

2019-01-25

# Accuracy of FibroScan Controlled Attenuation Parameter and Liver Stiffness Measurement in Assessing Steatosis and Fibrosis in Patients With Non-alcoholic Fatty Liver Disease.

Eddowes, PJ

<http://hdl.handle.net/10026.1/13286>

---

10.1053/j.gastro.2019.01.042

Gastroenterology

Elsevier

---

*All content in PEARL is protected by copyright law. Author manuscripts are made available in accordance with publisher policies. Please cite only the published version using the details provided on the item record or document. In the absence of an open licence (e.g. Creative Commons), permissions for further reuse of content should be sought from the publisher or author.*

1 **Title:** Accuracy of FibroScan Controlled Attenuation Parameter and Liver Stiffness  
2 Measurement in Assessing Steatosis and Fibrosis in Patients With Non-alcoholic Fatty Liver  
3 Disease

4  
5  
6 **Short title:** Diagnostic accuracy of CAP and LSM in NAFLD patients

7  
8 Peter J Eddowes<sup>1,2,3,4</sup>, Magali Sasso<sup>5</sup>, Michael Allison<sup>6</sup>, Emmanuel Tsochatzis<sup>7</sup>, Quentin M  
9 Anstee<sup>8</sup>, David Sheridan<sup>9</sup>, Indra N Guha<sup>4</sup>, Jeremy F Cobbold<sup>10</sup>, Jonathan J Deeks<sup>11</sup>, Valérie  
10 Paradis<sup>12</sup>, Pierre Bedossa<sup>12</sup>, Philip N Newsome\*<sup>1,2,3</sup>.

11  
12 <sup>1</sup>National Institute for Health Research Biomedical Research Centre at University Hospitals  
13 Birmingham NHS Foundation Trust and the University of Birmingham

14 <sup>2</sup>Centre for Liver and Gastrointestinal Research, Institute of Immunology and  
15 Immunotherapy, University of Birmingham

16 <sup>3</sup>Liver Unit, University Hospitals Birmingham NHS Foundation Trust, Birmingham

17 <sup>4</sup>National Institute for Health Research Nottingham Biomedical Research Centre, Nottingham  
18 University Hospitals NHS Trust and University of Nottingham, Nottingham, United  
19 Kingdom

20 <sup>5</sup>Echosens, R&D department, Paris, France

21 <sup>6</sup>Liver Unit, Addenbrooke's Hospital, Cambridge Biomedical Research Centre, Cambridge,  
22 United Kingdom

23 <sup>7</sup>University College London Institute for Liver and Digestive Health, Royal Free Hospital,  
24 London, United Kingdom

1 <sup>8</sup>Institute of Cellular Medicine, Faculty of Medical Sciences, Newcastle University,  
2 Newcastle upon Tyne, United Kingdom

3 <sup>9</sup>Institute of Translational and Stratified Medicine, Faculty of Medicine and Dentistry,  
4 University of Plymouth, United Kingdom

5 <sup>10</sup>Department of Gastroenterology and Hepatology, Oxford University Hospitals NHS  
6 Foundation Trust, John Radcliffe Hospital, Oxford, United Kingdom

7 <sup>11</sup>National Institute for Health Research Biomedical Research Centre at University Hospitals  
8 Birmingham NHS Foundation Trust and the Institute of Applied Health Research, University  
9 of Birmingham

10 <sup>12</sup>Department of Pathology, Physiology and Imaging, Beaujon Hospital Paris Diderot  
11 University, Paris, France

12

13

14 Grant support: This work was funded by Echosens who were sponsors of this study. PJE and PNN were  
15 supported by the National Institute of Health Research (NIHR) Birmingham Biomedical Research  
16 Centre (BRC). JFC was supported by the National Institute for Health Research (NIHR) Oxford  
17 Biomedical Research Centre (BRC). ING was supported by the National Institute for Health Research  
18 (NIHR) Nottingham Biomedical Research Centre (BRC). The views expressed are those of the authors  
19 and not necessarily those of the NHS, the NIHR or the Department of Health.

20

21

1 **Abbreviations:**

- 2 A2M: alpha-2 macroglobulin
- 3 ALT: alanine transaminase
- 4 AST: aspartate aminotransferase
- 5 AUROC: area under the receiver operating characteristic curve
- 6 BIC: Bayesian information criteria
- 7 CAP: controlled attenuation parameter
- 8 CI: confidence interval
- 9 CK18-M30: cytokeratin 18 neo-epitope M30
- 10 CRP: C-reactive protein
- 11 FLIP: fatty liver: inhibition of progression
- 12 FN: false negative
- 13 FP: false positive
- 14 GGT: gamma-glutamyl transferase
- 15 HDL: high-density lipoprotein
- 16 HSI: hepatic steatosis index
- 17 IQR: interquartile range
- 18 INR: international normalized ratio
- 19 LDL: low-density lipoprotein
- 20 LB: liver biopsy
- 21 LR+: positive likelihood ratio
- 22 LR-: negative likelihood ratio
- 23 LSM: liver stiffness measurement
- 24 NAFL: non-alcoholic fatty liver

- 1 NAFLD: non-alcoholic fatty liver disease
- 2 NAS: non-alcoholic fatty liver disease activity score
- 3 NASH: non-alcoholic steato-hepatitis
- 4 NFS: NAFLD fibrosis score
- 5 NPV: negative predictive value
- 6 PPV: positive predictive value
- 7 ROC: receiver operating characteristic
- 8 SAF: steatosis activity fibrosis
- 9 Se: sensitivity
- 10 Sp: specificity
- 11 STARD: standards for reporting of diagnostic accuracy studies
- 12 TN: true negative
- 13 TP: true positive
- 14 VCTE: vibration-controlled transient elastography
- 15

1 \* Corresponding Author

2 Professor Philip Newsome

3 NIHR Birmingham Biomedical Research Centre and Centre for Liver and Gastrointestinal Research

4 5th Floor Institute of Biomedical Research

5 University of Birmingham

6 Birmingham

7 B15 2TT

8 UK

9 Telephone: +44-121-415-8700

10 Fax: +44-121-415-8701

11 Email: P.N.Newsome@bham.ac.uk

12

13 Disclosures: No relevant disclosures.

14

15 Author contributions: PNN had the original concept and contributed to the design of the study protocol.

16 PJE, with the assistance of the other recruiting sites performed the study and generated all of the data for

17 the manuscript. MS, on behalf of the sponsor, performed the statistical analysis. PNN and MS wrote the

18 first draft of the manuscript, and all authors reviewed the final version. PNN is guarantor.

19

20

1 **Abstract**

2 **Background & Aims:** We estimated the accuracy of FibroScan vibration-controlled transient  
3 elastography controlled attenuation parameter (CAP) and liver stiffness measurements  
4 (LSMs) in assessing steatosis and fibrosis in patients with suspected NAFLD.

5  
6 **Methods:** We collected data from 450 consecutive adults who underwent liver biopsy  
7 analysis for suspected NAFLD at 7 centers in the United Kingdom from March 2014 through  
8 January 2017. FibroScan examinations with M or XL probe were completed within the 2  
9 weeks of the biopsy analysis (404 had a valid examination). The biopsies were scored by 2  
10 blinded expert pathologists according to non-alcoholic steatohepatitis clinical research  
11 network criteria. Diagnostic accuracy was estimated using the area under the receiver  
12 operating characteristic curves (AUROC) for the categories of steatosis and fibrosis. We  
13 assessed effects of disease prevalence on positive and negative predictive values. For LSMs,  
14 the effects of histological parameters and probe type were appraised using multivariable  
15 analysis.

16  
17 **Results:** Using biopsy analysis as the reference standard, we found that CAP identified  
18 patients with steatosis with an AUROCs of 0.87 (95% CI, 0.82–0.92) for  $S \geq S1$ , 0.77 (95%  
19 CI, 0.71–0.82) for  $S \geq S2$ , and 0.70 (95% CI, 0.64–0.75) for  $S = S3$ . Youden cut-off values for  
20  $S \geq S1$ ,  $S \geq S2$  and  $S \geq S3$  were 302 dB/m, 331 dB/m and 337 dB/m respectively. LSM identified  
21 patients with fibrosis with AUROCs of 0.77 (95% CI, 0.72–0.82) for  $F \geq F2$ , 0.80 (95% CI,  
22 0.75–0.84) for  $F \geq F3$ , and 0.89 (95% CI, 0.84–0.93) for  $F = F4$ . Youden cut-off values for  
23  $F \geq F2$ ,  $F \geq F3$  and  $F = F4$  were 8.2 kPa, 9.7 kPa, and 13.6 kPa respectively. Applying the  
24 optimal cut-off values, determined from this cohort, to populations of lower fibrosis  
25 prevalence increased negative predictive values and reduced positive predictive values.  
26 Multivariable analysis found that the only parameter that significantly affect LSMs was  
27 fibrosis stage ( $P < 10^{-16}$ ); we found no association with steatosis or probe type.

28  
29 **Conclusions:** In a prospective analysis of patients with NAFLD, we found CAP and LSMs  
30 by FibroScan to assess liver steatosis and fibrosis, respectively, with AUROC values ranging  
31 from 0.7 to 0.89. Probe type and steatosis did not affect LSMs.

32  
33 **KEY WORDS:** VCTE, NASH, non-invasive, biomarker

1 **Study registration:** ClinicalTrials.gov Identifier: NCT01985009.

