medium (IDR56.500,- or USD 3.49), and most expensive (IDR135.000,- or USD 8.33) with the exact measurement of 250mL

**Table 1.** The table summarizes the selected gel types along with their corresponding price ranges in USD.

| Gel Code | Price Range (USD) |
|----------|-------------------|
| A        | 0.69              |
| B        | 3.49              |
| C        | 8.33              |

This study was designed to evaluate and compare the physicochemical and imaging performance of commercial ultrasound gels across three different price categories. The overall experimental workflow is summarized as follows. First, three ultrasound gels representing low-, medium-, and high-price ranges were selected and labeled as Gel A, Gel B, and Gel C. Each sample then underwent a series of physicochemical characterizations, including Fourier Transform Infrared (FTIR) spectroscopy to analyze functional groups, UV-Vis spectroscopy to assess optical properties, thermogravimetric analysis (TGA) to evaluate thermal stability, density measurement, and pH analysis to determine basic physicochemical parameters. Following material characterization, the gels were further evaluated through ultrasound imaging tests to assess their practical performance as coupling media. The results from all characterization and imaging analyses were then compared to identify potential correlations between gel price, material properties, and imaging quality.

### 2.1 Fourier Transform Infrared (FTIR)

FTIR is an infrared spectroscopy (IR) method used to characterize materials and identify functional groups in solid, liquid, or gas compounds based on absorption in the infrared region, where each functional group has a unique vibration frequency that produces a distinct spectrum (Sharma, 2018). This study employed FTIR to confirm functional groups present in each USTG. Testing was conducted using a Bruker Alpha 2 instrument from Germany, with spectra measured in the wavenumber range of  $1600\text{ cm}^{-1}$  to  $500\text{ cm}^{-1}$ .

## 2.2 UV-Visible Spectroscopy (UV-Vis)

The UV-Vis test was conducted to measure the transmittance or absorbance of a sample as a function of wavelength in the ultraviolet and visible regions. UV-Vis testing was performed using a Thermo Scientific Evolution 201/220 UV-Visible Spectrophotometer within a wavelength range of 400 to 600 nm.

## 2.3 Thermogravimetric Analysis (TGA)

TGA testing measures the amount and rate of mass change in a sample as a function of temperature and time under controlled conditions, primarily to determine the thermal stability of the sample. The sample is placed on a holder, which is then positioned inside a heated furnace during the experiment.

This study heated the sample from  $20\text{ }^{\circ}\text{C}$  to  $400\text{ }^{\circ}\text{C}$  at a  $20\text{ }^{\circ}\text{C}/\text{minute}$  rate. Sample preparation was carried out by placing the sample on an aluminum pan. The purpose of the TGA characterization in this research was to determine the thermal degradation of the ultrasound gel, as the use of ultrasound probes can result in temperature changes. The TGA testing was conducted using a Hitachi TG/DTA STA7300 instrument.

## 2.4 Density Measurement

The density test was conducted using a 10 mL pycnometer. The measurement procedure was as follows:

1. Weighing the empty pycnometer: The empty pycnometer was weighed using a Radwag AS220 R2 analytical digital balance with an accuracy of  $\pm 0.0001\text{ g}$ .
2. Filling the pycnometer with aqua dest: The pycnometer was filled with distilled water (aqua dest) as a control until it was full. Then, the pycnometer cap was inserted, causing the excess distilled water to overflow.
3. Weighing the filled pycnometer: the pycnometer filled with distilled water was weighed again.
4. Repeat steps 2 and 3 procedures for all gels.

The density of the three gel categories was calculated by comparing their density to that of the aqua dest at room temperature ( $997.05\text{ g/m}^3$ ), which served as the control, and was then incorporated into Equation (1):

$$\rho_{gel} = \frac{\text{Gel mass}}{\text{Aquadest mass}} \rho_{aquadest} \quad (1)$$

## 2.5 pH Measurement

The measurement was conducted three times. Before pH testing, calibration solutions or pH buffers were prepared. The buffers used were in powder form with pH values of 9.18, 4.01, and 6.86, following these steps:

1. Preparation of the buffer solution: The preparation was carried out at room temperature by pouring each buffer powder into a beaker containing 250 mL of deionized water.
2. Mixing the solution: the solution was stirred using a magnetic stirrer to ensure thorough mixing.
3. pH measurements of the buffer solution: The pH of the buffer was measured using litmus paper and a digital pH meter

Each measurement was performed three times for each solution.

