The Technology of Ultrasound Scanning Gels

A Sonotech Technical Paper Revised 2006 Edition

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Introduction to Scanning Gels

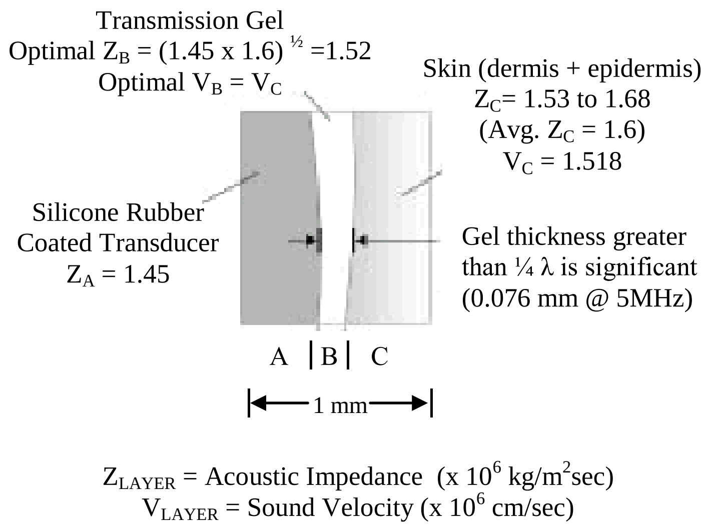
Ultrasound transmission or "scanning" gels are found nearly everywhere diagnostic ultrasonic imaging is performed. Scanning gels act as "couplants" that provide an acoustic pathway between the transducer and the skin. The couplant eliminates air from the interface and adapts the contours of the probe to the skin. Couplants are also required inside sterile sheaths for the same reasons, but these sterile couplants have more extensive design criteria, including in-vivo biocompatibility, not covered in the scope of this paper.

Because the primary purpose of the scanning gel is to couple ultrasound, the efficiency and accuracy of this transmission is of primary importance. Additionally, the scanning gel functions in intimate contact with both the scanhead, or probe, and the patient's skin, thus it should be inherently safe for both. This paper explains some of the key technical issues surrounding scanning gels and demonstrates that there is a clear difference between the commercially available products commonly used as couplants.

Acoustic Performance

The skin is the first tissue that the acoustic wave encounters when entering the body during ultrasound imaging. Skin thickness is a combination of the epidermis (0.1 mm) and the dermis (0.5 to 3.0 mm). This combined thickness represents multiple wavelengths of standard imaging frequencies (up to 10 wavelengths at 5 MHz). Because the skin contains multiple wavelengths, the sound velocity and acoustic impedance of the skin are important considerations in transmitting and receiving diagnostic ultrasound.

Most ultrasonic instrument and transducer manufacturers use convex elastomer lenses on flat and curved linear array transducers and on cardiac phased arrays. The external curvature of the lens often results in a couplant thickness of multiple wavelengths on a part, but not all, of the transducer's individual elements. Additionally, only light pressure is used on the transducer to maintain an adequate couplant layer and to avoid "snowplowing" of the scanning gel and transducer drag. Thus, the couplant layer is acoustically significant, and has the potential to be a weak link in the transmission of ultrasound between the transducer and the skin.



Reflective and Refractive Signal Degradation: When ultrasound waves encounter layer boundaries A:B and B:C, reflection occurs proportional to the acoustic mismatch at each boundary. When the angle of incidence is non-perpendicular to the skin, refraction occurs at every material boundary having velocity mismatches. Because the ultrasound travels both to and from the skin, it encounters a total of four boundaries, resulting in significant potential signal loss and degradation due to reflection and refraction. In order to optimize the transmission of acoustic energy, a gel with an acoustic impedance equal to the geometric mean of the transducer and skin is ideal. In order to minimize refraction, the gel sound velocity should equal that of skin.

Acoustic Impedance and Reflection

Acoustic impedance = (density) x (longitudinal sound velocity). Reflection of the sound beam occurs when it hits a boundary between materials having different acoustic impedance. This reflection within the body produces the ultrasound image, but should be minimized at the couplant to skin boundary where the couplant acts as an acoustic "window" through which the image is seen. Just as reflections from a glass window can sometimes obscure what is on the other side, an improper couplant match causes reflections that decrease acoustic energy transfer and create a larger first reflection that must be filtered out of the image.

