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Non-Invasive Markers of Liver Fibrosis in Patients After Fontan Surgery: A Case Series

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Abstract

Background

Fontan circulation predisposes patients to Fontan-Associated Liver Disease (FALD), characterized by chronic congestion and progressive hepatic fibrosis. Although liver biopsy is the gold standard for fibrosis assessment, its use is limited owing to the risk of complications in these patients. In this context, liver elastography and non-invasive serum markers of fibrosis, such as APRI and FIB-4, have been proposed as alternatives for liver monitoring; however, their applicability and correlation with the progression of FALD in pediatric patients remain uncertain.

Methods

This was an observational case series cohort with both retrospective and prospective components, including patients with univentricular congenital heart disease who underwent the Fontan procedure and had liver elastography performed during follow-up. Liver stiffness was assessed using the 2D-SWE method. Clinical and laboratory data (AST, ALT, and platelets count) were collected to calculate APRI and FIB-4. Spearman correlation and partial correlation analyses were performed to identify factors associated with liver elastography. In the subgroup with longitudinal assessments, paired tests were applied.

Results

A total of 32 patients (62.5% male) were included with a mean age of 3.75 ± 1.77 years at the time of Fontan surgery and 13.83 ± 8.18 years at the time of elastography evaluation. The mean liver stiffness was 12.05 ± 2.49 kPa. No significant correlation was found between liver elastography and APRI or FIB-4, nor was there any association with sex, age at surgery, or age at elastography evaluation. In the longitudinal subgroup (N = 22), no significant variation was observed between LE1 and LE2, nor were there relevant changes in APRI and FIB-4 over time.

Conclusions

In pediatric post-Fontan patients, liver elastography did not correlate with APRI or FIB-4, nor with the clinical variables analyzed, in both cross-sectional and longitudinal assessments. The findings suggest limitations of serum markers and reinforce the need for specific and validated strategies for liver monitoring in this population.

BACKGROUND

The Fontan procedure, conceived in the late 1970s by Francis Fontan et al. [1, 2], is the final stage of a series of surgical procedures performed in patients with univentricular congenital heart disease [3, 4]. The procedure consists of an extracardiac cavopulmonary connection, linking the superior vena cava (SVC) to the right pulmonary artery (RPA) (Glenn shunt), while the inferior vena cava (IVC) is directed to the RPA with or without fenestration [3, 5, 6]. The optimal age for each stage remains under discussion; however, the second stage is generally performed between 6 and 12 months of age, and the final stage is completed between 18 months and 4 years of age. The new Fontan circulation directs systemic venous return directly to the pulmonary arteries, resulting in elevated central venous pressure (CVP) and low pulmonary vascular resistance (PVR) [7]. This contributes to hepatic overload and congestion, a condition known as Fontan-Associated Liver Disease (FALD) [3, 4]. The resulting fibrosis presents a centrilobular and perisinusoidal pattern and may progress to advanced liver disease with signs of portal hypertension (PH) and hepatocellular carcinoma (HCC) [3, 8]. Diagnosis involves a combined assessment of clinical, biochemical, and radiological findings of chronic liver disease or PH, and treatment is directed toward managing FALD complications and evaluating candidates for heart transplantation or combined liver-heart transplantation [3]. Follow-up of patients with FALD should be conducted at referral centers with multidisciplinary teams, through liver and cardiovascular evaluations, as well as screening for complications such as PH and HCC [3, 4, 9].

Liver biopsy remains the gold standard for assessing hepatic fibrosis; however, post-Fontan patients have a higher risk of bleeding, as they are frequently anticoagulated and have elevated CVP. In this context, the development and validation of non-invasive markers of liver fibrosis have become a priority in the follow-up of this group of patients [10, 11]. The most used in clinical practice are the Aspartate Aminotransferase-to-Platelet Ratio Index (APRI) and the Fibrosis-4 index (FIB-4). Although they lack specific validation for FALD, they may assist in the diagnosis and monitoring of advanced FALD with PH. However, both markers were primarily validated in liver diseases with a predominantly inflammatory, hepatocellular pattern of injury, whereas the fibrogenesis underlying FALD stems from pure passive sinusoidal congestion rather than hepatocyte injury; this pathophysiological distinction may account for their limited sensitivity in detecting and monitoring congestive hepatic fibrosis [3].

Liver elastography (LE) has emerged as the main non-invasive modality for assessing liver stiffness in recent decades [3, 12]. Different techniques have been evaluated in post-Fontan patients in both pediatric and adult populations, including Magnetic Resonance Elastography (MRE), Transient Elastography (TE), and Shear-Wave Elastography (SWE); however, the heterogeneity of liver stiffness (LS) values limits the routine validation of this method [13, 14, 15]. Interpretation of LS values in post-Fontan patients should be performed with caution, as chronic elevation of CVP may directly influence liver stiffness, independently of the degree of structural fibrosis [3, 8].

