LOGIQ P9 and LOGIQ P7 Shear Wave Elastography

Introduction

Tissue stiffness is often related to underlying disease. For millennia, physicians have used palpation as a diagnostic tool to detect various ailments such as lesions, aneurysms, and inflammation. Stiff masses found during routine physical exams can be an early indication of disease, as in the cases of breast and prostate cancer. In some ailments, such as liver fibrosis, disease progression is marked by a gradual change in tissue stiffness. The ability to non-invasively measure tissue stiffness can therefore be a valuable tool in the diagnosis, staging, and management of disease.[1]

Shear Wave Elastography

Shear wave elastography is an imaging technique which quantifies tissue stiffness by measuring the speed of shear waves in tissue.[2] This technique uses dynamic excitation to generate shear waves in the body. The shear waves are monitored as they travel through tissue by a real-time imaging modality. Under simplifying assumptions, the shear wave speed (Ct) in a medium is related to the Young's modulus (E), which is a measure of stiffness: $E=3\rho Ct^2$, where ρ is density. Therefore, by estimating the shear wave speed, the underlying tissue stiffness can be quantified. A low speed corresponds to a soft medium, while a high speed indicates a stiff medium. The shear wave speed can be directly used as a proxy for stiffness or converted to Young's modulus. Shear wave elastography quantifies tissue stiffness on an absolute scale.

Shear Wave Elastography with Ultrasound

Ultrasound technology is well suited for implementing shear wave elastography. First, ultrasound can be used to generate shear waves in tissue. As sound waves propagate, a portion of their energy is transferred to the medium on the path by absorption or reflection, as shown in *Figure 1*. Application of high intensity ultrasound for a duration on the order of 100 µs generates localized displacement, which serves as a source of shear waves in tissue.[3] Another advantage of ultrasound is its capability to image motion. The micron-level shear wave displacements induced by acoustic radiation force can be detected by Doppler techniques used in color flow imaging.[4] Since the speed of sound in tissue is approximately 1000 times faster than the shear wave speed, it is possible to use ultrasound to fully monitor the dynamics of shear wave propagation through tissue. The fact that ultrasound can provide both the stimulus to generate shear waves in tissue and the means to observe the resulting tissue response enables shear wave elastography to be performed using a single diagnostic ultrasound probe.

GE Healthcare curved probe, example

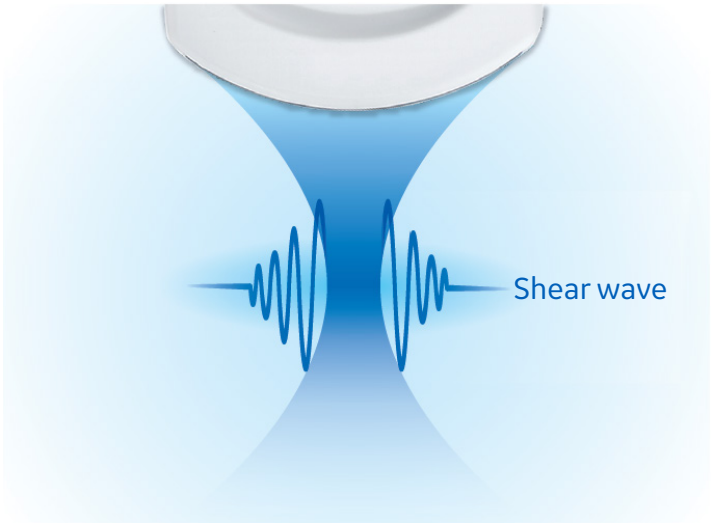

Figure 1. High intensity focused ultrasound beams can be used to push on tissue to generate shear waves, which propagate laterally away from the region of excitation.

LOGIQ P9 and LOGIQ P7 Technology

Two-dimensional shear wave imaging

The LOGIQ™ P9/7 shear wave elastography displays 2D images of shear wave speed or Young's modulus in a region of interest (ROI).[5] This shear wave elastography image is overlaid on top of a larger B-Mode image at the same location. The user can adjust the size and position of the ROI using the B-Mode image for guidance so that it is at the anatomy of interest. The stiffness at any location within the ROI can then be sampled using measurement tools to obtain a quantitative measurement of stiffness either in terms of shear wave speed (m/s), or Young's modulus (kPa) as shown in *Figure 2*.