2 **Background & Aims:**

3 Non-alcoholic fatty liver disease is an increasingly common cause of chronic liver disease,  
4 and is expected to soon become the commonest indication for liver transplantation<sup>1, 2</sup>.  
5 Estimates of its prevalence vary from 20-40% in the general population, although only 1-3%  
6 have evidence of significant inflammation and fibrosis<sup>3</sup>. The presence of liver fibrosis in  
7 particular is an important predictor of clinical events, both in terms of overall mortality and  
8 also liver-related morbidities and mortality<sup>4, 5</sup>. The challenge therefore remains how to  
9 identify those individuals with NAFLD that have more significant pathology in a manner  
10 which is non-invasive and affordable by healthcare systems.

11

12 Vibration-controlled transient elastography (VTCE) is one such approach which is in  
13 widespread clinical usage and for which there is an increasing understanding of clinically  
14 relevant cut-off values. By the use of a pulse-echo ultrasonic acquisition, vibration-controlled  
15 transient elastography (VCTE) can quantify the speed of a mechanically induced shear wave  
16 in liver tissue and hence generate an estimate of the degree of liver fibrosis with a liver  
17 stiffness measurement (LSM)<sup>6, 7</sup>. More recently this has been supplemented by the ability to  
18 quantify hepatic steatosis by measuring ultrasonic attenuation of the echo wave, termed the  
19 controlled attenuation parameter (CAP)<sup>8, 9</sup>, which has been compared to liver biopsy in  
20 prospective studies with the M probe<sup>10-12</sup>.

21

22 Previous studies have demonstrated the limitations of the M probe in patients with an  
23 increased skin to liver capsular distance as can occur commonly in NAFLD and  
24 overweight/obese patients<sup>13, 14</sup>; there is a much higher failure rate which led to the



1 development of the XL probe. However, much of the published literature with the XL probe  
2 and CAP consists of either retrospective<sup>15</sup> or small/medium prospective cohort studies<sup>16-19</sup>,  
3 with the exception of the recent NASH CRN studies<sup>20, 21</sup>. However, none have been the  
4 subject of large prospective powered diagnostic studies adhering to standards for reporting of  
5 diagnostic accuracy studies (STARD) guidelines<sup>22</sup>.

6

7 Importantly, there are still uncertainties about the impact of other histological features on  
8 LSM readings with reports suggesting that steatosis may be a contributor<sup>23, 24</sup>, although these  
9 studies were limited in that only the M probe was used. Similarly, whilst the advent of the XL  
10 probe has markedly reduced the failure rate in overweight/obese individuals<sup>25</sup>, there are  
11 reports suggesting that cut-off ranges differ according to probe choice<sup>26</sup>.

12

13 We designed a large prospective diagnostic study across 7 centres in the United Kingdom to  
14 evaluate the diagnostic accuracy of CAP measured either with the M or XL probe (depending  
15 on the FibroScan device automatic probe recommendation tool) in patients being investigated  
16 for potential NAFLD compared to a reference standard of histological evaluation of steatosis.  
17 The secondary objectives were to evaluate the diagnostic accuracy of LSM (with either M or  
18 XL probe) compared to a reference standard based on histological evaluation of fibrosis, and  
19 study of impact of histological parameters and probe type on LSM reading. In addition we  
20 aimed to identify cutoffs for use in clinical practice with both CAP and LSM.

21

## 1 **Methods**

### 2 *Study participant and design*

3 The study was a cross-sectional prospective multi-centre study, with the primary and  
4 secondary outcomes being to assess the diagnostic accuracy of CAP and LSM against liver  
5 histology which is the gold standard to evaluate the liver steatosis and fibrosis. NAFLD was  
6 suspected on the basis of the presence of abnormal liver enzymes in the presence of an  
7 ultrasound scan showing and echobright liver was the principle reason, usually in the  
8 presence of metabolic syndrome components. The STARD guidelines were followed to  
9 report the methods and results of this study<sup>22</sup> (see Supplementary Table 1 for further details).  
10 Consecutive patients were prospectively recruited between March 2014 and January 2017 in  
11 7 liver centres across the United Kingdom (University Hospitals Birmingham NHS  
12 Foundation Trust, Birmingham; Addenbrooke's Hospital, Cambridge; Royal Free Hospital,  
13 London; Freeman Hospital, Newcastle upon Tyne; University Hospitals Plymouth NHS  
14 Trust, Plymouth; Queen's Medical Centre, Nottingham and John Radcliffe Hospital, Oxford).

15  
16 The study (NCT01985009) was approved by the North Wales Research Ethics Committee  
17 (13/WA/0385) and by the Local Research Ethics Committee at each centre. All patients gave  
18 written informed consent to participate in the study. The study was conducted in accordance  
19 with the declaration of Helsinki and in agreement with the International Conference on  
20 Harmonisation (ICH) guidelines on Good Clinical Practice (GCP). All authors had access to  
21 the study data and reviewed and approved the final manuscript.

22  
23 Main analyses: The primary outcome of the protocol was to evaluate the diagnostic accuracy  
24 of CAP measured either with the M or XL probe (depending on the FibroScan device  
25 automatic probe recommendation tool) against histological evaluation of steatosis. A

1 secondary outcome of the protocol was to evaluate the diagnostic accuracy of liver stiffness  
2 measured either with M or XL probe (depending on the FibroScan device automatic probe  
3 recommendation tool) against histological evaluation of fibrosis.

4

#### 5 *Inclusion and exclusion criteria*

6 Inclusion criteria were as follows: patients were  $\geq 18$  years of age, able to give written  
7 informed consent and were scheduled, independently from this study, to have a liver biopsy  
8 (LB) for investigation of assumed NAFLD within 2 weeks of Fibroscan examination (before  
9 or after). Patients were also negative for HBsAg, anti-HCV, HCV-RNA and HBVDNA.  
10 Exclusion criteria were as follows: patients with ascites, pregnant women, patient with any  
11 active implantable medical device (such as pacemaker or defibrillator), patients who had  
12 undergone liver transplantation, patients with cardiac failure and/or significant valvular  
13 disease, patients with haemochromatosis, patients that refused to undergo liver biopsy or  
14 blood tests, patients with an alcohol consumption above recommended limits ( $>14$  units/week  
15 for women and  $>21$  units/week for men; 1 unit = 8 g of ethanol), patients with a confirmed  
16 diagnosis of active malignancy, or other terminal disease, patient participating in another  
17 clinical trial within the preceding 30 days.

18

#### 19 *Patient Characteristics*

20 The following characteristics were recorded for each patient: age, gender, BMI, presence of  
21 diabetes, hypertension, and hypercholesterolemia. For each patient, a 12 hour fasting blood  
22 collection was performed locally on the same day of the FibroScan procedure and was then  
23 shipped to a central laboratory for assessment of the following laboratory parameters:  
24 platelets count, international normalized ratio (INR), aspartate transaminase (AST), alanine  
25 transaminase (ALT), gamma-glutamyl-transferase (GGT), alkaline phosphatase, albumin,

1 bilirubin, fasting glucose, total cholesterol, high density lipoprotein (HDL) cholesterol, low  
2 density lipoprotein (LDL) cholesterol, triglyceride, ferritin, urea, creatinine, alpha-2-  
3 macroglobulin (A2M), hyaluronic acid, C-reactive protein (CRP) and cytokeratin 18 neo-  
4 epitope M30 (CK18-M30).

5

#### 6 *Histopathologic evaluation*

7 Percutaneous LB was performed on all patients according to local standard procedure LB  
8 specimens were fixed in formalin, embedded in paraffin and stained with Hematoxylin and  
9 Eosin and Sirius Red for fibrosis evaluation. Slides were analysed independently by two  
10 experienced pathologists (PB and VP) who were blinded to each other's reading and also to  
11 the patient's clinical and Fibroscan data if available. In case of disagreement, they reviewed  
12 the slides together to reach consensus.

13

14 Steatosis (from 0 to 3), ballooning (from 0 to 2), lobular inflammation (from 0 to 3), fibrosis  
15 (from 0 to 4) and NAFLD activity score (NAS) were scored using the NASH clinical  
16 research network (NASH CRN) scoring system <sup>27</sup>. NASH was diagnosed using the "fatty  
17 liver: inhibition of progression" (FLIP) definition (presence of steatosis, hepatocyte  
18 ballooning and lobular inflammation with at least 1 point for each category). In addition,  
19 steatosis was semi-quantitatively assessed in percentage and the activity score (Ballooning  
20 (0-2) plus lobular inflammation (0-2)) according to the Steatosis Activity Fibrosis (SAF) was  
21 also assessed <sup>28</sup>. The presence of portal inflammation was also recorded. Biopsies were  
22 categorised by the pathologists as normal liver (no liver pathology), NAFL (steatosis but no  
23 NASH), NASH or other diagnosis when no NAFLD but other histological features suggestive  
24 of another diagnostic were observed (*e.g.* granulomatous hepatitis, biliary disease,  
25 autoimmune hepatitis). Interpretability for liver biopsy was based on the standard criteria of

1 length, width and lack of major fragmentation. These criteria were occasionally over-looked  
2 by the pathologist when the biopsy showed obvious histological criteria of NASH, septal  
3 fibrosis or cirrhosis even if the biopsy was small or fragmented.