This study aims to evaluate the role of LE and the APRI and FIB-4 markers in the longitudinal follow-up of pediatric patients with univentricular congenital heart disease who have undergone the Fontan procedure, as well as to describe their clinical profile. In addition, we sought to evaluate whether, in this congestive and non-inflammatory context of FALD, traditional biomarkers would correlate with LS.

METHODS

This was an ambispective case series study including patients diagnosed with univentricular congenital heart disease who completed the final stage of surgical palliation through the Fontan procedure. These patients were referred for FALD screening and underwent LE at a radiology clinic between September 2020 and December 2025. The study comprised a retrospective component, involving the collection of clinical and demographic data from medical records, and a prospective component, consisting of standardized LE examinations.

Inclusion criteria: patients of both sexes with no age restriction; who underwent LE at some point during postoperative follow-up; biochemical evaluation within a maximum interval of 6 months from the LE examination.

Exclusion criteria: biochemical tests and LE performed with an interval greater than 6 months between them; prior diagnosis of any congenital or acquired liver disease; prior diagnosis of any systemic or metabolic disorder with liver involvement; patients who had undergone liver or heart transplantation.

The 2D-SWE ultrasound technique was used, employing the Philips® Affiniti 70 device equipped with a transducer (linear or convex, depending on age). This technique allows real-time visualization of the color-coded stiffness map (elastogram), ensuring that measurements are obtained from homogeneous tissue [16]. The propagation velocity of the ultrasound wave is directly related to tissue elasticity; that is, the stiffer the tissue, the faster the propagation of vibrations. Therefore, higher values indicate a greater degree of fibrosis in the hepatic parenchyma. Results were expressed in kilopascals (kPa), using the median of the measurements [17]. All patients were instructed to maintain absolute fasting for at least 6 hours prior to the examination, as postprandial splanchnic blood flow significantly increases LS [18]. Patients who underwent only one LE examination during follow-up were analyzed as a single sample. Patients who underwent at least two examinations were classified as LE1 and LE2, where LE1 corresponds to the first postoperative evaluation and LE2 to the most recent evaluation. All examinations were performed using the same device and by two experienced observers (LRA and CPO).

Clinical and biochemical data were collected from electronic and paper medical records. Clinical data included: sex; age at the time of Fontan surgery; age at the time of LE evaluations; and time elapsed between Fontan surgery and LE assessments. Laboratory data included alanine aminotransferase (ALT), aspartate aminotransferase (AST), and platelet count [12].

APRI is calculated by dividing the AST value by the upper limit of normal for this enzyme and multiplying by 100. The obtained value is then divided by the platelet count.

- APRI = (AST / upper limit of normal of AST) × 100 / platelet count (10^9/L).

FIB-4 uses basic biochemical values (AST, ALT, and platelet count) associated with age and is calculated using the following formula: in the numerator, age (in years) multiplied by the AST value (U/L), and in the denominator, the platelet count (10^9/L) multiplied by the square root of the ALT value (U/L).

- FIB-4 = age (years) × AST (U/L) / [platelet count (10^9/L) × √ALT (U/L)].

Categorical variables were presented as absolute and relative frequencies (n; %). For continuous variables, distribution was assessed using the Shapiro–Wilk normality test. Variables with a normal distribution were described as mean ± standard deviation (SD), while variables with a non-normal distribution were presented as median and interquartile range (IQR: P25–P75).

To investigate correlations between APRI and FIB-4 with demographic/temporal variables and with LE, correlations were estimated using Spearman's coefficient (r). Additionally, partial correlations (rank-based) were performed to assess the association between: current age and the non-invasive markers, adjusting for time elapsed between surgery and LE; and time since the Fontan procedure and the biochemical non-invasive markers, adjusting for current age. All analyses adopted a significance level of 5%.

To evaluate longitudinal changes between LE1 and LE2, paired tests were performed: for variables with non-normal distribution or presented as median (IQR), the paired Wilcoxon test (two-tailed) was used; for variables presented as mean ± SD, paired comparisons were performed using the paired t-test (two-tailed), maintaining $\alpha = 0.05$.

The study was approved by the Research Ethics Committee of the local radiology clinic and the Research Ethics Committee involving Human Subjects of the State University of Campinas (UNICAMP) on April 24, 2024, under protocol number 6,783,626.

RESULTS

A total of 32 patients with univentricular congenital heart disease who underwent the Fontan procedure and had LE performed during follow-up were evaluated. In this sample, there was a predominance of males (n = 20; 62.5%). Table 1 shows clinical and epidemiological profile of patients with univentricular congenital heart disease who underwent Fontan surgery.

