Non-invasive offline characterisation of contrast-enhanced ultrasound evaluations of focal liver lesions: dynamic assessment using a new tracking method

Poster No.:	C-1378
Congress:	ECR 2014
Type:	Scientific Exhibit
Authors:	S. Bakas[1], P. Sidhu[1], M. Sellars[1], G. J. A. Hunter[1], D. Makris[1], K. Chatzimichail[2]; [1]London/UK, [2]Greece/GR
Keywords:	Liver, Abdomen, Computer applications, Ultrasound, Image manipulation / Reconstruction, Contrast agent-intravenous, Computer Applications-Detection, diagnosis, Segmentation, Cancer, Tissue characterisation
DOI:	10.1594/ecr2014/C-1378

Aims and objectives

Liver cancer is the fifth largest cause of death in the United Kingdom [3], with European mortality rates rising by approximately 400% over the last 40 years [7]. Around 400,000 focal liver lesions (FLLs) are diagnosed annually in the UK, 25% of which are diagnosed as malignant and the rest as benign, not requiring treatment [4]. Making such a diagnostic decision and distinguishing between a benign and a malignant FLL at the earliest stage possible is of importance, as the patient's survival rates and the chances of successful treatment in case of a malignant lesion, depend on the stage of the lesion at the time of diagnosis. The case of a benign lesion being diagnosed early, would lead to less distress to patients and families, as well as reduced healthcare costs. Contrast-Enhanced Ultrasound (CEUS) is recognised as the most cost-efficient solution, without any delays as it can be performed at the same initial conventional Ultrasound examination [10]. Importantly, CEUS effectiveness, in terms of diagnostic accuracy, for the evaluation of malignant FLLs exceeds 95% [9]. However, interpretation of CEUS recordings requires time from experienced and CEUS-trained radiologists.

This study depicts an endeavour to provide radiologists with an accurate and easy-to-use computer-aided evaluation tool (ET) that optimises the offline assessment, quantification and characterisation of FLLs in CEUS screening recordings. Offline dynamic assessment of an FLL's behaviour, i.e. its perfusion rate relative to the rest of the healthy liver (parenchyma), can lead to its characterisation as benign or malignant [11]. This behaviour is currently obtained by observations of the relative average intensity enhancement between the two regions (FLL and parenchyma) over time, i.e. the signal of the FLL's vascular signature (Fig.1) [8]. The proposed autonomous ET could help radiologists to perform an efficient and confident offline assessment of FLLs with minimal interaction, leading to more reliable diagnoses, workflow and outcome, without any special/additional training, based on quantitative results of automated tracking of the FLL and parenchyma regions.

Images for this section:

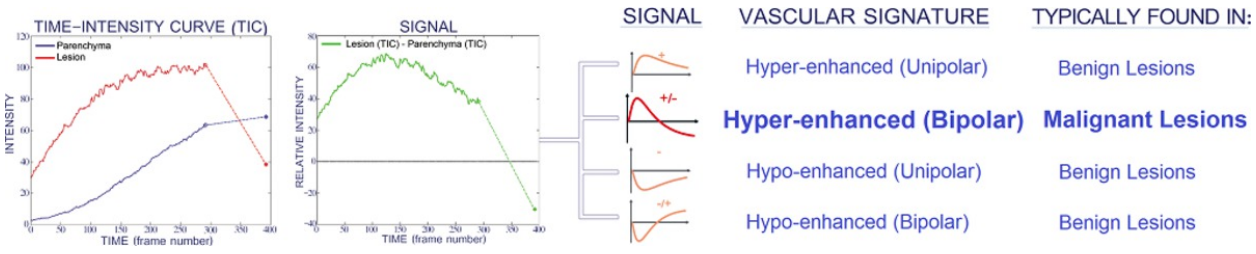

Fig. 1: Dynamic Behaviour Analysis of a Focal Liver Lesion (FLL). The Time-Intensity Curve (i.e. TIC, or perfusion curve) and the Signal of a malignant FLL's vascular signature

are depicted in the left of the figure. The four major vascular signatures with their corresponding signals are shown in the right of the figure.