## 2.6 Ultrasound Imaging Measurement

The ultrasound image testing was conducted using a basic ultrasound device with the following specifications as shown in Table 2.

**Table 2.** Specifications of the ultrasound device used in this study, including model, transducer type, and phantom medium, ensuring standardized imaging evaluation

| Ultrasound Device | Specification                                             |
|-------------------|-----------------------------------------------------------|
| Type              | Mindray DP-10                                             |
| Transducer        | Linear Transducer Mindray 75L38 EV 5-10 MHz               |
| Object Medium     | CIRS General Purpose Ultrasound Calibration 054GS Phantom |

The parameters used are shown in Table 3.

**Table 3.** Parameters applied in ultrasound imaging measurements, Image mode, depth, and gain settings to maintain consistency across frequency variations

| Parameters | Specification |
|------------|---------------|
| Image Mode | B-Mode        |
| Depth (D)  | 4.6           |
| Gain (G)   | 125           |

Three frequency values, 5 MHz, 7.5 MHz, and 10 MHz, were applied for each gel type. Additionally, vertical and horizontal distance measurements were performed by scanning the axial and lateral Resolution on the phantom.

A one-way analysis of variance (ANOVA) was conducted to compare group means, and the corresponding p-value was computed to assess statistical significance using Origin and ImageJ (Bonovas & Piovani, 2023; Hazra & Gogtay, 2016).

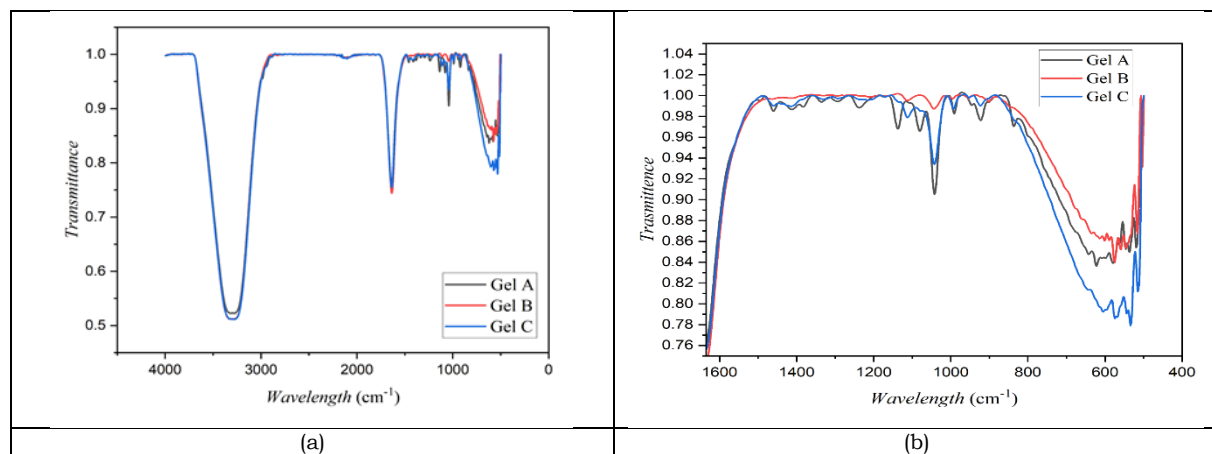
### 3. Results and Discussion

#### 3.1 FTIR

The FTIR testing results are shown in Figure 1. The graph shows that gels A and C exhibit more significant fluctuations at the wavenumber  $1500\text{ cm}^{-1}$  due to variations in molecular vibrations. Gels A and C also show the presence of specific functional groups such as -OH, C-H, and C=O.

On the other hand, gel B does not exhibit significant vibrations, concluding that gel B lacks complex functional groups. The highest transmittance is observed in the wavenumber range of  $3500$  to  $3000\text{ cm}^{-1}$  as shown in Figure 1 (a), corresponding to the vibrations of -OH groups, which originate from the composition of water, glycerine, humectants, and carbomer/polymers in the gel material.