Table 1
– Clinical and epidemiological profile of patients with univentricular congenital heart disease who underwent Fontan surgery.

Variable	Total (N = 32)
Fontan age (years) – Mean ± SD	3,75 ± 1,77
Age at the time of LE (years) – Mean ± SD	13,83 ± 8,18
Time between Fontan and LE (years) – Median (IQR)	4,62 (1,88–9,96)
AST (U/L) – Median (IQR)	25 (24–36)
ALT (U/L) – Median (IQR)	25 (24–34)
Platelet count (×10⁹/L) – Median (IQR)	250 (230–250)
Liver stiffness (kPa) – Mean ± SD	12,05 ± 2,49
APRI – Median (IQR)	0,30 (0,30–0,40)
FIB-4 – Median (IQR)	0,21 (0,14–0,39)
SD: standard deviation; LE: liver elastography; IQR: interquartile range; AST: aspartate aminotransferase; ALT: alanine aminotransferase; APRI: Aspartate Aminotransferase-to-Platelet Ratio Index; FIB-4: Fibrosis-4 index; kPa: kilopascals	

The non-invasive markers APRI and FIB-4 showed no evidence of association with age at the time of the Fontan procedure (APRI: r = 0.113; p = 0.539; FIB-4: r = 0.064; p = 0.728), nor with age at the time of LE evaluation (APRI: r = − 0.098; p = 0.593; FIB-4: r = 0.290; p = 0.108). Furthermore, there was no statistically significant association between APRI and FIB-4 and LS measured by LE (APRI: r = 0.207; p = 0.256; FIB-4: r = − 0.157; p = 0.390).

Among the initial sample (N = 32), 22 patients underwent longitudinal LE (two examinations, with an interval of at least 1 year between them). In this subgroup of paired samples, 13 patients (59.1%) were male. Table 2 shows longitudinal comparison of clinical, biochemical, and non-invasive liver fibrosis parameters between the first (LE1) and second (LE2) elastography evaluations.

Table 2
– Longitudinal comparison of clinical, biochemical, and non-invasive liver fibrosis parameters between the first (LE1) and second (LE2) elastography evaluations.

Variable	LE1	LE2	*p* value
Age at evaluation (years) – Mean ± SD	10.97 ± 7.36	14.29 ± 8,73	-
Time since Fontan (years) – Median (IQR)	4.62 (2.19–11.27)	7.18 (4.21–14.00)	-
AST (U/L) – Mean ± SD	33.78 ± 24.4	33.55 ± 13.95	-
ALT (U/L) – Mean ± SD	29.25 ± 12.31	34.14 ± 17.77	NR
Platelet count (×10⁹/L) – Mean ± SD	238.053 ± 41.07	256.14 ± 48.71	NR
Liver stiffness (kPa) – Mean ± SD	11.96 ± 2.45	11.57 ± 2.51	0.610
APRI – Mean ± SD	0.37 ± 0.27	0.35 ± 0.15	0.860
FIB-4 – Mean ± SD	0.28 ± 0.18	0.29 ± 0.16	0.406

SD: standard deviation; IQR: interquartile range; LE1: first liver elastography; LE2: second liver elastography; AST: aspartate aminotransferase; ALT: alanine aminotransferase; APRI: Aspartate Aminotransferase-to-Platelet Ratio Index; FIB-4: Fibrosis-4 index; NR: not reported.

DISCUSSION

In the cross-sectional analysis (N = 32), there was no significant association between LS measured by LE and the APRI and FIB-4 markers in post-Fontan patients. Similarly, a retrospective evaluation including 32 pediatric patients found a low correlation between LS (assessed by SWE) and the APRI and FIB-4 markers [19]. Another study including 27 pediatric and adult post-Fontan patients, which used liver histology as a reference, demonstrated that LS did not show good performance; however, APRI and FIB-4 showed good performance in predicting significant fibrosis [20]. This is largely due to the stratification of the sample into patients with and without advanced fibrosis, as well as the higher mean age of that sample compared to our study.

