Preliminary clinical experience with Shear Wave Dispersion Imaging for liver viscosity

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Introduction

Shear Wave Elastography (SWE) provides a quantitative measurement and real-time display of tissue elasticity. Literature reviews demonstrate that SWE is a fast and effective method for assessing liver fibrosis, though there is limitation when assessing patients with inflammation or steatosis. The main cause of the limitation is that viscosity properties are neglected in current algorithms for quantifying liver elasticity. In reality, liver tissue exhibits viscoelastic characteristics and the propagation of shear waves in the liver depends on both elasticity and viscosity. It is reported that liver diseases such as nonalcoholic steatohepatitis (NASH), non-alcoholic fatty liver disease (NAFLD) or acute hepatitis, will increase the viscosity of the liver and this might affect stiffness assessment. Accurate stiffness quantification for liver diseases associated with steatosis and inflammation is therefore challenging. Early detection and treatment for acute hepatitis and the highly prevalent fatty liver allows the opportunity to reverse the deterioration. As a result, early detection is critical to take liver viscosity into account.

Shear Wave Dispersion Imaging (SWD), a new imaging technology, has been developed on the Aplio i-series for assessing the dispersion of shear wave, which is related to the viscosity properties in diffuse liver disease. In this paper, the feasibility of liver viscosity evaluation using SWD is studied through preliminary clinical evaluation.

Shear Wave Dispersion Imaging on Aplio i-series

Shear Wave Dispersion Imaging can be activated automatically in the Shear Wave Elastography mode. A Dispersion map provides visualization of the dispersion slope, which is a parameter directly related to viscosity. The calculated dispersion slope value (m/s/kHz) and its standard deviation are displayed. In SWE quad view mode (Figure 1), shear wave speed or shear wave elasticity (Speed Map, Elasticity Map), shear wave arrival time contour (Propagation Map), grayscale, and the dispersion slope (Dispersion Map) can be viewed simultaneously.

Principle of Shear Wave Dispersion Imaging

Liver is viscoelastic and shear wave speed depends on both elasticity and viscosity. In rheological models of viscoelastic material, viscosity (Pa·s) is represented as a damper and elasticity is represented as a spring (kPa). Viscosity is the measure of resistance to relative shearing motion, i.e. similar to a damper, tissue exhibits movement under gradual deformation instead of sudden deformation. Elasticity measures the ability of tissue to resist deformation and return to its original state, i.e. similar to a spring which contracts under pressure and expands when the pressure is released. There are two common viscoelastic models: Maxwell, represented by a spring and a damper connected in a series; and Voigt, represented by a spring and a damper connected in parallel.
Similar to Shear Wave Elastography, for assessment of viscosity, SWD measures the shear wave propagation generated through tissue deformation caused by a “push pulse”. In current algorithms for SWE (kPa) quantification, the viscosity properties are neglected. In an example for elasticity calculation with the Voigt model, liver tissue is assumed to be perfectly elastic, thus shear elasticity is calculated by neglecting viscosity. By relating shear elasticity and Young’s modulus $E$, elasticity $E$ (kPa) can be acquired from shear wave propagation speed (Figure 3).

In reality, liver tissue has viscoelastic properties. Chronic diseases such as hepatitis or steatosis are considered to increase liver viscosity. In viscoelastic tissue, shear wave speed experiences frequency dispersion, which describes the change of shear wave speed, $c_s$ depending on its shear wave frequency, $f$. The relationship between shear wave speed and shear wave frequency is observed using the Voigt model, i.e. shear wave speed is plotted against its frequency with different shear elasticity and shear viscosity (Figure 4). In perfectly elastic tissue, shear wave speed is constant regardless of the shear wave frequency. However, in viscoelastic tissue, shear wave speed does vary depending on the frequency. At a constant shear elasticity, with increased shear viscosity, there is an increase of slope, i.e. the slope demonstrates the degree of frequency dispersion (Figure 5). Dispersion and viscosity demonstrate a positive correlation.