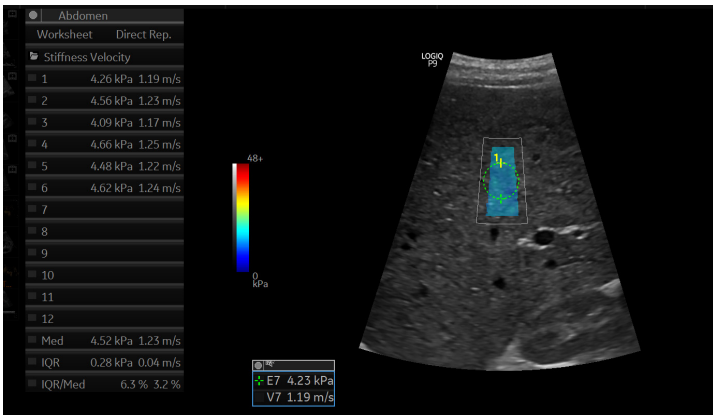

Figure 2. Examples of liver shear wave elastography screen of LOGIQ P9 obtained on a patient with normal liver function tests. Two-dimensional shear wave imaging technology provides a larger sampling area of liver stiffness measurement than 1D transient elastography and liver biopsy.

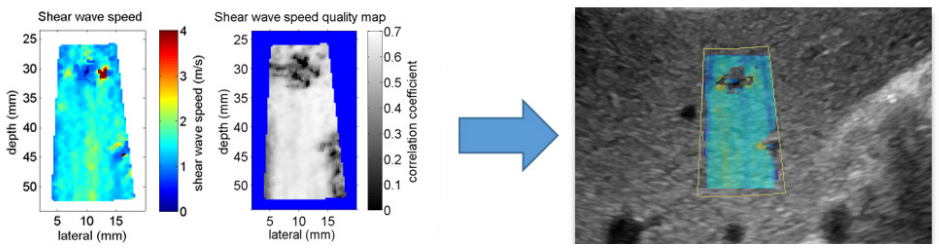

Figure 3. Quality assessment helps the user to instantly perform a visual quality assessment of the result. This feedback gives the user additional information on the quality of the measurement. In the example, artifacts caused by blood vessels within the ROI are removed by applying the quality threshold.

Quality Assessment

As one of the challenges of shear wave measurement, there are various measurement inhibiting factors such as poor probe contact, probe motion, breathing, heart beating, acoustic attenuation, reflection, scattering and rib shadowing. Quality assessment notifies these factors (artifacts) and increases clinical reliability. Quality assessment uses the cross-correlation function which is also used to estimate the local shear wave speed at every location in the shear wave elastography ROI. Thus, both shear wave speed maps and quality maps are created. This quality map which can be used by the user to prevent areas with low measurement quality from being displayed as shown in *Figure 3*.

Evaluating the Effectiveness of LOGIQ P9 and LOGIQ P7 Shear Wave Elastography for Determining the Progression of Hepatic Fibrosis

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Background

Ultrasound shear wave elastography is becoming a standard technology for assessment of liver fibrosis[6,7] as it is non-invasive, low cost, portable, and suitable for use in a variety of clinical settings. The standard of care for staging liver fibrosis is Transient Elastography (TE), which is widely used for assessment of liver fibrosis.[8] TE has several meta-analysis studies to establish the validity of the assessments.[9,10,11,12]

Materials and Methods

Subjects

205 patients, including 78 healthy volunteers with no history of liver disease, were recruited. The average age of the subjects was 52 years (age range 15-85 years). The subject demographics and disease etiology are summarized in *Table 1*.

Data collection methods

Shear wave elastography data in the liver were acquired using a GE Healthcare LOGIQ P9 and LOGIQ P7 ultrasound system with the R3.0.0 software version, using the C1-5-RS probe and 4C-RS probe respectively. Ten measurements were performed and a median value was calculated as a final SWE result for each subject. Although SWE results were available for both shear wave speed in m/s and elasticity in kPa, we used elasticity value for analysis.