Methods and materials

Data

The CEUS dynamic behaviour of a variety of 107 examples of FLLs from patients in different physical conditions is assessed. The mean and median values of patients' age were 51.8 and 50 years, respectively (range: 19-91 years). Local Ethics Board approval waivers are attained in King's College Hospital (UK) and in Evgenidion Hospital (GR), where maintenance of randomisation codes for each clinical case and patients' confidentiality are also secured by anonymising the screened data. Consent for using the CEUS screening recordings and diagnostic results was acquired from all the patients.

Screening data for the 93 of the 107 real clinical cases were collected using a Siemens ACUSON S2000 Ultrasound System (Mountainview CA) equipped with 4 (or) 6 MHz curvy-linear transducer in the UK (Dataset A) and for the 14 of the 107 cases using a Siemens ACUSON Sequoia C512 Ultrasound System (Mountainview CA) equipped with 6-2 MHz curvy-linear transducer in Greece (Dataset B). The data of each patient collected, following a standard protocol, is represented by a digital video sequence/ recording including the arterial and portal-venous phase and a static image of the late-portal phase. In all examinations the second generation contrast agent SonoVue (Bracco S.p.A., Milan, Italy) was used in 2.4 ml bolus intravenous injection (i.e. into an arm vein), without prior knowledge of subsequent processing by an ET. This method of data collection, reflecting true clinical practice, leads to increased variability in the data acquisition parameters, as well as to different lengths of the video sequences. Each examination/acquisition of Dataset A was performed by two experienced radiologists with specifically fifteen and ten years of experience in CEUS, whilst each examination/ acquisition of Dataset B was performed by one radiologist with twelve years of experience in CEUS. The reference standard (RS) was based on other imaging and histology.

Challenges

Assessment of an FLL's dynamic behaviour in CEUS screening recordings, poses a substantial challenge, mainly due to the alterations of the field of view, as well as the diverse regions captured within it, occurring during the clinical data acquisition. Variability is observed in scale, location and orientation due to the relative motion between the US transducer and the liver. Causes for this will include; the patient's irregular breathing pattern, the radiologist's attempt to manually stabilise the US target's view, resulting in the FLL's dispersion in depth and out-of-plane movement. The continuous irregular repetitiveness of all these disturbances inevitably degrades the quality of the acquired data (Fig.2). Furthermore, acoustic shadows, low signal-to-noise ratio and the

introduction of contrast-enhancing agents affect the FLL's apparent 2D shape and size during the examination.

Proposed Solution

The proposed computer-aided evaluation tool analysed retrospectively the acquired data. During this analysis, FLL and parenchyma contours (i.e. shape descriptors) were tracked automatically, between successive frames of the CEUS video sequence, overcoming the aforementioned challenges. Automated motion tracking of these ROIs is based on Compact and Real-time Descriptors (CARD) [1], whilst following a concept recently introduced [2] (Fig.3). Size and shape information obtained for each of the ROIs (i.e. contours), throughout the screening recording, are combined with the statistical analysis method of Generalised Procrustes Analysis (GPA) [5] to enable the estimation of the best mean shape of all the contours, by optimally superimposing the set of all the contours on a single reference orientation. Such a shape is expected to be more accurate than the shape defined manually by the radiologist based on local texture information, as the former takes into account variation across all the frames. Then this best mean shape is used for the localisation of the two ROIs in the late phase image. Subsequent averaging of the brightness intensity of the pixels included within each ROI's shape descriptors for each of the frames, leads to estimation of the Time-Intensity-Curves (TICs). Then the difference of the parenchyma's TIC from the FLL's TIC leads to the estimation of the signal of the FLL's vascular signature, used for its characterisation as benign or malignant. The sole manual processes included within the use of the proposed evaluation tool, are the initialisations of the FLL and the parenchyma contours in a single video frame of the CEUS video sequence and one seed-point in the late phase static image for the region of the FLL.