4

5 *FibroScan liver stiffness measurement and controlled attenuation parameter*

6 FibroScan (Echosens, Paris, France) examination was performed in each centre by nurses or  
7 physicians trained and certified by the manufacturer and blinded to the patient's histological  
8 evaluation. The FibroScan used in each center was a FibroScan 502 Touch model, equipped  
9 with both M and XL probes. An automatic probe selection tool was embedded in the device  
10 software which recommends the appropriate probe for each patient according to the real time  
11 assessment of the skin to liver capsule distance. The FibroScan examination procedure has  
12 been detailed previously<sup>6, 29</sup>. Briefly, all patients were asked to fast at least 3 hours prior to  
13 the examination, and then placed in the supine position with their right arm fully abducted.  
14 Measurements were performed by scanning the right liver lobe through an intercostal space.

15

16 The FibroScan device simultaneously measures LSM and CAP using VCTE technology.  
17 CAP has been designed to measure liver ultrasonic attenuation (go and return path) at 3.5  
18 MHz on both M and XL probes<sup>8</sup>, on signals acquired by the Fibroscan. The principle of CAP  
19 measurement has been described elsewhere<sup>8, 9</sup>, and CAP was computed only when the  
20 associated LSM was valid and using the same signals as the one used to measure liver  
21 stiffness. At the beginning of the study, CAP was not available on the XL probe, therefore,  
22 the raw ultrasonic radio-frequency signals were stored in the Fibroscan examination file to  
23 enable computation of CAP off-line. CAP computation was performed blinded to all patients'  
24 clinical and histological data using the exact same configuration and algorithm to the one  
25 embedded in the commercial device for N=116 patients. When CAP was commercially

1 available for the XL probe, all software were updated and the CAP value was displayed on  
2 the device screen for both probes during the procedure. The final CAP and LSM results were  
3 expressed in dB/m and kPa respectively. Only examinations with at least 10 valid individual  
4 measurements were deemed valid.

5

## 6 *Statistical Analysis*

7 Sample size estimation: Since no study had been performed previously using the probe  
8 recommendation on the FibroScan device, the sample size was calculated for patient  
9 measured with the XL probe only. It was hypothesized that approximately 1/3 of the total  
10 patients would be measured with M probe. Given the expected performance of CAP to detect  
11 steatosis ( $S \geq S1$ ) with an AUROC  $\geq 0.80$ <sup>9, 30, 31</sup>, a projected sample size of 212 patients was  
12 deemed necessary to estimate an AUROC of 0.80 with the XL probe with an  $(1-\alpha)$   
13 confidence interval,  $\alpha$  being set to 5%, at a 5% standard error level, for the XL probe only.  
14 The total number of patients measured using both probes was set to 312 patients and the final  
15 number of patients was set at 450 assuming a 30% drop-out rate

16

17 For descriptive statistics, continuous variables were expressed as medians [interquartile range  
18 (IQR)] and categorical variables as absolute figures with percentages. Confidence intervals  
19 were reported at the 95% level. Evidence for differences between CAP and LSM between  
20 steatosis grades and fibrosis stages was assessed using Kruskal-Wallis test followed by  
21 Dunn's tests with *post hoc* comparison. P values of  $< 0.05$  were considered statistically  
22 significant.

23

24 Overall diagnostic accuracy of CAP and LSM was estimated as the area under the ROC curve  
25 (AUROC) together with its 95% confidence interval (CI). Data are reported for thresholds of

1 steatosis and fibrosis. Cut-off values for CAP and LSM were identified that (a) maximise the  
2 Youden index, and also (b) at fixed values of sensitivity and specificity of 90%. For each cut-  
3 off value, we reported sensitivity (Se), specificity (Sp), positive predictive value (PPV),  
4 negative predictive value (NPV), positive likelihood ratio (LR+), negative likelihood ratio  
5 (LR-) together with 95% confidence intervals. In additional analyses we investigated the  
6 performance of the tests in settings with different prevalence using Bayes equation to  
7 estimate post-test probabilities from the estimated likelihood ratios. For these computations  
8 we focused on fibrosis thresholds of  $F \geq F2$  and  $F=4$  which are of particular importance as they  
9 correspond with stages which result in changes in patient management. We also identified  
10 cutoffs which minimized the consequences of test errors across different relative weightings  
11 of false positives and false negatives (see Supplementary Methods).

12

13 Factors influencing LSM: To evaluate the impact of histological parameters that possibly  
14 influenced LSM, a multivariable linear regression model was constructed with fibrosis stage,  
15 steatosis grade, ballooning grade, lobular inflammation and portal inflammation as candidate  
16 covariates and LSM as the outcome variable. In addition, the probe type used (M or XL) was  
17 also entered as a candidate covariate to evaluate if it had an impact on LSM when adjusted on  
18 histological parameters. All first order interactions were entered into the model. LSM was  
19 Box-Cox transformed to approximate a normal distribution. Final model selection was  
20 performed with a backward elimination procedure based on Bayesian information criteria  
21 (BIC). Multi-collinearity of independent variables was checked using the variance inflation  
22 factor. In addition to this multivariable analysis, LSM versus fibrosis stage stratified by  
23 probe type and by semi-quantitative steatosis percentage quartile was represented using a  
24 boxplot. Univariate analysis was performed using Kendall rank correlation coefficient

1 between each histological parameter and LSM and was performed using the Mann-Whitney  
2 U test between the probe type and LSM.

3

4 The sensitivity analyses on CAP and LSM diagnostic accuracy and the analyses relative to  
5 the influence of disease prevalence on PPV and NPV, the cutoffs which minimized the  
6 consequences of test errors across different relative weightings of false positives and false  
7 negatives and factors influencing LSM were exploratory analyses which were not pre-  
8 specified.

9

10 For all analyses, only patients with histological results and median LSM or CAP values  
11 available with at least ten valid measurements were analyzed. In addition, no replacement of  
12 missing data has been performed. All analyses were performed using the software R, version  
13 3.3.0<sup>32</sup>.

14

15



## 1 **Results**

### 2 *Patient Characteristics*

3 The study flow chart is represented in Figure 1. Table 1 details the clinical, serological,  
4 histological characteristics and Fibroscan data of 383 patients with a valid FibroScan reading  
5 and an interpretable liver biopsy.

6

### 7 *FibroScan applicability*

8 Of 415 patients evaluated using the FibroScan (Figure 1), 138 (33%) were with the M probe  
9 and 277 (67%) with the XL probe. FibroScan readings were valid (with at least 10 valid  
10 individual measurements as per the manufacturer's recommendations) in 404 patients leading  
11 to an applicability value of 97%. For the 11 patients for whom a valid FibroScan was not  
12 achieved; 2 were with the M probe and 9 with the XL probe. Of note 4 of these 11 patients  
13 had 9 valid measurements (rather than the 10 required). Patients with less than 9 valid  
14 measurements (n=7) had a significantly higher BMI than others (46.5 [13.6] kg.m<sup>-2</sup> versus  
15 36.4 [9.2] kg.m<sup>-2</sup>; P = 0.003). Within the 404 patients with valid FibroScan, patients assessed  
16 with the XL probe (N=268) had a significantly higher BMI than patients measured by the M  
17 probe (36.3 [7.8] kg.m<sup>-2</sup> versus 29.3 [4.7] kg.m<sup>-2</sup>; P < 10<sup>-16</sup>). No adverse event has been  
18 reported related to the use of the FibroScan device.

19

### 20 *Liver biopsies*

21 A total of 412 patients underwent LB (see Figure 1: 433 eligible patients minus 16 patients  
22 who did not have LB, 4 patients who had LB cancelled by the investigator and 1 patient who  
23 withdrew consent before LB). The LB slides of 3 patients were lost during shipment and a  
24 further 15 LB were judged as non-interpretable by the pathologist leaving 394 (96%) as  
25 having an interpretable LB. A further ten patients had a LB that although interpretable by the

1 pathologist could not be staged according to the NASH CRN scoring system. A description  
2 of those LB is provided in Supplementary Table 2 (2 patients being NAFLD with associated  
3 lesions and 8 being not NAFLD but not normal liver). Of note, 33 patients (8% of the patients  
4 with interpretable LB) had a histological diagnosis other than NAFLD or normal liver. A  
5 description of those LB is provided in Supplementary Table 2. After LB, 3 adverse events  
6 were reported: 1 patient had a syncopal episode following LB and pain at LB site requiring  
7 oral analgesia, 1 patient had hemorrhage following LB requiring hospitalization and 1 patient  
8 was admitted with pain and fever.