Transducer manufacturers expend considerable engineering resources to match the relatively high acoustic impedance of the piezoelectric element, which generates the acoustic wave, to the acoustic impedance of the skin. Transducer designs use silicone, epoxy, or plastic on the front face of the scan head. Electronic array transducers with convex lenses are the most important consideration due to the multiple wavelength thickness of the coupling gel. The acoustic impedance of RTV-560® silicone, a common transducer lense material, is 1.45 (x 10^6 Kg/m^{2}sec), and the range of acoustic impedance for skin is 1.53 to 1.68.[2]

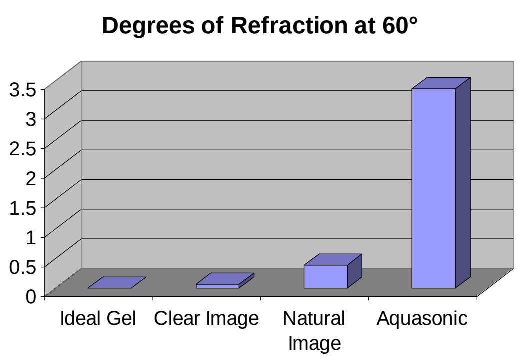
For maximum acoustic transmission (bandwidth and intensity), the couplant must have an acoustic impedance between that of skin and the lens or "face" of the transducer. Specifically, the optimal acoustic impedance of a scanning gel is the geometric mean value between that of skin and RTV silicone. This range is calculated as follows: $(1.45 \times 1.53)^{1/2}$ to $(1.45 \times 1.68)^{1/2}$ = 1.489 min. to 1.561 max.

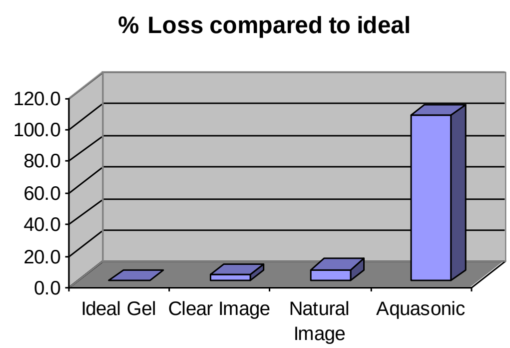
Acoustic Properties of Various Scanning Gels

Sample[1]	Sound Velocity[2] (cm/sec $x10^5$)	Velocity Error[3] (ref. skin, cm/sec)	Acoustic Impedance[4] ($x\ 10^6$ Kg/m^2sec)	Reflectance Loss[5] ($x\ 10^{-2}$)
"Ideal" gel	1.518	0	1.52	0.2426
Clear Image®	1.519	100	1.538	0.2515
Natural Image®	1.524	600	1.543	0.2589
Aquasonic®	1.574	5,600	1.602	0.4962

[1] Measured by Acoustics Bioengineering Laboratory, Penn State University.
[2] Longitudinal velocity, Skin = 1.518
[3] Deviation from skin velocity
[4] Optimal average = 1.52
[5] Total Intensity Reflection Coefficient $= 2 \times \left(\frac{Z_1 - Z_2}{Z_1 + Z_2} \right)$ (this represents the cumulative relative signal loss due to reflection at the couplant boundaries)

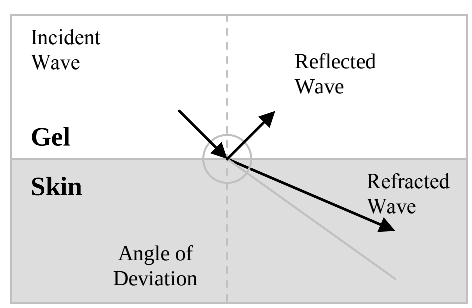
The results taken from the above table can be illustrated as follows, clearly demonstrating the superior performance of Clear Image and Natural Image compared to a well-known competitor:





Sound Velocity and Refraction

Refraction, or bending, of sound waves occurs when waves pass between materials of different sound velocity at an angle other than 90°. The most familiar example of this phenomenon is the illusion of a pencil bending when inserted into a glass of water. In ultrasound, refraction is due to sound velocity mismatches combined with oblique angles of incidence, most commonly with convex scanheads. With convex elastomer lens transducers, sound beam refraction at the skin interface can alter the transducer's focusing characteristics and beam profile, cause element-to-element nonuniformity, and cause phase changes in the acoustic wave. These cumulative refraction induced errors degrade the image quality through distortion and loss of resolution.



The sound velocity in skin is 1.518×10^5 cm/sec.[1] Therefore, if refraction at the couplant/skin boundary is to be eliminated, the sound velocity of the couplant should be as close to 1.518×10^5 cm/sec as possible. Because the amount of refraction is proportional to the velocity mismatch, the greater the mismatch, the greater the refraction.