A peak around  $1700\text{ cm}^{-1}$  may indicate the presence of C=O (carbonyl) groups, commonly found in gels containing organic compounds. All three gels share similarities in the fingerprint region, which corresponds to single bonds in the  $640\text{ cm}^{-1}$  to  $523\text{ cm}^{-1}$  range. The peak response of all three gels occurs around  $1040\text{ cm}^{-1}$ , which is associated with the C-O functional group.



**Figure 1.** FTIR characterization result of three gel categories. (a) wavenumber  $0\text{--}4000\text{ cm}^{-1}$  (b)  $400\text{--}1600\text{ cm}^{-1}$

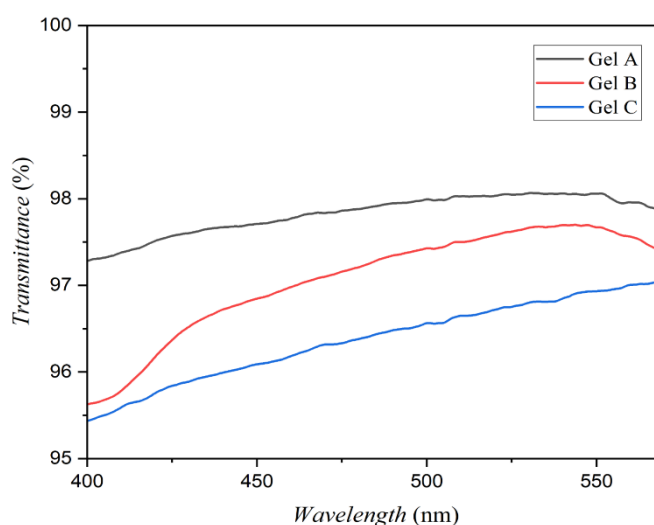
However, significant differences can be observed when examining the region between  $1600\text{ cm}^{-1}$  and  $500\text{ cm}^{-1}$ , as shown in Figure 1 (b), due to the specific composition variations among the three samples. These differences correspond to the compositions listed on the packaging of the three gels used, as shown in Table 4.

**Table 4.** Composition of the three gel types based on each product descriptions

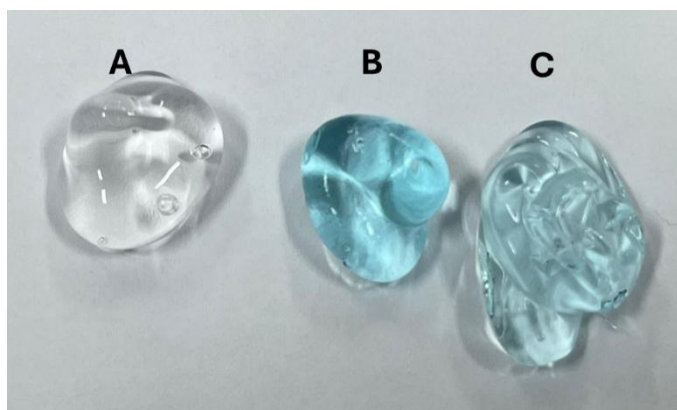
| Gel Code | Composition                                                                        |
|----------|------------------------------------------------------------------------------------|
| A        | Carbomer, glycerine, triethanolamine, water, lubricants, and preservatives         |
| B        | Deionized water, carbomer, triethanolamine, glycerine, dimethyl-dimethyl-hydantoin |
| C        | Polymer, humectant, preservative, reverse-osmosis water                            |

#### 3.2 UV-Vis

UV-Vis testing was conducted on the three gels within the visible light range, specifically from  $400\text{ cm}^{-1}$  to  $500\text{ cm}^{-1}$ . The differences in transmission among the three gels did not yield significant results, as shown in Figure 2. Gels A, B, and C, respectively, exhibited transmission percentages from high to low. These transmission percentages indicate the transparency of each gel as shown in Figure 3. The higher the transmission produced, the greater the transparency of the gel.