Images for this section:

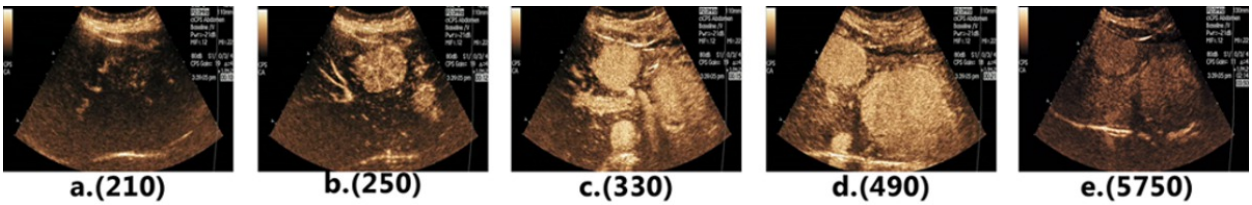

Fig. 2: Significant changes in the appearance of the FLL and the parenchyma during a CEUS screening recording. The number under each figure depicts the frame number.

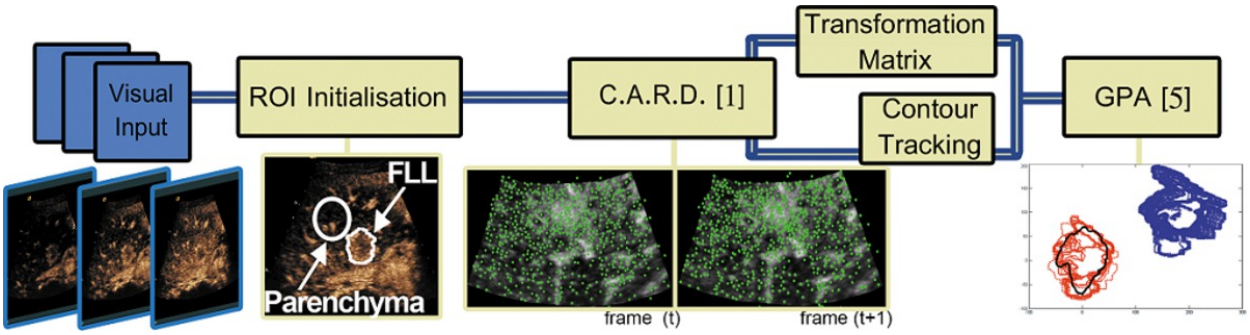

Fig. 3: Pipeline of the processing of a CEUS screening recording by the proposed computer-aided evaluation tool.

Results

Comparison of the proposed computer-aided evaluation tool's decision with the reference standard depicts a correct characterisation rate (i.e. diagnostic accuracy) of 91.6%, with individual rates of 91.4% and 92.8% for Dataset A and Dataset B, respectively.

Considering 18 of the 107 cases with FLL dispersion in depth, the proposed ET performs satisfactory in 14 of them (i.e. characterising the FLL correctly), whilst it mischaracterises only 4. Additional mischaracterisations are due to i) FLL circular enrichment patterns, ii) heterogeneous enrichment of parenchyma and iii) the existence of a malignant FLL within a cirrhotic liver.

Images for this section:

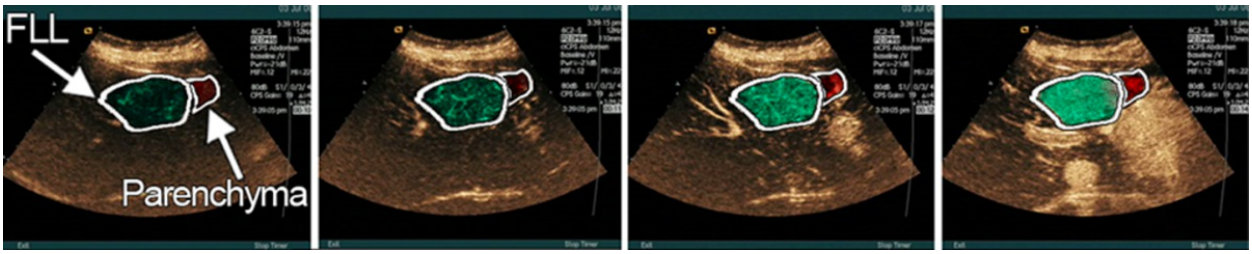

Fig. 4: Motion tracking of the FLL and parenchyma regions by the proposed computer-aided evaluation tool.