9

#### 10 *Assessment of steatosis using controlled attenuation parameter*

11 Of 415 patients, 380 patients had an interpretable liver biopsy and valid CAP values (Figure  
12 1). According to histological assessment, steatosis grade distribution was as follows: S0 = 47  
13 (12%), S1 = 89 (23%), S2 = 107 (28%), S3 = 137 (36%) and the boxplot of CAP versus  
14 steatosis grade is shown in Figure 2a. CAP was significantly different between S0, S1 and S2  
15 but not S2 and S3 (Kruskal-Wallis  $H = 97.70$ ,  $P < 10^{-16}$ ; Dunn's post hoc tests,  $P = 0.19$   
16 between CAP in S2 and CAP in S3,  $P < 10^{-3}$  otherwise). Areas under the ROC curve  
17 (AUROC) as well as diagnostic performance of CAP cut-off values optimized using  
18 Youden's index, a sensitivity of 90% or a specificity of 90% are detailed in Table 2 for S0  
19 versus S1 and above, S0-S1 versus S2-S3 and S0-S2 versus S3. Accuracy was highest at the  
20  $S \geq S1$  threshold, with an AUROC of 0.87 (95% CI: 0.82-0.92) and sensitivity of 0.80 (0.75-  
21 0.84) and specificity of 0.83 (0.69-0.92) at a threshold of 302 dB/m selected by maximizing  
22 Youden's Index. Accuracy dropped to an AUC of 0.77 (0.71-0.82) for the  $S \geq S2$  threshold,  
23 with the corresponding sensitivity of 0.70 (0.63-0.75) and specificity of 0.76 (0.68-0.83) at  
24 the threshold of 331 dB/m maximizing Youden's index and to an AUROC of 0.70 (0.64-  
25 0.75) for the  $S = S3$  threshold with the corresponding sensitivity of 0.72 (0.63-0.79) and a

1 specificity of 0.63 (0.56-0.69) at the threshold of 337 dB/m maximizing Youden's index.  
2 The ROC plots for  $S \geq S1$ ,  $S \geq S2$  and  $S=S3$  are given in Supplementary Figure 1. Performance  
3 of CAP to diagnose NASH was also assessed. Corresponding AUC was 0.71 (0.65-0.76).  
4  
5 The use of quality criteria based on the IQR of CAP as proposed by Caussy *et al*<sup>33</sup> and Wong  
6 *et al*<sup>34</sup> which recommend excluding patients with IQR of CAP greater or equal to 30 dB/m or  
7 40 dB/m, respectively was tested in our cohort. A large proportion of patients had an IQR of  
8  $CAP \geq 30$  or 40 dB/m (57% and 39%, respectively), and performance was no better in  
9 patients with an IQR of CAP  $< 30$  or  $< 40$  dB/m (Supplementary Table 3). Indeed for the  
10 diagnosis of higher stages of steatosis performance was even lower in patient with an IQR of  
11  $CAP < 30$  or  $< 40$  dB/m. To determine the influence of serum ALT on CAP diagnostic  
12 performance patients were stratified by ALT values ( $\leq$ ULN, between ULN and 2xULN and  
13  $> 2x$ ULN), but this did not influence CAP AUROCs (Supplementary Table 4). Performance  
14 of CAP was compared to the hepatic steatosis index (HSI)<sup>35</sup> in a subset of patients (N=375,  
15 due to 5 missing biological data). CAP significantly outperformed HSI for each steatosis  
16 grade  $S \geq S1$ ,  $S \geq S2$  and  $S=S3$  (Supplementary Table 5).

17

#### 18 *Assessment of fibrosis using liver stiffness measurement*

19 Of the 384 patients with valid LSM and interpretable LB, only 373 had fibrosis interpretable  
20 according to the NASH CRN scoring system (Figure 1). Differences in characteristics  
21 between the 373 patients used for fibrosis staging analysis and the 10 patients with fibrosis  
22 not staged are given in Supplementary Table 6.

23

24 Fibrosis stage distribution was as follows: F0: 62 (17%), F1: 86 (23%), F2: 85 (23%), F3:  
25 106 (28%), F4: 34 (9%). LSM versus fibrosis stage is presented as a boxplot in Figure 2b.

1 LSM was significantly different between all fibrosis stages with the exception of F0 and F1  
2 (Kruskal-Wallis  $H = 119.8$ ,  $P < 10^{-16}$ ; Dunn's post hoc tests,  $P = 1$  between LSM in F0 and  
3 LSM in F1,  $P < 0.05$  otherwise). AUC as well as diagnostic performance of LSM cut-off  
4 values optimized using Youden's index, a sensitivity of 90% or a specificity of 90% are  
5 detailed in Table 3 for F0-F1 versus F2 and above, F0-F2 versus F3-F4 and F0-F3 versus F4.  
6 Accuracy was highest at the  $F=F4$  threshold, with an AUC of 0.89 (95% CI: 0.84-0.93) and  
7 sensitivity of 0.85 (0.69-0.95) and specificity of 0.79 (0.74-0.83) at a threshold of 13.6 kPa  
8 selected by maximizing Youden's Index. Accuracy was lower at lower fibrosis thresholds  
9 dropping to an AUROC of 0.80 (0.75-0.84) for  $F \geq F3$  with the corresponding sensitivity of  
10 0.71 (0.62-0.78) and a specificity of 0.75 (0.69-0.80) at a threshold of 9.7 kPa maximizing the  
11 Youden's index and to an AUROC of 0.77 (0.72-0.82) for the  $F \geq F2$  threshold, with the  
12 corresponding sensitivity of 0.71 (0.64-0.77) and specificity of 0.70 (0.62-0.77) at the  
13 threshold of 8.2 kPa maximizing the Youden's index. The ROC plots for  $F \geq F2$ ,  $F \geq F3$  and  
14  $F=F4$  are given in Supplementary Figure 2. Performance of LSM to diagnose NASH was also  
15 assessed. Corresponding AUC was 0.68 (0.62-0.74).

16

17 The performance of the Boursier criteria<sup>36</sup> as a quality control for Fibroscan were evaluated  
18 in this cohort (IQR/median < 30% in patient with  $LSM \geq 7.1$  kPa). Whilst 43 (12%) patients did  
19 not reach the Boursier criteria, analysis in this cohort did not find evidence that these criteria  
20 improved performance of Fibroscan (Supplementary Table 7) where we have assessed  
21 AUROC for patients reliable according to Boursier's criteria only. The influence of ALT on  
22 LSM diagnostic performance was evaluated by stratifying patients on ALT values ( $\leq$ ULN,  
23 between ULN and 2xULN and  $>2x$ ULN). No significant influence of the effect of ALT on  
24 the LSM AUROC for each fibrosis stage was observed (Supplementary Table 8). The  
25 performance of the Baveno VI cut-offs<sup>37</sup>, in relation to patients with compensated advanced

1 chronic liver disease with advanced fibrosis ( $F \geq F3$ ) were tested in this cohort. The NPV  
2 associated with the  $\leq 10$  kPa cutoff was 0.80 and the PPV associated with the  $\geq 15$  kPa cutoff  
3 was 0.75.

4 Performance of LSM was also compared to Fib4<sup>38</sup> and the NAFLD fibrosis score (NFS<sup>39</sup>).  
5 Diagnostic performance in terms of AUROC for each fibrosis stage ( $\geq F2$ ,  $F \geq F3$  and  $F = F4$ )  
6 are provided in Supplementary Table 9. LSM outperformed Fib4 and NFS for the diagnosis  
7 of cirrhosis and NFS for the diagnosis of  $F \geq 2$ . For the diagnosis of advanced fibrosis,  
8 performance of LSM was compared using the dual cut-offs (cut-off for  $Se \geq 0.90 = 7.1$  kPa  
9 and cut-off for  $Sp \geq 0.90 = 14.1$  kPa determined in the present cohort) against the dual cut-offs  
10 for Fib4 (1.30 and 3.25)<sup>38</sup> and NFS (-1.455 and 0.676)<sup>39</sup>. LSM had a higher Se for the  
11 confirmation of advanced fibrosis ( $F \geq 3$ ) with a PPV = 0.74 (Supplementary Table 10).

12

13 Further analysis was performed to identify cutoffs which minimized the consequences of test  
14 errors across different relative weightings of false positives and false negatives (see  
15 Supplementary Results and Supplementary Table 11). In these analyses the consequences of  
16 diagnostic error were explored in situations where the priority was to either avoid false  
17 positive diagnoses (for the diagnostic of  $F \geq F2$ ) or false negative diagnoses (for the diagnostic  
18 of  $F = F4$ ). The analyses were performed under a range of scenarios with the cost of a false  
19 positive (FP) being set at 2 times, 5 times and 10 times worse than a false negative (FN) for  
20 the diagnostic of  $F \geq F2$ . The effect on threshold is shown in Supplementary Table 11 along  
21 with the corollary analyses for the diagnostic of  $F = F4$ .

22

### 23 *Impact of fibrosis prevalence on predictive value of liver stiffness measurement*

24 We set out to determine the impact of fibrosis prevalence on PPV and NPV values by  
25 utilising a range of different pre-test probabilities values (prevalence). The prevalence figures

1 used represent values from this cohort (60, 38% and 9% for  $F \geq F2$ ,  $F \geq F3$  and  $F=4$   
2 respectively) and also values seen in cohorts of patients with type 2 diabetes mellitus, patients  
3 at risk of liver disease and the general population<sup>40-42</sup>. For a diagnosis of  $F \geq F2$ ,  $F \geq F3$  and  
4  $F=F4$  there was a marked reduction in the PPV as the prevalence of fibrosis was lowered  
5 (Table 4). Rounding the proposed cut-offs did not affect the PPV and NPV, irrespective of  
6 prevalence (see Supplementary Table 12).

7

### 8 *Influence of probe type and histological parameters on liver stiffness measurement*

9 We next investigated the influence of probe type and histological parameters on LSM values.  
10 In univariate analysis, no significant difference was found between LSM and the probe type  
11 ( $P = 0.55$ ); all histological parameters were significantly correlated to LSM: fibrosis stage ( $\tau$   
12  $= 0.43$ ,  $P < 10^{-16}$ ), ballooning grade ( $\tau = 0.22$ ,  $P < 10^{-7}$ ), lobular inflammation grade ( $\tau = 0.21$ ,  
13  $P < 10^{-6}$ ), portal inflammation grade ( $\tau = 0.17$ ,  $P < 10^{-4}$ ) and steatosis grade ( $\tau = 0.11$ ,  $P =$   
14  $0.004$ ). Then, a multivariable linear regression analysis was performed. Following a  
15 backward selection procedure based on BIC, the only covariate influencing LSM was fibrosis  
16 stage ( $\beta = 0.18$ , 95% CI =  $(0.15-0.21)$ ,  $P < 10^{-16}$ ). When adjusted for fibrosis stage, there was  
17 no significant influence of probe type or steatosis grade on the LSM value. To further  
18 illustrate this, a boxplot of LSM versus fibrosis stage stratified by probe type is presented in  
19 Figure 3a and a boxplot of LSM stratified by semi-quantitative steatosis percentage quartile is  
20 presented in Figure 3b.