**Figure 2.** UV-Vis characterization results of gels A, B, and C, displaying transmission behavior across the visible light spectrum between 400 and 600 nm



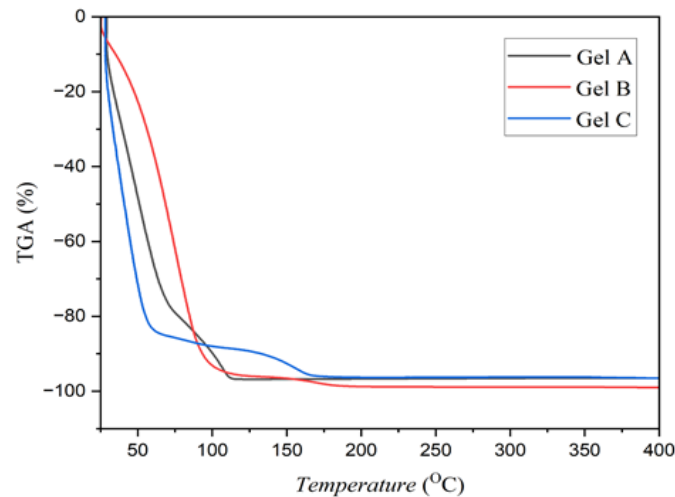
**Figure 3.** Visual comparison of gels A, B, and C, illustrating differences in appearance and transparency that correspond to UV-Vis results

Gel A exhibited the highest average transmittance ( $\sim 97.8\%$ ) with minimal variation across the measured wavelength range ( $\Delta T \approx 0.7\%$ ), indicating superior optical stability. In contrast, Gel B and Gel C showed larger increases in transmittance with wavelength ( $\Delta T \approx 2.0\%$  and  $1.5\%$ , respectively), suggesting greater wavelength-dependent optical behavior. Across the spectrum, Gel A consistently demonstrated higher transmittance than Gel B ( $\sim 0.5\%$ ) and Gel C ( $\sim 1.2\%$ ), while Gel C exhibited the lowest overall optical transparency.

The high transmittance observed in all samples indicates that the gels possess good optical clarity and structural homogeneity. However, Gel A demonstrated the highest and most stable transmittance across the measured wavelength range, suggesting a more uniform internal structure with minimal scattering centers. In contrast, Gel B and Gel C exhibited greater wavelength-dependent behavior, indicating the presence of microstructural inhomogeneities that contribute to light scattering. The lower transmittance of Gel C further suggests a higher degree of optical attenuation, potentially due to differences in composition or dispersion quality. These findings imply that Gel A may provide more consistent performance as a coupling medium due to its superior structural uniformity.

### 3.3 TGA

TGA measurements were performed to evaluate the thermal degradation of the three gels shown in Figure 4. The results indicated no significant differences among the three categories of gels. The mass reduction of gels A, B, and C was 96.53%, 99.03%, and 96.51% of the total mass, respectively. Gel C exhibited the fastest degradation at a temperature of approximately  $55^\circ\text{C}$ , whereas gels A and B showed similar degradation patterns within the range of  $90$ – $110^\circ\text{C}$ . Gel C also displayed two stages of mass reduction, occurring at approximately  $25$ – $50^\circ\text{C}$  and  $50$ – $180^\circ\text{C}$ , likely due to the presence of preservatives in the gel, resulting in a two-step degradation process. However, all three gels experienced significant mass loss before reaching  $200^\circ\text{C}$ , indicating that their composition is primarily water-based and contains organic or volatile compounds, as stated on the packaging.



**Figure 4.** Thermogravimetric analysis (TGA) results for the three gels, highlighting mass reduction patterns and thermal degradation profiles across temperature ranges up to 400 °C

The mass reduction of Gels A, B, and C was 96.53%, 99.03%, and 96.51%, respectively, suggesting that all samples underwent a broadly similar thermal degradation process. Notably, Gel B exhibited a higher extent of mass loss, with less than 1% residual mass remaining at the end of TGA, whereas Gels A and C displayed nearly identical residual mass fractions.

### 3.4 Density Measurement

Density measurements were conducted following the steps outlined in the previous chapter. The results of the measurements yielded the density values for each gel, as shown in Table 5.