TE examinations were performed with a FibroScan® device (Echosens, Paris, France). During the examination, subjects were asked to lie in a supine position and raise their right arms above their heads. The operator scanned the right lobe of the liver through the intercostal using the M probe (frequency 3.5 MHz) or the XL probe (frequency 2.5 MHz) and acquired ten liver stiffness values. The auto calculated result was the median value of the ten liver stiffness values, expressed in kilopascal. The criterion of result validity was defined by interquartile range (IQR)/median value < 30% and success rate (SR) ≥ 60%.[12,13,14]

Characteristic	LOGIQ P9/P7 Values
Subjects	205
Age	53 ± 16 (mean ± SD)
Gender	
Male	106 (52%)
Female	99 (48%)
Disease	
Healthy	78
HBV	69
HCV	22
NAFLD	22
Other (AIH, PBC, ALCOH, etc.)	14

Table 1. Subjects and demographics. HBV = Hepatitis B virus, HCV = Hepatitis C virus, AIH = autoimmune Hepatitis, ALCOH = alcoholic steatohepatitis, PBC = primary biliary cirrhosis, NAFLD = Nonalcoholic fatty liver disease.

Data analysis methods

After the data collection, shear wave measurements were performed by placing at least ten circular measurement regions over the stored images. The measurement regions were chosen by the operators to exclude obvious artifacts in the shear wave elastography image. Each measurement region was approximately 1 cm in diameter. The average stiffness expressed in terms of Young's modulus (kPa)[15] within each measurement region was automatically recorded by the system in a worksheet. These measurement regions were typically placed on different shear wave image frames so that independent measurements of liver stiffness were obtained for each subject. MedCalc Statistical Software version 18.11 (MedCalc Software bvba, Ostend, Belgium) was used to analyze data. The diagnostic accuracy of this study to measure liver stiffness for fibrosis stages were calculated by the receiver operating characteristic (ROC) curves, and the optimal cutoff values were calculated from optimal criterion using Bayesian analysis. Median values of these measurements are grouped by TE criteria confirmed fibrosis stage. The Tsochatzis meta-analysis was used to determine the stage of liver fibrosis based on the TE result, F≥2: 7 kPa; F≥3: 9.5 kPa; F=4: 12 kPa.[9,12]

Results

The shear wave elastography stiffness value for each fibrosis stage determined by corresponding TE value according to the above criteria is shown in *Figure 4*.

As expected, liver stiffness measured by LOGIQ P9/7 shear wave elastography increased with the level of fibrosis. There was a correlation between liver stiffness and fibrosis stage (R^2 = 0.55, p < 0.001 for LOGIQ P9, R^2 = 0.62, p < 0.001 for LOGIQ P7). The ROC curves for LOGIQ P9/7 is shown in *Figure 5*. and optimum cutoff values were calculated to F≥2: 6.82 kPa; F≥3: 7.60 kPa; F=4: 9.30 kPa for LOGIQ P9 and F≥2: 6.65 kPa; F≥3: 7.50 kPa; F=4: 9.30 kPa for LOGIQ P7.

As shown, the cutoff values for each fibrosis stage are close between LOGIQ P9 and P7. Also, two similar studies were conducted with LOGIQ S8 shear wave elastography, in comparison with liver biopsy (N = 90) and TE (N=171) as a gold standard. The resulting cutoff values with liver biopsy were 6.60 kPa, 8.07 kPa, and 9.31 kPa with a sensitivity of 73.5%, 69.6%, 88.7% and 94.9%; specificity of 73.2%, 91.2%, 78.9% and 81.8%, respectively for F2, F3 and F4. The resulting cutoff values with TE were 6.9 kPa, 8.2 kPa and 9.3 kPa with a sensitivity of 85.8%, 87.5% and 85.7%; specificity of 90.2%, 86.8% and 81.2%, respectively for F2, F3 and F4.[16,17] These results are comparable to those for LOGIQ P9/P7 in comparison with TE. Thus, a combined cutoff chart was created as shown in *Figure 7*, which can be used for the LOGIQ P9, LOGIQ P7, and LOGIQ S8.