21

22

## 1 **Conclusions**

2 This prospective study examined the association of contemporaneous VTCE and liver  
3 histology in a cohort of patients undergoing liver biopsy for investigation for suspected  
4 NAFLD, and the results were reported according to the STARD guidelines. It demonstrates  
5 the high applicability rate of VTCE (97%) in a large UK NAFLD cohort with BMI up to 53.2  
6 kg/m<sup>2</sup> and provides optimised cut-off values for staging steatosis and fibrosis depending on  
7 prevalence and clinical context (Youden criteria, 90% sensitivity or 90% specificity). This  
8 study also provides novel approaches to threshold setting taking into account the prevalence  
9 of fibrosis in the population to be tested and also basing thresholds around clinical priorities  
10 such as minimising false positive diagnoses of  $F \geq F2$  or false negative diagnoses of  $F=4$ .  
11 Critically this study demonstrates that only fibrosis stage, and not probe type or any other  
12 histological parameters, influence LSM values.

13

14 Whilst the cut-offs for steatosis grade increase progressively from S0 to S3 when set for high  
15 sensitivity or high specificity there is not much difference between S2 and S3 when using the  
16 Youden cut-off values which were 331 dB/m and 337 dB/m respectively. Nevertheless in  
17 clinical practice the identification of moderate steatosis is of greater utility than distinctions  
18 between S2 and S3, and thus the Youden cut-off for  $S \geq S2$  of 331 dB/m is sufficient. The  
19 determination of steatosis by CAP is relevant for the confirmation of any degree of steatosis  
20 and also potentially as a serial measure in response to lifestyle or pharmacological/surgical  
21 intervention. The former is demonstrably feasible in this study whereas the latter will require  
22 examination in intervention studies.

23

1 With regards to the association between LSM values and histological evaluation of liver  
2 fibrosis there is a clear demarcation between the different degrees of fibrosis for Youden cut-  
3 off as well as for those with high sensitivity or specificity. As expected the cut-off for liver  
4 cirrhosis is markedly higher at 20.9 kPa when the specificity is set at 90%. The Youden cut-  
5 off values from this study for  $F \geq F_2$ ,  $F \geq F_3$  and  $F = F_4$  were 8.2 kPa, 9.7 kPa, and 13.6 kPa  
6 respectively, which demonstrate a clear upward increment with progressive liver fibrosis.  
7 These cut-off values have good sensitivity and specificity with a good PPV (0.78) for  $\geq F_2$   
8 and an excellent NPV (0.98) for  $F_4$ . Distinguishing  $F_0$ - $F_2$  versus  $F_3$ - $F_4$  can be achieved  
9 despite a slightly lower PPV (0.63), although there is a higher NPV (0.81) with the cut-off for  
10  $F \geq F_3$ .

11

12 The diagnostic performance of LSM and cutoffs for stages of fibrosis in this study are  
13 broadly in keeping with data from a US cohort<sup>20</sup> (Supplementary Table 13) and those  
14 recommended in a UK guideline<sup>43</sup>. The cutoffs from a range of other published studies are  
15 included in Supplementary Table 14 for comparison. Whilst reasonably similar there are  
16 some differences in the UK cohort such as gender (45% female vs 68% female in US cohort)  
17 and presence of diabetes mellitus (50% vs 44% in US cohort). For CAP however, diagnostic  
18 performance is higher in our cohort than in the US cohort (AUROC 0.87 (0.82-0.92) for the  
19 diagnostic of  $S \geq 1$  in our cohort versus 0.76 (0.64-0.89) in the US cohort. This difference may  
20 be accounted to the prevalence of patients with  $S \geq S_1$  steatosis which is 88% in our cohort  
21 versus 95% in the US cohort. Another possibility is that the delay between FibroScan and LB  
22 was up to 12 months in NASH CRN study whereas in this study it was only 2 weeks.

23



1 Reports have suggested that factors other than liver fibrosis, such as steatosis<sup>23</sup>, may  
2 influence LSM readings. To evaluate this question we performed multivariable analysis  
3 including all potentially relevant factors and notably the only factor that predicted LSM was  
4 the degree of liver fibrosis. Explicitly, neither the degree of steatosis or inflammation was  
5 associated with differences in LSM. This is likely because prior studies had not included  
6 other factors such as degree of fibrosis in their analyses, which when taken into account  
7 reveal that other histological elements do not influence LSM readings<sup>23</sup>. Also these studies  
8 only used the M probe which is likely to give an incorrect reading in many patients with  
9 NAFLD. Similarly, groups have suggested that LSM cut-offs differ according to probe  
10 choice<sup>20,26</sup>, although in this study we did not find this to be the case.

11

12 The threshold values will also be significantly impacted by the prevalence of the underlying  
13 condition. In Table 4 the effect of changing prevalence is demonstrated again allowing for  
14 appropriate choice of cut-off values depending on the clinical setting. This modelling data  
15 demonstrates that as the prevalence of liver fibrosis ( $\geq$ F2 or F4) decreases there is a  
16 commensurate reduction in PPV and increase in NPV. This is relevant as cut-offs generated  
17 in secondary care are often applied in primary care without taking into account the marked  
18 difference in prevalence. In this situation a negative test would be very reassuring although a  
19 positive test would have a low likelihood of capturing a true positive and raises the question  
20 of needing further confirmatory tests.

21

22 Conventional cut-off criteria for grades of steatosis and fibrosis whilst useful, do not capture  
23 the importance to clinical decision making and its dependence on the relevant clinical setting.  
24 To better model this we explored two settings; one in which the presence of  $\geq$ F2 or F4 was

1 being tested (Supplementary Appendix). In the former setting ( $\geq F2$ ) the assumption was  
2 made that a false positive was two, five or ten times worse than a false negative, with  
3 concomitant increases in the threshold. In contrast for F4 the opposite view was taken,  
4 namely that it was more important to not miss a diagnosis (Supplementary Table 11). This  
5 allows for healthcare organisations to make decision depending on how they value the ratio  
6 of false positive to false negatives.

7

8 Our study has several strengths; it is a large prospective appropriately powered study, and  
9 captures real world clinical practice of clinicians evaluating patients with potential NAFLD.  
10 By incorporating the automatic probe recommendation tool we also ensured that the correct  
11 probe was used to generate LSM and CAP values. It defines a number of cut-offs which can  
12 be used according to the clinical setting and also provides modelling data on the impact of  
13 prevalence on performance.

14

15 A potential weakness of our study is that a number of biopsies were not interpretable as they  
16 did not show NAFLD but there again this is representative of real-world examination of this  
17 technology. In addition, we did not establish whether repeat VTCE examination would have  
18 generated consistent readings as demonstrated recently<sup>20</sup>.

19

20 In summary, this study confirms the high applicability/low failure rate of VTCE in a cohort  
21 of patients with potential NAFLD, and demonstrate that LSM readings are not influenced by  
22 other histological components or choice of probe. Finally, our study provides a  
23 comprehensive range of cut-offs for LSM and CAP depending on the value a clinician places

- 1 on false positive/false negatives as well as taking into account the prevalence of the degree of
- 2 fibrosis. This will be critical for the roll-out of VTCE in a range of clinical settings.
- 3

1 **Figure legends**

2

3 **Figure 1. Study flow chart.**

4 Of 450 patients enrolled, 433 were eligible, 415 had the FibroScan examination performed  
5 and 404 had a valid FibroScan examination. Eventually 383 had a valid controlled attenuation  
6 parameter (CAP) measurements and steatosis grade assessed on liver biopsy (LB) and 373  
7 had a valid liver stiffness measurement (LSM) and fibrosis stage assessed on LB.

8

9 **Figure 2. Boxplot of (a) controlled attenuation parameter (CAP) versus steatosis grade,**  
10 **(b) liver stiffness measurement (LSM) versus fibrosis stage.**

11 (a) CAP values increase with increasing steatosis grade (Kruskal–Wallis test  $p < 10^{-16}$ ,  
12 Dunn's *post hoc* tests,  $p = 0.19$  between CAP in S2 and CAP in S3,  $p < 10^{-3}$  otherwise); (b)  
13 LSM values increase significantly with increasing fibrosis stage (Kruskal-Wallis  $p < 10^{-16}$ ;  
14 Dunn's *post hoc* tests,  $p = 1$  between LSM in F0 and LSM in F1,  $p < 0.05$  otherwise).

15

16 **Figure 3. Boxplot of LSM versus fibrosis stage stratified by (a) probe type, (b) quartile**  
17 **of semi-quantitative steatosis percentage.**

18 The boxplot represent the LSM distribution for each fibrosis stage (a) according to the probe  
19 used. Patients were scanned either with the M or XL probe as proposed by the automatic  
20 probe recommendation tool. (b) stratified by steatosis amount: for each fibrosis stage, patients  
21 are stratified by steatosis quartile in the fibrosis stage.