**Table 5.** The Measured density values of the three selected gel types.

| Gel Code | Density (kg/m <sup>3</sup> ) |
|----------|------------------------------|
| A        | 1004.77                      |
| B        | 1004.19                      |
| C        | 1001.60                      |

The obtained density values are comparable to those of human soft tissues, indicating that the gels are suitable for minimizing acoustic impedance mismatch between air and the body. As shown in Table 5, Gel A, Gel B, and Gel C exhibited densities of 1004.77, 1004.19, and 1001.60 kg/m<sup>3</sup>, respectively. All samples fall within a narrow range close to that of water and soft tissue, suggesting similar acoustic compatibility. However, Gel C shows a slightly greater deviation compared to Gels A and B, which may indicate minor differences in composition or structural uniformity.

**Table 6.** Reference density values of air, water, soft tissue, muscle, and blood in human body (DeWerd & Kissick, 2014).

| Material    | Density (kg/m <sup>3</sup> ) |
|-------------|------------------------------|
| Air         | 1200                         |
| Water       | 1000                         |
| Soft Tissue | 960-1043                     |
| Muscle      | 1050                         |
| Blood       | 1060                         |

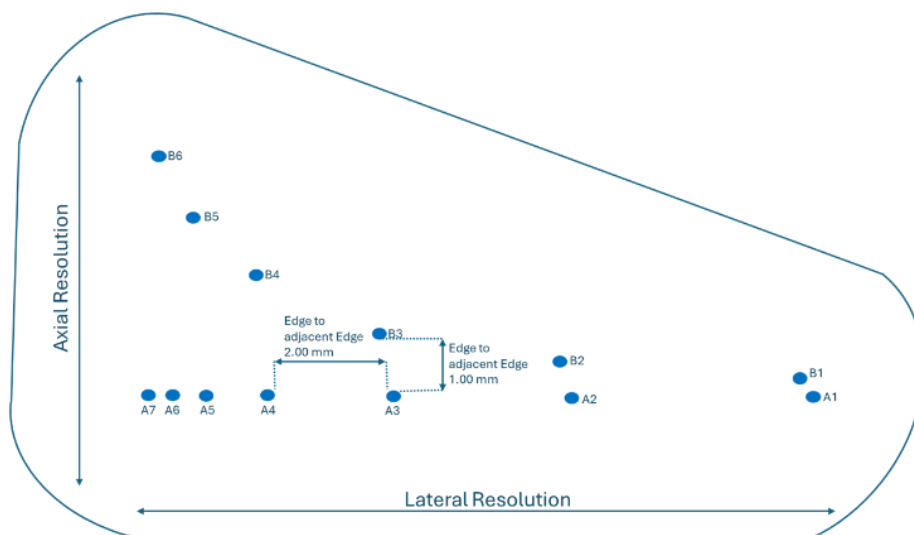
### 3.5 pH Measurement

The pH testing was conducted following the procedure described in the previous section. However, inaccurate data were observed during the measurement using a pH meter. One example is the measurement of aqua dest as a control (standard pH 7), which yielded a value of 8.24. This discrepancy indicates inaccuracies either in the measuring device or the measurement process. Consequently, data from the pH meter were excluded from the study results.

Instead, pH measurements were performed using Merck litmus paper. The pH measurements, conducted three times for each sample using litmus paper, showed that the pH of gels A, B, and C ranged from 4 to 6, aligning with the pH of human skin.

### 3.6 Ultrasound Imaging Measurement

Image testing was conducted on the three gels using three different frequencies: 5 MHz, 7.5 MHz, and 10 MHz. Axial and lateral resolution tests were performed. Axial resolution refers to the ability of the ultrasound system to distinguish closely spaced objects along the axial axis, which is directly proportional to the pulse length of the ultrasound wave, as shown in Figure 5. and Table 7. Meanwhile, lateral Resolution refers to the system's ability to distinguish objects perpendicular to the wave axis.