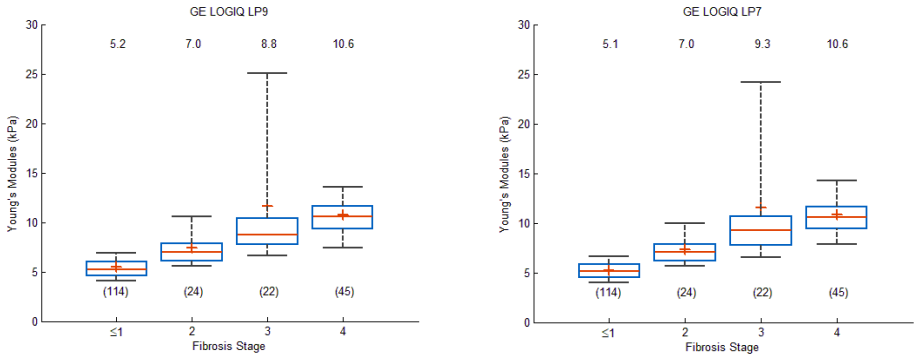

Figure 4. Median of 10 shear wave elastography measurements for 205 subjects in the study, grouped by fibrosis stage based on TE. The boxes represent interquartile range, while the whiskers represent the 9th and 91st percentiles. The plus sign indicates the mean, while the red line indicates the median value of the group. The numerical value at the top of the box-whisker shows the median value at each stage. The numbers in parentheses show the number of subjects in each group.

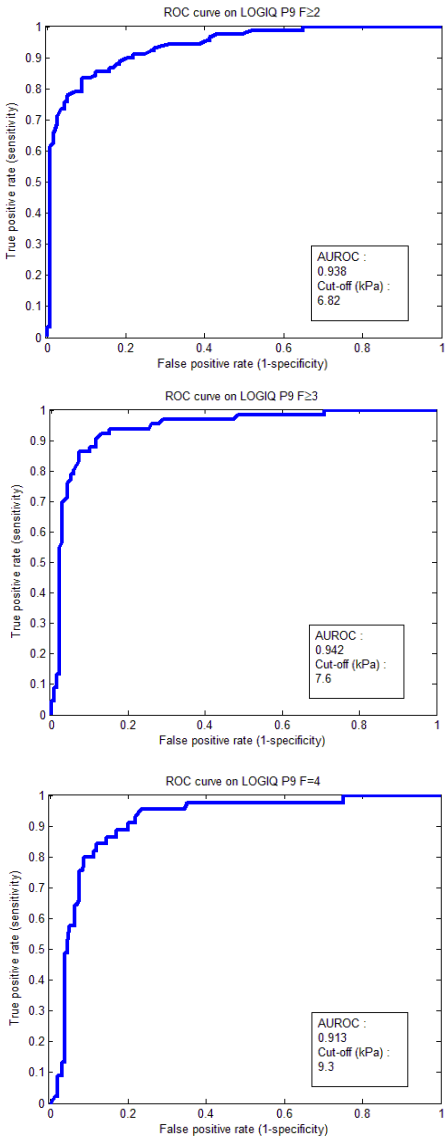

Figure 5. ROC curves for discriminating different stages of fibrosis using shear wave elastography measured by the LOGIQ P9 (C1-5-RS). The optimal cutoff values were calculated based on optimal criterion. ROC in the differentiation of stage F2 fibrosis or greater, stage F3 fibrosis or greater, and stage F4 fibrosis was 0.94 (95% confidence interval-CI: 0.90, 0.97), 0.94 (95% CI: 0.90, 0.97) and 0.91 (95% CI: 0.87, 0.95), respectively. Cutoff values were 6.82 kPa, 7.60 kPa and 9.3 kPa with a sensitivity of 83.5%, 86.6% and 75.6%; specificity of 91.2%, 92.8%, and 92.6%, respectively.