22

1 **Table legends**

2

3 **Table 1. Patient characteristics**

4

5 **Table 2. Diagnostic performance of controlled attenuation parameter (CAP) for**  
6 **steatosis grade greater or equal than 1, greater or equal than 2 and equal to 3.**

7

8 **Table 3. Diagnostic performance of liver stiffness measurement (LSM) for each fibrosis**  
9 **stage greater or equal than 2, greater or equal than 3 and equal to 4.**

10

11 **Table 4. Impact of prevalence of  $F \geq F2$  and  $F=4$  on positive predictive value (PPV) and**  
12 **negative predictive value (NPV) for cut-offs.**

13

14

15

16

1 **Table 1. Patient characteristics**

<i>Characteristic</i>	<i>N</i>	<i>Distribution</i>	<i>Range</i>
<i>Centre</i>	383	Birmingham: 102 (27%) Newcastle: 51 (13%) London: 52 (14%) Nottingham: 40 (10%) Plymouth: 48 (13%) Cambridge: 60 (16%) Oxford: 30 (8%)	—
<i>Age (years)</i>	383	54 [18]	[19-77]
<i>BMI (kg.m<sup>-2</sup>)</i>	383	33.8 [9.2],	[19.5-53.2]
<i>Female gender</i>	383	171 (45%)	—
<i>Diabetes mellitus</i>	383	193 (50%)	—
<i>Hypertension</i>	383	207 (54%)	—
<i>Hypercholesterolemia</i>	383	199 (52%)	—
<i>Platelets count (x10<sup>9</sup>/L)</i>	373	236 [84]	[57-446]
<i>INR</i>	361	1.08 [0.09]	[0.81-2.54]
<i>AST (IU/L)</i>	378	36 [25]	[9-203]
<i>ALT (IU/L)</i>	378	50 [40]	[7-298]
<i>GGT (IU/L)</i>	378	59 [88]	[9-1718]

<i>Alkaline phosphatase (IU/L)</i>	377	82 [40]	[4-738]
<i>Albumin (g/dL)</i>	379	4.5 [0.4]	[3.6-5.5]
<i>Bilirubin (mg/dL)</i>	378	0.50 [0.35]	[0.12-3.96]
<i>Fasting glucose (mg/dL)</i>	376	106 [51]	[50-312]
<i>Total cholesterol (mg/dL)</i>	363	179 [64]	[80-274]
<i>HDL cholesterol (mg/dL)</i>	351	43 [17]	[15-101]
<i>LDL cholesterol (mg/dL)</i>	350	102 [51]	[3-189]
<i>Triglyceride (mg/dL)</i>	362	161 [92]	[51-501]
<i>Ferritin (ng/mL)</i>	378	134 [214]	[7-4320]
<i>Urea (mg/dL)</i>	378	29 [11]	[12-84]
<i>Creatinine (mg/dL)</i>	379	0.85 [0.22]	[0.36-1.94]
<i>A2M (mg/dL)</i>	376	205 [121]	[91-523]
<i>Hyaluronic acid (ug/L)</i>	379	40 [55]	[19-1850]
<i>CRP (mg/dL)</i>	378	0.31 [0.47]	[0.02-7.53]
<i>CK18-M30 (IU/L)</i>	369	415 [395]	[74-1825]
<i>Time between FibroScan and liver biopsy (day)</i>	383	0 [7]	[0-14]
<i>XL probe</i>	383	255 (67%)	—
<i>LSM (kPa), range 1.5-75 kPa</i>	383	8.8 [7.8]	[1.7-75.0]

<i>CAP (dB/m), range 100-400 dB/m</i>	380	336 [74]	[100-400]
<i>Length of liver biopsy specimen (mm)</i>	383	23 [10]	[5-60]
<i>Fibrosis stage</i>	373	F0: 62 (17%) F1: 86 (23%) F2: 85 (23%) F3: 106 (28%) F4: 34 (9%)	—
<i>Steatosis grade</i>	383	S0: 47 (12%) S1: 89 (23%) S2: 109 (28%) S3: 138 (36%)	—
<i>Ballooning grade</i>	383	B0: 106 (28%) B1: 147 (38%) B2: 130 (34%)	—
<i>Lobular inflammation grade</i>	383	I0: 90 (23%) I1: 235 (61%) I2: 51 (13%) I3: 7 (2%)	—
<i>NAS score</i>	383	0-2: 90 (23%) 3-4: 122 (32%)	—



		5-8: 171 (45%)	
<i>Activity grade (according to SAF)</i>	383	A0: 55 (14%) A1: 80 (21%) A2: 102 (27%) A3: 110 (29%) A4: 36 (9%)	—
<i>Portal inflammation present</i>	382	172 (45%)	—
<i>Pathologists diagnosis</i>	383	Normal liver: 17 (4%) NAFL: 91 (24%) NASH: 242 (63%) Other: 33 (9%)	—

- 1 Distribution is expressed as median [interquartile range] or figure (percentage).
- 2 A2M: alpha-2 macroglobulin, ALT: alanine transaminase, AST: aspartate aminotransferase,
- 3 BMI: body mass index, CK18-M30: cytokeratin 18 neopeptide M30, CAP: controlled
- 4 attenuation parameter, CRP: C-reactive protein, GGT: gamma-glutamyl transferase, HDL:
- 5 high-density lipoprotein, INR: international normalized ratio, LDL: low-density lipoprotein,
- 6 LSM: liver stiffness measurement, NAFL: non-alcoholic fatty liver, NAFLD: NAFL disease,
- 7 NASH: non-alcoholic steato-hepatitis, NAS: NAFLD activity score.
- 8

**Table 2. Diagnostic performance of controlled attenuation parameter (CAP) for steatosis grade greater or equal than 1, greater or equal than 2 and equal to 3.**

		<b>S<math>\geq</math>S1 (<math>\geq</math>5% steatosis)</b>	<b>S<math>\geq</math>S2 (<math>\geq</math>34% steatosis)</b>	<b>S=S3 (<math>\geq</math>67% steatosis)</b>
AUROC (95% CI)		0.87 (0.82-0.92)	0.77 (0.71-0.82)	0.70 (0.64-0.75)
Prevalence (N)		0.88 (N=303)	0.64 (N=244)	0.36 (N=137)
Youden Index	Cut-off (dB/m)	302	331	337
	Se (95% CI)	0.80 (0.75-0.84)	0.70 (0.63-0.75)	0.72 (0.63-0.79)
	<i>TP/(TP+FN)</i>	<i>(266/333)</i>	<i>(170/244)</i>	<i>(98/137)</i>
	Sp (95% CI)	0.83 (0.69-0.92)	0.76 (0.68-0.83)	0.63 (0.56-0.69)
	<i>TN/(TN+FP)</i>	<i>(39/47)</i>	<i>(104/136)</i>	<i>(152/243)</i>
	PPV (95% CI)	0.97 (0.94-0.98)	0.84 (0.78-0.88)	0.52 (0.45-0.62)
	NPV (95% CI)	0.37 (0.31-0.59)	0.58 (0.52-0.68)	0.80 (0.73-0.84)
	LR+ (95% CI)	4.69 (2.49-8.84)	2.96 (2.16-4.05)	1.91 (1.57-2.32)

	LR- (95% CI)	0.24 (0.19-0.31)	0.40 (0.32-0.49)	0.46 (0.34-0.60)
Se=0.90	Cut-off (dB/m)	274	290	302
	Se (95%CI)	Se = 0.90 (0.87-0.93)	Se = 0.90 (0.86-0.94)	Se = 0.90 (0.83-0.94)
	<i>TP/(TP+FN)</i>	<i>(301/333)</i>	<i>(220/244)</i>	<i>(123/137)</i>
	Sp (95%CI)	Sp = 0.60 (0.44-0.74)	Sp = 0.44 (0.36-0.53)	Sp = 0.38 (0.32-0.44)
	<i>TN/(TN+FP)</i>	<i>(28/47)</i>	<i>(60/136)</i>	<i>(92/243)</i>
	PPV (95% CI)	PPV = 0.94 (0.90-0.96)	PPV = 0.74 (0.67-0.82)	PPV = 0.45 (0.38-0.61)
	NPV (95% CI)	NPV = 0.47 (0.38-0.62)	NPV = 0.71 (0.62-0.78)	NPV = 0.87 (0.79-0.90)
	LR+ (95% CI)	LR+ = 2.24 (1.58-3.17)	LR+ = 1.61 (1.38-1.88)	LR+ = 1.44 (1.29-1.62)
	LR- (95% CI)	LR- = 0.16 (0.11-0.24)	LR- = 0.22 (0.15-0.34)	LR- = 0.27 (0.16-0.45)
Sp=0.90	Cut-off (dB/m)	325	370	398
	Se (95%CI)	Se = 0.66 (0.61-0.71)]	Se = 0.34 (0.28-0.40)	Se = 0.14 (0.09-0.21)
	<i>TP/(TP+FN)</i>	<i>(220/333)</i>	<i>(83/244)</i>	<i>(19/137)</i>

Sp (95%CI)	Sp = 0.90 (0.77-0.96)	Sp = 0.90 (0.83-0.94)	Sp = 0.90 (0.86-0.94)
<i>TN/(TN+FP)</i>	<i>(42/47)</i>	<i>(122/136)</i>	<i>(219/243)</i>
PPV (95% CI)	PPV = 0.98 (0.95-0.98)	PPV = 0.86 (0.77-0.89)	PPV = 0.44 (0.34-0.56)
NPV (95% CI)	NPV = 0.27 (0.23-0.55)	NPV = 0.43 (0.36-0.59)	NPV = 0.65 (0.52-0.75)
LR+ (95% CI)	LR+ = 6.21 (2.70-14.27)	LR+ = 3.30 (1.95-5.59)	LR+ = 1.40 (0.80-2.47)
LR- (95% CI)	LR- = 0.38 (0.32-0.45)	LR- = 0.74 (0.66-0.82)	LR- = 0.96 (0.88-1.03)

AUROC: area under the receiver operating curve, CI: confidence interval, FN: number of false negative, FP: number of false positive, LR-: negative likelihood ratio, LP+: positive likelihood ratio, NPV: negative predictive value, PPV: positive predictive value, S: steatosis, Se: sensitivity, Sp: specificity, TN: true negative, TP: true positive.