In the present study, APRI and FIB-4 did not show an association with age at the time of LE, nor with age at the time of the Fontan procedure. This may reinforce the low sensitivity of these markers in detecting the subtle and indolent progression of fibrosis that occurs over the years in FALD [21]. Furthermore, APRI and FIB-4 were validated for inflammatory liver diseases, in which the hepatocellular component plays a major role in disease progression. In our study, with a mean age at the time of Fontan of 3.75 years, the interpretation of FIB-4 must be performed with caution. This occurs because age is one of the components in the FIB-4 score and, when applied to very young children, its reduced numerical value tends to artificially produce low FIB-4 values, as observed in this series, in which the median ranged from 0.28 to 0.29. Thus, it is important to emphasize that the low FIB-4 value in this population may reflect, in part, a mathematical limitation of the score itself, rather than necessarily indicating the absence or

lesser severity of hepatic fibrosis. This particularity should be considered when interpreting and comparing FIB-4 results in pediatric patients. The pathophysiology of FALD is predominantly sinusoidal and congestive/ischemic in nature, rather than necro-inflammatory. Since patients present strictly normal transaminases, the APRI and FIB-4 scores remain low, even in the presence of elevated hepatic stiffness. A retrospective study demonstrated that although these markers show modest discrimination in detecting advanced fibrosis in FALD, they were not sufficiently accurate specifically in the pediatric population [22]. Thus, the LS values obtained probably reflect a combination of two distinct but related phenomena: structural tissue fibrosis and the mechanical effect of passive venous congestion. In this context, LS should be interpreted together with hemodynamic, clinical, laboratory, and radiological parameters, particularly those capable of reflecting the degree of venous congestion [14, 15].

The lack of correlation of non-invasive markers persists in longitudinal analyses (N = 22), with no significant variation in LS or in the APRI and FIB-4 markers between two distinct time points (LE1 and LE2). *Serai et al.* compared histology with MRE in 34 pediatric and adult patients. There was no correlation between these two variables; however, in the longitudinal analysis (N = 20), a significant association was found between increased LS and worsening histology over a 24-month period [23]. Another retrospective evaluation analyzed LS at two different points (before and after angioplasty with stent placement in the Fontan conduit) and also found no longitudinal difference in stiffness over 12.1 ± 8.9 months of follow-up [24]. In contrast to these longitudinal findings, in a multicenter study including 137 patients, FIB-4 performed 2 years after the Fontan procedure was a good independent predictor for the development of FALD after 10 years [25]. This study included patients with at least 3 years of follow-up, which is likely a determining factor explaining the difference from our findings. This type of longitudinal prognostic assessment may be fundamental in determining the optimal frequency of non-invasive marker evaluation in the management of these patients.

Among the limitations of this study, it is important to highlight the relatively small sample size; however, this is a rare and poorly understood condition. In addition, the sample was selected from a single center, retrospectively, and with a limited follow-up period. Furthermore, the lack of comparison between non-invasive methods and histology is a limitation of the study, but also an inherent limitation in FALD.

This finding reinforces the urgent need for integrated protocols combining LS with other non-invasive markers associated with hemodynamic and radiological variables. Multicenter efforts would facilitate the standardization of accurate FALD diagnosis and the most appropriate strategies for monitoring these patients.

CONCLUSIONS

In this case series of patients with Fontan circulation and FALD, LS assessed by LE did not correlate with the APRI and FIB-4 markers, in both cross-sectional and longitudinal analyses.

Abbreviations

SVC
superior vena cava
RPA
right pulmonary artery
IVC
inferior vena cava
CVP
central venous pressure
PVR
pulmonary vascular resistance
FALD
Fontan-Associated Liver Disease
PH
portal hypertension
HCC
hepatocellular carcinoma
APRI
Aspartate Aminotransferase-to-Platelet Ratio Index
FIB-4
Fibrosis-4 index
LE
liver elastography
MRE
Magnetic Resonance Elastography
TE
Transient Elastography
SWE
Shear-Wave Elastography
LS
liver stiffness
kPa
kilopascals
ALT
alanine aminotransferase
AST
aspartate aminotransferase
SD
standard deviation
IQR
interquartile range

Declarations

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Authors' contribution

Lucas R. Alvarenga and Pietra R. Möller conceptualized the article, obtained REB approval and collected the data.

Lucas Rocha Alvarenga and Cacilda P. Oliveira drafted the initial manuscript, reviewed and revised the manuscript, approved the final draft as submitted.

Dr. Maria Angela Bellomo-Brandão supervised throughout all the different phases of this study, analyzed the data, reviewed and revised the manuscript, and approved the final draft as submitted.

Ethics Approval and Consent to Participate:

The study was approved by the Human Research Ethics Committee of the local radiology clinic and the Research Ethics Committee of the State University of Campinas (UNICAMP) on April 24, 2024, under protocol number 6,783,626. The requirement for informed consent to participate was waived by the Ethics Committee, and therefore individual informed consent was not required for this study. All procedures involving human participants were conducted in accordance with the ethical standards of the institutional and/or national research committee and with the principles of the Declaration of Helsinki.

Consent to Participate Declaration:

Not applicable.

Consent for Publication:

Not applicable.

Availability of Data and Materials:

Not applicable.

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