Shear Wave Dispersion Imaging (SWD) is an innovative imaging technology for visualizing the dispersion (slope). It should be noted that SWD does not calculate viscosity directly, however, SWD has the advantage of obtaining actual quantification of dispersion, which is a parameter directly related to viscosity.

Shear Wave Dispersion Map

The Shear Wave Dispersion (SWD) Map provides visualization of the dispersion slope, allowing clinicians to estimate the viscosity of the liver.

Similar to SWE, a push pulse causes deformation of the liver tissue, generating shear waves. The displacement at each data point (A and B on Figure 6) is detected, time information and its displacement amplitude are acquired. By using a fast Fourier transform (FFT) algorithm, shear wave signals are converted to its shear wave frequency...
components. The shear wave frequencies obtained forms the x-axis for dispersion slope calculation. The shear wave speed is calculated for each frequency based on the displacement relationship among data points.

The shear wave speed calculated at each frequency is plotted on the y-axis. The slope of the shear wave speed is obtained as the dispersion value with a unit of m/s/kHz, representing shear wave speed versus shear wave frequency. Dispersion values are superimposed over the B-mode image and create the Dispersion map. By placing a measurement ROI on the Dispersion map, quantification of the dispersion slope can be obtained, and viscosity of the liver can be estimated.

Clinical evaluation

In our preliminary clinical experience with Shear Wave Dispersion Imaging, we quantified the viscoelasticity using SWE and the dispersion slope with SWD on patients with normal liver (control group), non-alcoholic fatty liver disease (NAFLD), nonalcoholic steatohepatitis (NASH), chronic hepatitis (HBV, HCV, alcoholic), liver cirrhosis (HCV, alcoholic), and acute hepatitis. The following cases are based on our preliminary study.

Case 1 (Figure 7) is a normal liver and case 2 (Figure 8) is a liver with NASH. NASH is a type of steatosis that demonstrates histologic evidence of hepatocyte injury, including hepatocellular ballooning, lobular inflammation, and/or liver fibrosis. Compared to a normal liver, NASH shows a slight increase in elasticity but remains in the normal range. However, there is an obvious increase in the dispersion slope.

In a case of acute hepatitis A infection (Case 3, Figure 9), the highly elevated AST and ALT values in the blood test are accompanied with a slight increase in elasticity but significant increase in dispersion slope.

In a case of NASH-LC (Case 4, Figure 10), the B-mode image did not reveal the characteristics of a fatty liver. Instead, NASH-LC has a slightly higher elasticity but an extremely high dispersion slope. In a case of HCV-induced cirrhosis (Case 5, Figure 11), elasticity is exceptionally high but with an obvious increase in dispersion slope.

Compared with NASH-LC, HCV-induced cirrhosis has an exceptionally high elasticity but the dispersion slope is not as high. In contrast, the dispersion slope of NASH-LC is extremely high but accompanied with a moderate increase in elasticity. Further study is necessary to confirm the relationship between elasticity and dispersion slope results versus histopathology.

The effect of the etiology on the dispersion slope and shear wave speed is obtained from the clinical evaluation. By sorting the results by etiology, a strong correlation can be observed (Figure 12). The results from NASH are grouped along a (yellow) slope which is tilting towards the dispersion slope axis, demonstrating that NASH has a stronger correlation with dispersion rather than shear wave speed. In comparison, data related to liver cirrhosis is mostly concentrated along the (green) slope which is tilting towards the shear wave speed axis, indicating that liver cirrhosis has a stronger effect on shear wave speed. Further clinical evaluation with a larger sample size is however recommended.
Conclusion

The preliminary clinical experience with Shear Wave Dispersion Imaging (SWD) indicates that elasticity is a more effective parameter for assessing hepatic fibrosis while viscosity is more effective in assessing necroinflammatory change and fat deposition. In addition to conventional viscoelasticity imaging with shear wave, SWD is an innovative imaging technique that offers viscosity evaluation with a potential for additional pathophysiological insights on clinical evaluation of the liver.

Reference