**Table 3. Diagnostic performance of liver stiffness measurement (LSM) for each fibrosis stage greater or equal than 2, greater or equal than 3 and equal to 4.**

		<b>F<math>\geq</math>F2</b>	<b>F<math>\geq</math>F3</b>	<b>F=F4</b>
<b>AUROC (95% CI)</b>		<b>HIS</b>	<b>0.80 (0.75-0.84)</b>	<b>0.89 (0.84-0.93)</b>
<b>Prevalence (N)</b>		0.60 (N=225)	0.38 (N=140)	0.09 (N=34)
<b>Youden Index</b>	<b>Cut-off (kPa)</b>	8.2	9.7	13.6
	<b>Se (95% CI)</b>	Se = 0.71 (0.64-0.77)	Se = 0.71 (0.62-0.78)	Se = 0.85 (0.69-0.95)
	<b>TP/(TP+FN)</b>	(159/225)	(99/140)	(29/34)
	<b>Sp (95% CI)</b>	Sp = 0.70 (0.62-0.77)	Sp = 0.75 (0.69-0.80)	Sp = 0.79 (0.74-0.83)
	<b>TN/(TN+FP)</b>	(103/148)	(174/233)	(267/339)
	<b>PPV (95% CI)</b>	PPV = 0.78 (0.71-0.83)	PPV = 0.63 (0.55-0.71)	PPV = 0.29 (0.24-0.57)
	<b>NPV (95% CI)</b>	NPV = 0.61 (0.54-0.69)	NPV = 0.81 (0.74-0.85)	NPV = 0.98 (0.95-0.99)
	<b>LR+ (95% CI)</b>	LR+ = 2.32 (1.80-3.01)	LR+ = 2.79 (2.19-3.57)	LR+ = 4.02 (3.13-5.15)

	LR- (95% CI)	LR- = 0.42 (0.34-0.53)	LR- = 0.39 (0.30-0.51)	LR- = 0.19 (0.08-0.42)
Se=0.90	Cut-off (kPa)	6.1	7.1	10.9
	Se (95%CI)	Se = 0.90 (0.86-0.94)	Se = 0.90 (0.84-0.94)	Se = 0.91 (0.76-0.98)
	<i>TP/(TP+FN)</i>	<i>(203/225)</i>	<i>(126/140)</i>	<i>(31/34)</i>
	Sp (95%CI)	Sp = 0.38 (0.30-0.46)	Sp = 0.50 (0.43-0.56)	Sp = 0.70 (0.64-0.74)
	<i>TN/(TN+FP)</i>	<i>(56/148)</i>	<i>(116/233)</i>	<i>(236/339)</i>
	PPV (95% CI)	PPV = 0.69 (0.61-0.78)	PPV = 0.52 (0.45-0.67)	PPV = 0.23 (0.19-0.61)
	NPV (95% CI)	NPV = 0.72 (0.62-0.78)	NPV = 0.89 (0.83-0.92)	NPV = 0.99 (0.96-0.99)
	LR+ (95% CI)	LR+ = 1.45 (1.27-1.66)	LR+ = 1.79 (1.56-2.06)	LR+ = 3.00 (2.48-3.64)
LR- (95% CI)	LR- = 0.26 (0.17-0.40)	LR- = 0.20 (0.12-0.34)	LR- = 0.13 (0.04-0.37)	
Sp=0.90	Cut-off (kPa)	12.1	14.1	20.9
	Se (95%CI)	Se = 0.44 (0.38-0.51)	Se = 0.48 (0.39-0.56)	Se = 0.59 (0.41-0.75)
	<i>TP/(TP+FN)</i>	<i>(100/225)</i>	<i>(67/140)</i>	<i>(20/34)</i>

Sp (95% CI) <i>TN/(TN+FP)</i>	Sp = 0.91 (0.85-0.95) <i>(134/148)</i>	Sp = 0.90 (0.86-0.94) <i>(210/233)</i>	Sp = 0.90 (0.86-0.93) <i>(305/339)</i>
PPV (95% CI)	PPV = 0.88 (0.80-0.90)	PPV = 0.74 (0.65-0.80)	PPV = 0.37 (0.29-0.56)
NPV (95% CI)	NPV = 0.52 (0.45-0.67)	NPV = 0.74 (0.67-0.82)	NPV = 0.96 (0.91-0.97)
LR+ (95% CI)	LR+ = 4.70 (2.79-7.90)	LR+ = 4.85 (3.17-7.41)	LR+ = 5.87 (3.83-8.97)
LR- (95% CI)	LR- = 0.61 (0.54-0.70)	LR- = 0.58 (0.49-0.68)	LR- = 0.46 (0.31-0.69)

AUROC: area under the receiver operating curve, CI: confidence interval, FN: number of false negative, FP: number of false positive, LR-: negative likelihood ratio, LR+: positive likelihood ratio, NPV: negative predictive value, PPV: positive predictive value, Se: sensitivity, Sp: specificity, TN: true negative, TP: true positive.

**Table 4. Impact of prevalence of  $F \geq F_2$ ,  $F \geq F_3$  and  $F=4$  on positive predictive value (PPV) and negative predictive value (NPV) together with their (95% confidence interval) of LSM for the cutoff for  $Se=0.90$ , for the Youden index cutoff and for the cutoff for  $Sp=0.90$ .**

	Prevalence	Justification	Cutoff for $Se=0.90$	Youden index cutoff	Cutoff for $Se=0.90$
<b>Diagnostic of <math>F \geq F_2</math></b>	-	-	<u>Cutoff = 6.1 kPa</u>	<u>Cutoff = 8.2 kPa</u>	<u>Cutoff = 12.1 kPa</u>
	60%	Actual prevalence in our population	PPV=69% (66%-71%) NPV=72% (62%-80%)	PPV=78% (73%-82%) NPV=61% (56%-67%)	PPV=88% (81%-92%) NPV=52% (49%-55%)
	40%	Estimated prevalence in diabetic clinic <sup>42</sup>	PPV=49% (46%-53%) NPV=85% (79%-90%)	PPV=61% (54%-67%) NPV=78% (74%-82%)	PPV=76% (65%-84%) NPV=71% (68%-74%)
	7%	Estimated prevalence in general population <sup>40</sup>	PPV=10% (9%-11%) NPV=98% (97%-99%)	PPV=15% (12%-18%) NPV=97% (96%-98%)	PPV=26% (17%-37%) NPV=96% (95%-96%)
<b>Diagnostic of <math>F \geq F_3</math></b>	-	-	<u>Cutoff = 7.1 kPa</u>	<u>Cutoff = 9.7 kPa</u>	<u>Cutoff = 14.1 kPa</u>
	38%	Actual prevalence in our population	PPV = 52% (45%-67%) NPV = 89% (83%-92%)	PPV = 63% (55%-71%) NPV = 81% (74%-85%)	PPV = 74% (65%-80%) NPV = 74% (67%-82%)
	18%	Estimated prevalence in diabetic clinic <sup>42</sup>	PPV=28% (24%-32%) NPV=96% (92%-98%)	PPV=38% (30%-46%) NPV=92% (89%-94%)	PPV=52% (37%-66%) NPV=89% (87%-91%)
	2%	Estimated prevalence in general population <sup>41</sup>	PPV=4% (3%-4%) NPV=99.6% (99.2%-99.8%)	PPV=5% (4%-7%) NPV=99.2% (98.9%-99.4%)	PPV=9% (5%-15%) NPV=98.8% (98.6%-99.1%)
<b>Diagnostic</b>	-	-	<u>Cutoff = 10.9 kPa</u>	<u>Cutoff = 13.6 kPa</u>	<u>Cutoff = 20.9 kPa</u>



<b>of F=F4</b>	9%	Actual prevalence in our population	PPV=23% (20%-26%) NPV=98.7% (96.5%-99.6%)	PPV=28% (24%-34%) NPV=98.2% (96.0%-99.2)	PPV=37% (27%-47%) NPV=95.7% (93.7%-97.1%)
	3%	Estimated prevalence in population at risk of liver disease <sup>41</sup>	PPV=8% (7%-10%) NPV=99.6% (98.9%-99.9%)	PPV=11% (9%-14%) NPV=99.4% (98.7%-99.8%)	PPV=15% (11%-22%) NPV=98.6% (97.9%-99.1%)
	1%	Estimated prevalence in general population <sup>41</sup>	PPV=3% (2%-4%) NPV=99.9% (99.6%-100%)	PPV=4% (3%-5%) NPV=99.8% (99.6%-99.9%)	PPV=6% (4%-8%) NPV=99.5% (99.3%-99.7%)