**Figure 5.** Axial and lateral targets placement on phantom (CIRS, 2013)

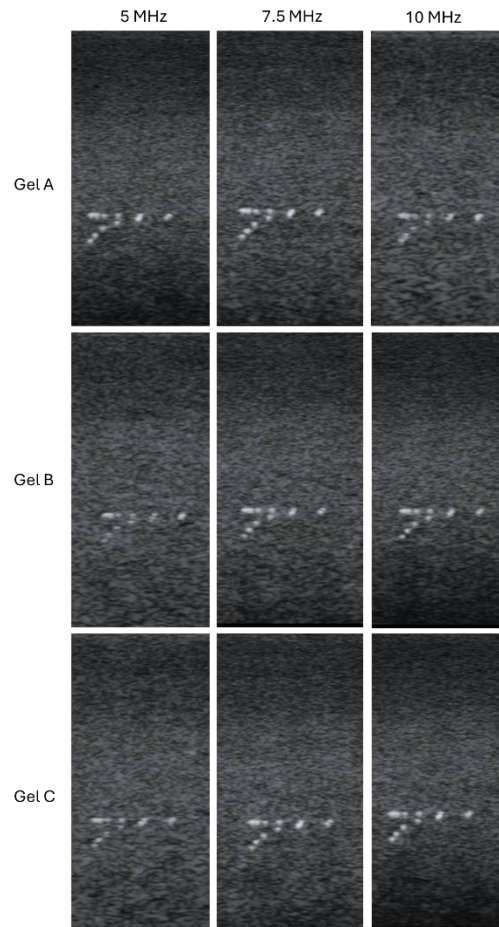
**Table 7.** Axial and lateral targets resolution on phantom (CIRS, 2013)

|                                | Targets |       |       |       |       |       |
|--------------------------------|---------|-------|-------|-------|-------|-------|
|                                | A1-B1   | A2-B2 | A3-B3 | A4-B4 | A5-B5 | A6-B6 |
| <b>Axial Resolution (mm)</b>   | 0.25    | 0.5   | 1.0   | 2.0   | 3.0   | 4.0   |
|                                | Targets |       |       |       |       |       |
|                                | A1-A2   | A2-A3 | A3-A4 | A4-A5 | A5-A6 | A6-A7 |
| <b>Lateral Resolution (mm)</b> | 4.0     | 3.0   | 2.0   | 1.0   | 0.5   | 0.25  |

The imaging results also depend on the operator is skilled in operating the ultrasonography device. Based on the information from the user manual, it was observed that all three gels achieved the closest axial distance at targets A4-B4 with a minimum detectable distance of 2.0 mm. For lateral Resolution, the closest detectable distance was observed at targets A5-A6 with a resolution of 0.5 mm, as shown in Figure 6.

A comparative analysis of axial and lateral resolution across the three gel samples reveals that axial resolution remains largely consistent, with all gels demonstrating comparable ability to resolve targets along the axial (depth) direction. However, differences are observed in lateral resolution, where Gel A exhibits the sharpest and most well-defined target separation, followed by Gel B, while Gel C shows noticeable blurring and reduced separation between adjacent targets. This indicates that Gel A provides superior lateral imaging performance, likely due to its more homogeneous structure and reduced scattering effects. The decreased clarity observed in Gel C suggests the presence of greater microstructural inhomogeneities, which may contribute to increased lateral beam distortion and reduced image resolution.

Quantitative analysis was performed using ImageJ to measure target separation and resolution parameters, followed by one-way ANOVA to assess statistical differences among the samples. The analysis yielded a p-value of 0.33, indicating that the observed variations in resolution are not statistically significant ( $p > 0.05$ ). This supports the conclusion that, despite minor visual differences, the overall imaging performance of the ultrasound gels remains comparable (Bonovas & Piovani, 2023).



**Figure 6.** Axial and lateral resolution test results on phantom

#### 4. Conclusion

Based on the series of material characterization and imaging tests, the three ultrasound gels demonstrated comparable performance with only minor quantitative differences. UV-Vis analysis showed consistently high transmittance across all samples, with average values of approximately 97.8%, 97.2%, and 96.5% for Gels A, B, and C, respectively, indicating similar optical clarity. Density measurements were also closely aligned (1004.77, 1004.19, and 1001.60 kg/m<sup>3</sup>), remaining within a narrow range comparable to soft tissue. TGA results revealed similar degradation behavior, with total mass reductions exceeding 96% for all samples. In imaging evaluation, axial resolution was consistent across all gels, while only slight differences in lateral resolution were observed, with Gel A showing higher clarity than Gels B and C. Overall, the observed variations across all tests were minimal and within a narrow range, supporting the conclusion that there are no practically significant differences in performance among the gels. Therefore, these findings suggest that lower-cost ultrasound gels can provide comparable functionality for training purposes, making them a viable and cost-effective alternative.

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