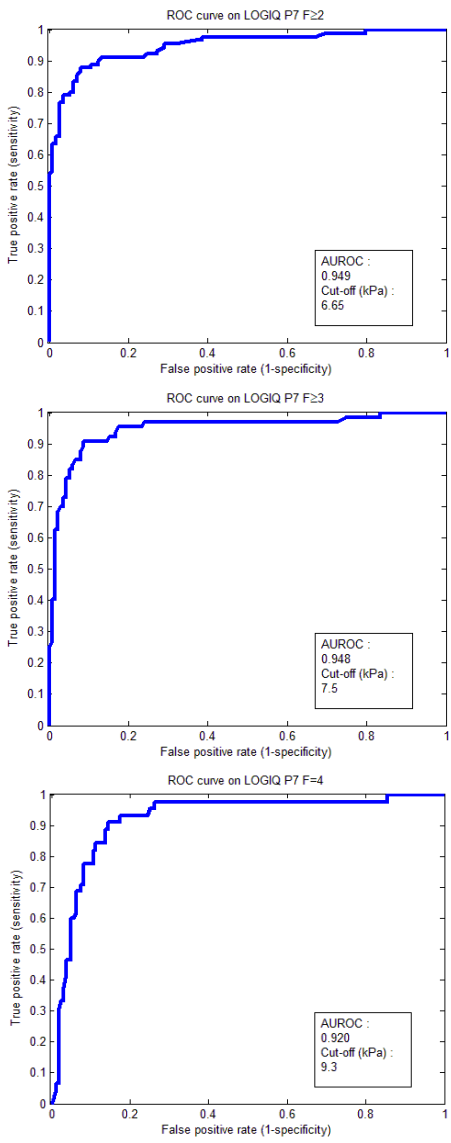

Figure 6. ROC curves for discriminating different stages of fibrosis using shear wave elastography measured by the LOGIQ P7 (4C-RS). The optimal cutoff values were calculated based on optimal criterion. ROC in the differentiation of stage F2 fibrosis or greater, stage F3 fibrosis or greater, and stage F4 fibrosis was 0.95 (95% confidence interval-CI: 0.91, 0.98), 0.95 (95% CI: 0.91, 0.97) and 0.92 (95% CI: 0.87, 0.95), respectively. Cutoff values were 6.65 kPa, 7.5 kPa, and 9.3 kPa with a sensitivity of 87.9%, 91.0% and 77.8%; specificity of 92.11%, 91.3% and 91.8%, respectively.

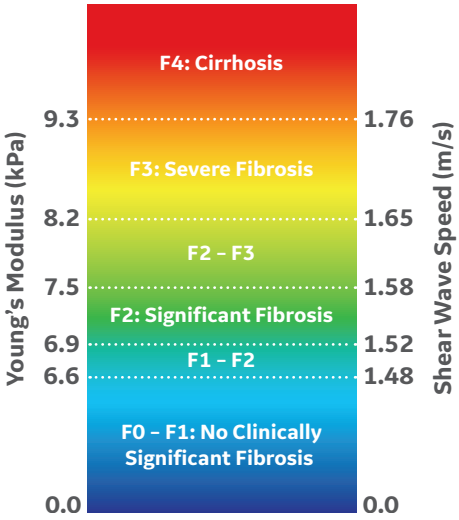

Figure 7. The combined cutoff charts. The results of LOGIQ P9/7 shear wave elastography study with TE gold standard and LOGIQ S8 shear wave elastography study with TE and liver biopsy gold standard are combined to create chart. Left and right side express in Young's modulus value (kPa) and shear wave speed (m/s) respectively.[18]

Discussion

Fibrosis staging using Transient Elastography as the gold standard

Although a limited number of subjects and a mix of disease etiologies were evaluated in this study, liver stiffness measured by LOGIQ P9/7 shear wave elastography increased with fibrosis, so this was shown to be useful for discriminating different stages of fibrosis.

Conclusions

Shear wave elastography on the LOGIQ P9/7 allows the user to visualize the tissue stiffness as a color-coded map in a 2D region of interest and provides the user with a quantitative measurement. Shear wave elastography is a promising technique for non-invasive quantification of tissue stiffness and has the potential to be useful in the diagnosis, staging, and management of diseases associated with changes in tissue elasticity.

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