## References

1. Younossi ZM, Blissett D, Blissett R, et al. The economic and clinical burden of nonalcoholic fatty liver disease in the United States and Europe. *Hepatology* 2016;64:1577-1586.
2. Charlton MR, Burns JM, Pedersen RA, et al. Frequency and outcomes of liver transplantation for nonalcoholic steatohepatitis in the United States. *Gastroenterology* 2011;141:1249-53.
3. Younossi ZM, Koenig AB, Abdelatif D, et al. Global Epidemiology of Non-Alcoholic Fatty Liver Disease-Meta-Analytic Assessment of Prevalence, Incidence and Outcomes. *Hepatology* 2015.
4. Angulo P, Kleiner DE, Dam-Larsen S, et al. Liver Fibrosis, but No Other Histologic Features, Is Associated With Long-term Outcomes of Patients With Nonalcoholic Fatty Liver Disease. *Gastroenterology* 2015;149:389-97 e10.
5. Dulai PS, Singh S, Patel J, et al. Increased risk of mortality by fibrosis stage in nonalcoholic fatty liver disease: Systematic review and meta-analysis. *Hepatology* 2017;65:1557-1565.
6. Sandrin L, Fourquet B, Hasquenoph JM, et al. Transient elastography: a new noninvasive method for assessment of hepatic fibrosis. *Ultrasound Med Biol* 2003;29:1705-13.
7. Tsochatzis EA, Gurusamy KS, Ntaoula S, et al. Elastography for the diagnosis of severity of fibrosis in chronic liver disease: a meta-analysis of diagnostic accuracy. *J Hepatol* 2011;54:650-9.
8. Sasso M, Audiere S, Kemgang A, et al. Liver Steatosis Assessed by Controlled Attenuation Parameter (CAP) Measured with the XL Probe of the FibroScan: A Pilot Study Assessing Diagnostic Accuracy. *Ultrasound Med Biol* 2016;42:92-103.
9. Sasso M, Beaugrand M, de Ledinghen V, et al. Controlled attenuation parameter (CAP): a novel VCTE guided ultrasonic attenuation measurement for the evaluation of hepatic steatosis: preliminary study and validation in a cohort of patients with chronic liver disease from various causes. *Ultrasound Med Biol* 2010;36:1825-35.
10. de Ledinghen V, Vergniol J, Capdepon M, et al. Controlled attenuation parameter (CAP) for the diagnosis of steatosis: a prospective study of 5323 examinations. *J Hepatol* 2014;60:1026-31.
11. Jun BG, Park WY, Park EJ, et al. A prospective comparative assessment of the accuracy of the FibroScan in evaluating liver steatosis. *PLoS One* 2017;12:e0182784.
12. Runge JH, Smits LP, Verheij J, et al. MR Spectroscopy-derived Proton Density Fat Fraction Is Superior to Controlled Attenuation Parameter for Detecting and Grading Hepatic Steatosis. *Radiology* 2018;286:547-556.
13. Myers RP, Pomier-Layrargues G, Kirsch R, et al. Feasibility and diagnostic performance of the FibroScan XL probe for liver stiffness measurement in overweight and obese patients. *Hepatology* 2012;55:199-208.
14. Tapper EB, Challies T, Nasser I, et al. The Performance of Vibration Controlled Transient Elastography in a US Cohort of Patients With Nonalcoholic Fatty Liver Disease. *Am J Gastroenterol* 2016;111:677-84.
15. Naveau S, Voican CS, Lebrun A, et al. Controlled attenuation parameter for diagnosing steatosis in bariatric surgery candidates with suspected nonalcoholic fatty liver disease. *Eur J Gastroenterol Hepatol* 2017;29:1022-1030.
16. Chan WK, Nik Mustapha NR, Wong GL, et al. Controlled attenuation parameter using the FibroScan(R) XL probe for quantification of hepatic steatosis for non-

- alcoholic fatty liver disease in an Asian population. *United European Gastroenterol J* 2017;5:76-85.
17. Park CC, Nguyen P, Hernandez C, et al. Magnetic Resonance Elastography vs Transient Elastography in Detection of Fibrosis and Noninvasive Measurement of Steatosis in Patients With Biopsy-Proven Nonalcoholic Fatty Liver Disease. *Gastroenterology* 2017;152:598-607 e2.
  18. Garg H, Aggarwal S, Shalimar, et al. Utility of transient elastography (fibrosan) and impact of bariatric surgery on nonalcoholic fatty liver disease (NAFLD) in morbidly obese patients. *Surg Obes Relat Dis* 2018;14:81-91.
  19. de Ledinghen V, Hiriart JB, Vergniol J, et al. Controlled Attenuation Parameter (CAP) with the XL Probe of the Fibroscan((R)): A Comparative Study with the M Probe and Liver Biopsy. *Dig Dis Sci* 2017;62:2569-2577.
  20. Vuppalanchi R, Siddiqui MS, Van Natta ML, et al. Performance characteristics of vibration-controlled transient elastography for evaluation of nonalcoholic fatty liver disease. *Hepatology* 2018;67:134-144.
  21. Siddiqui MS, Vuppalanchi R, Van Natta ML, et al. Vibration-controlled Transient Elastography to Assess Fibrosis and Steatosis in Patients With Nonalcoholic Fatty Liver Disease. *Clin Gastroenterol Hepatol* 2018.
  22. Bossuyt PM, Reitsma JB, Bruns DE, et al. STARD 2015: an updated list of essential items for reporting diagnostic accuracy studies. *BMJ* 2015;351:h5527.
  23. Petta S, Maida M, Macaluso FS, et al. The severity of steatosis influences liver stiffness measurement in patients with nonalcoholic fatty liver disease. *Hepatology* 2015;62:1101-10.
  24. Petta S, Wong VW, Camma C, et al. Improved noninvasive prediction of liver fibrosis by liver stiffness measurement in patients with nonalcoholic fatty liver disease accounting for controlled attenuation parameter values. *Hepatology* 2017;65:1145-1155.
  25. Wong VW, Vergniol J, Wong GL, et al. Liver stiffness measurement using XL probe in patients with nonalcoholic fatty liver disease. *Am J Gastroenterol* 2012;107:1862-71.
  26. de Ledinghen V, Wong VW, Vergniol J, et al. Diagnosis of liver fibrosis and cirrhosis using liver stiffness measurement: comparison between M and XL probe of FibroScan(R). *J Hepatol* 2012;56:833-9.
  27. Kleiner DE, Brunt EM, Van Natta M, et al. Design and validation of a histological scoring system for nonalcoholic fatty liver disease. *Hepatology* 2005;41:1313-21.
  28. Bedossa P, Poitou C, Veyrie N, et al. Histopathological algorithm and scoring system for evaluation of liver lesions in morbidly obese patients. *Hepatology* 2012;56:1751-9.
  29. de Ledinghen V, Vergniol J. Transient elastography (FibroScan). *Gastroenterol Clin Biol* 2008;32:58-67.
  30. de Ledinghen V, Vergniol J, Foucher J, et al. Non-invasive diagnosis of liver steatosis using controlled attenuation parameter (CAP) and transient elastography. *Liver Int* 2012;32:911-8.
  31. Myers RP, Pollett A, Kirsch R, et al. Controlled Attenuation Parameter (CAP): a noninvasive method for the detection of hepatic steatosis based on transient elastography. *Liver Int* 2012;32:902-10.
  32. R Core Team. R: A Language and Environment for Statistical Computing. In: <https://www.R-project.org/>, ed. Vienna, Austria: R Foundation for Statistical Computing, 2016.

33. Caussy C, Alqiraish MH, Nguyen P, et al. Optimal threshold of controlled attenuation parameter with MRI-PDFF as the gold standard for the detection of hepatic steatosis. *Hepatology* 2017.
34. Wong VW, Petta S, Hiriart JB, et al. Validity criteria for the diagnosis of fatty liver by M probe-based controlled attenuation parameter. *J Hepatol* 2017.
35. Lee JH, Kim D, Kim HJ, et al. Hepatic steatosis index: a simple screening tool reflecting nonalcoholic fatty liver disease. *Dig Liver Dis* 2010;42:503-8.
36. Boursier J, Zarski JP, de Ledinghen V, et al. Determination of reliability criteria for liver stiffness evaluation by transient elastography. *Hepatology* 2013;57:1182-91.
37. de Franchis R, Baveno VIF. Expanding consensus in portal hypertension: Report of the Baveno VI Consensus Workshop: Stratifying risk and individualizing care for portal hypertension. *J Hepatol* 2015;63:743-52.
38. Sterling RK, Lissen E, Clumeck N, et al. Development of a simple noninvasive index to predict significant fibrosis in patients with HIV/HCV coinfection. *Hepatology* 2006;43:1317-25.
39. Angulo P, Hui JM, Marchesini G, et al. The NAFLD fibrosis score: a noninvasive system that identifies liver fibrosis in patients with NAFLD. *Hepatology* 2007;45:846-54.
40. Roulot D, Costes JL, Buyck JF, et al. Transient elastography as a screening tool for liver fibrosis and cirrhosis in a community-based population aged over 45 years. *Gut* 2011;60:977-84.
41. Harris R, Harman DJ, Card TR, et al. Prevalence of clinically significant liver disease within the general population, as defined by non-invasive markers of liver fibrosis: a systematic review. *Lancet Gastroenterol Hepatol* 2017;2:288-297.
42. Kwok R, Choi KC, Wong GL, et al. Screening diabetic patients for non-alcoholic fatty liver disease with controlled attenuation parameter and liver stiffness measurements: a prospective cohort study. *Gut* 2016;65:1359-68.
43. Newsome PN, Cramb R, Davison SM, et al. Guidelines on the management of abnormal liver blood tests. *Gut* 2018;67:6-19.