Effect of Air Bubbles

The effect of small bubbles in the scanning gel under the transducer in Diagnostic Ultrasound Imaging is to disperse the ultrasound which results in clouding of the image. This effect is most clearly seen on echo free regions of the image (such as the echo free area of a cyst) which becomes cloudy. This has the potential to cause unnecessary biopsies.

Another use of ultrasound requiring a coupling gel media is ESWL Lithotripsy, where high-energy ultrasound pulses are used to break up calcified stones in the kidney, bladder, or urethra. In Lithotripsy itself, ultrasound energy at high power levels is focused to a point exactly on the stone. Air bubbles in the gel have the following effect:

A. If the air bubbles are smaller that 1/4 wavelength, they cause scattering of the Acoustic energy (sound waves) as Omni directional scatterers and less acoustic energy reaches the focal point. The result is less acoustic energy at the focal point to disintegrate the Kidney Stone.

B. If the air bubbles are larger than 1/4 wavelength they act as reflectors and deflect the acoustic energy off in a different direction resulting in less acoustic energy at the focal point (similar to A. above but a more pronounced effect).

C. If the air bubbles are microbubbles dispersed throughout the couplant (transmission gel) layer, the effect is to change the average acoustic impedance of the gel layer (which reduces the total transmitted energy) and, due to refraction, to change the focal point.

Air bubbles, regardless of their size, degrade the performance of ultrasound in all medical applications including imaging, Lithotripsy and physical therapy. Among scanning gel manufacturers worldwide, only Sonotech has engineered a manufacturing process which produces a gel completely free of any air or gas bubbles. This includes microbubbles which are difficult to see and larger bubbles in the 3 to 15 mm. range.

Dermatological Considerations

The basic dermatological requirement of a scanning gel is that it be free of known skin irritants or sensitizers. The broad range of patients imaged with ultrasound, from pregnant women and infants to the infirm or elderly dictates that the risk of skin reaction be minimized. Common irritants and sensitizers typically found in cosmetics include dyes, fragrances,[3,4] preservatives such as parabens, and humectants. While ingredients such as dyes and fragrances may be justified in a consumer cosmetic market, they pose unnecessary risk when used in a clinical situation.

Transducer Compatibility

Instrument and transducer manufacturers build scanheads to be compatible with couplants that are water based and contain glycerine or glycol humectants. There are some chemicals that can degrade the acoustic lens, destroy bonding, or change the acoustic properties of the lens. This damage typically occurs over time, with chemicals that have been identified as problematic, including mineral oil, silicone oil, alcohol, surfactants, and fragrances. While oils and alcohols are commonly avoided by scanning gel manufacturers, surfactants and fragrance may be included. Fragrance can affect the transducer's acoustic lens or face material by absorption over time into elastomer and plastic materials, thus changing the material's weight, size, density, and acoustic impedance. Surfactants can degrade the bond between the lense and the piezoelectric elements and contribute to the accelerated degeneration of the lense. Use of gels or lotions containing these chemicals can void manufacturer's transducer warranties!

In therapeutic ultrasound, ultrasound transmission gels and lotions commonly contain oils and other chemicals not intended for use with diagnostic imaging transducers. Considering the high cost of replacement transducers, this underscores the importance of using only ultrasound transmission gels designed for medical imaging. Sonotech's Clear Image has been tested extensively by leading diagnostic ultrasound instrument manufacturers, and no transducer incompatibilities were found. Furthermore, each of the components of Clear Image has been individually tested at 100% concentration by long-term soaking of acoustic lens materials with no detrimental effects observed.

Preservative Safety and Efficacy

Scanning gels are typically used in refillable dispensing bottles, which may or may not be warmed. Effective preservatives are required to prevent microbiological degradation of the gel and prevent the growth of pathogenic microorganisms. Preservative efficacy can be reliably tested using the USP XXII Antimicrobial Preservative Effectiveness Test. But effectiveness alone is not enough. Preservatives like methyl and propyl paraben are known to be effective against mold and yeast, but are routinely associated with allergic skin reactions.

Sonotech has researched and tested cosmetic grade preservatives that combine effective preservation and low incidence of skin reaction. Clear Image has been independently challenge tested and found to be effectively preserved for a minimum of two years, with internal testing indicating stability exceeding five years.

Benefits of Clear Image:

- **Sound velocity nearly identical to skin for better image quality**
- **Acoustic impedance within optimal range to optimize signal transmission**
- **Air-free manufacturing process**
- **Proven transducer probe compatibility**
- **Formulated without using common skin irritants and sensitizers such as fragrance**
- **Safe and effective preservation without parabens or high glycol levels**

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