Acoustic Radiation Force Imaging Sono-elastography of Liver in Patients after Fontan Operation

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Introduction
Although late hepatic dysfunction and cirrhotic change were often seen in Fontan patients, not only the prevalence and progression of cirrhotic changes but also the non-invasive diagnostic tools for hepatic fibrosis have not been clearly clarified. In this study, we aim to clarify the clinical impact of the novel echographic imaging: sonoelastography using acoustic radiation force impulse (ARFI) to assess the liver stiffness in Fontan patients.

Methods
The study subjects were 37 patients with Fontan procedure (age: 12.5 +/- 5.6 years) and 75 patients either with minor cardiac anomalies or after uncomplicated definitive surgeries, having no hemodynamic compromise, (age: 12.1 +/- 4.9 years) as a control. The imaging apparatus was Acuson S-2000 (Siemens AG, USA) with 9L4 and 4C1 probe. The liver stiffness was measured and estimated by shear propagation velocity (m/s) (Vs) by Virtual Touch TM tissue quantification (VTTQ) which provided accurate numerical measurements related tissue stiffness at user-defined location using ARFI. The value of Vs was proportional to the degree of tissue stiffness (Young elastic modulus). The patients were in prone position and Vs at the 2-3cm inner portion of the right lobe of liver was measured at 5 times consecutively and averaged.

Results
Vs of Fontan patients (2.28 +/- 0.56 m/s) was significantly higher than those of the control patients (1.28 +/- 0.3 m/s) (p<0.001). In Fontan patients, Vs was weakly proportional to the ratio of mean pulmonary artery and aortic pressure : PA/AO (r^2=0.23), the ratio of pulmonary and systemic vascular resistance: Rp/Rs (r^2=0.13), and the multiplication of central venous pressure(CVP) and interval from Fontan (r^2=0.27), but not associated with age at measurement, the interval from Fontan procedure, CVP, cardiac index, and biomarkers (BNP, r-GTP, platelet). Vs of Fontan patients were lower than those of patients with end-staged liver cirrhosis (> 4.0).

Conclusion:
The liver stiffness after Fontan patients measured as Vs by VTTQ TM is higher than control from shortly after Fontan operation and weakly associated with PA/Ao, Rp/Rs, and CVP*Interval. The Vs by VTTQ TM could be a powerful tool for early non-invasive detection of liver fibrosis and cirrhosis in Fontan patients and stratified the risk to develop liver fibrosis.
Case

Vs=2.1  Vs=2.6  Vs=3.4

VTTQ™
Virtual Touch Tissue Quantification

Vs= \sqrt{\frac{E}{2(1+\sigma)\rho}}

E: Young’s modulus, \sigma: Poisson’s ratio, \rho: density

“Push” pulse: ARFI

Shear strain

“Shear wave velocity” (Vs) conduction

scanning (Vs) by detecting pulse

Measure “shear wave velocity”
Liver stiffness (Vs)

Liver stiffness (Vs) distribution among CPB(-), CPB(+)-Op, and Fontan patients.

- CPB(-): 1.23 ±0.2 m/s
- CPB(+)-Op: 1.28 ±0.3 m/s
- Fontan: 2.28 ±0.56 m/s

Liver stiffness (Vs) over years

Liver stiffness (Vs) across different time periods, showing trends and potential correlations with liver conditions.

- Liver cirrhosis
- Fontan
- Control
Liver stiffness (Vs) vs PA/Ao

\[ y = 4.5917x - 1.4377 \]
\[ R^2 = 0.23427 \]

Histology of the liver: Male Autopsy @ 16y
Dx: Polysplenia, SRV, DORV, PS, CAVVR, post-TCPC, giant PAVF+ VVcollaterals, chronic CHF & high CVP (16-18mmHg), hypoxia (SpO2=65-70%)

Vs=3.4 m/s Forns index=8.07

Liver cirrhosis & fibrosis with centrilobular necrosis & fibrosis