Conclusion

A computer-aided evaluation tool (ET) was presented in this study, with diagnostic accuracy of 91.6% on data collected from two totally independent clinical centres. This ET assists radiologists to assess CEUS screening recordings offline, whilst saving time and effort to them, by avoiding the manual annotation of the FLL region in every frame of the video sequence. Its diagnostic accuracy depicts its ability to distinguish and characterise FLLs as benign or malignant. The suggestive decision of the ET is based on quantitative results representative of the lesion's dynamic behaviour (i.e. TICs).

This study can form the basis for future parameterisation of the FLL's dynamic behaviour (TIC) and consequently its distinction to its exact type (e.g. Focal Nodular Hyperplasia, Haemangioma, Hepatocellular Carcinoma). Further improvements should include its extension to a fully-automated method, helping to assess the repeatability and reproducibility of a CEUS examination and the diagnostic procedure on different patients or between different clinical centres. Also, addressing the issue of dispersion in depth and/or out-of-plane movement (i.e. learning to recognise when the lesion is not visible in the image plane) would provide a more accurate and confident TIC leading to an improved characterisation rate.

Personal information

Spyridon Bakas, B.Sc., M.Sc.

Digital Imaging Research Centre

School of Computing and Information Systems

Faculty of Science, Engineering and Computing

Kingston University, London, U.K.

s.bakas@kingston.ac.uk

Paul S. Sidhu, B.Sc., MBBS, MRCP, FRCR DTM&H

Department of Radiology

King's College Hospital, Denmark Hill, London, U.K.

paulsidhu@nhs.net

Maria E. Sellars, MBBS, FRCR

Department of Radiology

King's College Hospital, Denmark Hill, London, U.K.

maria.sellars@nhs.net

Gordon J.A. Hunter, B.A., M.Sc., Ph.D.

School of Mathematics

Faculty of Science, Engineering and Computing

Kingston University, London, U.K.

g.hunter@kingston.ac.uk

Dimitrios Makris, Ph.D.

Digital Imaging Research Centre

School of Computing and Information Systems

Faculty of Science, Engineering and Computing

Kingston University, London, U.K.

d.makris@kingston.ac.uk

Katerina Chatzimichail, MD

Radiology & Imaging Research Centre

Evgenidion Hospital, University of Athens, Greece

katerina@hcsl.com

References

[1] Ambai M. and Yoshida Y., "CARD: Compact And Real-time Descriptors", IEEE International Conference on Computer Vision (ICCV) 2011;2011:97-104.

[2] Bakas S., Hoppe A., Chatzimichail K., Galariotis V., Hunter G., and Makris D., "Focal Liver Lesion Tracking in CEUS for Characterisation Based on Dynamic Behaviour", Advances in Visual Computing, Lecture Notes in Computer Science 2012;7431:32-41.

[3] British Liver Trust, "http://www.britishlivertrust.org.uk/home/looking-afteryour-liver.aspx" Website, (Date of last access: 09 December 2011), 2011.

[4] Department of Health - National Institute for Health and Clinical Excellence (NICE), "Diagnostic guidance 5 - Sonovue (sulphur hexafluoride microbubbles) - Contrast Agent for Contrast-enhanced Ultrasound Imaging of the Liver: Full Guidance", http://www.nice.org.uk/dg5, 2012.

[5] Gower J., "Generalized Procrustes Analysis", Psychometrika 1975;40:33-51.

[6] Hasebroock K.M., and Serkova N.J., "Toxicity of MRI and CT contrast agents", Expert Opin Drug Metab Toxicol 2009;5(4):403-416.

[7] Liver Cancer Mortality Statistics: Cancer Research UK - Website, "http://www.cancerresearchuk.org/cancer-info/cancerstats/types/liver/mortality/", (Date of last access: 20 December 2013), 2013.

[8] Rognin N.G., Mercier L., Frinking P., Arditi M., Perrenoud G., Anaye A., Meuwly J.Y., "Parametric imaging of dynamic vascular patterns of focal liver lesions in contrast-enhanced ultrasound", IEEE International Ultrasonics Symposium (IUS) 2009:1282-1285.

[9] Strobel D., Seitz K., Blank W., Schuler A., Dietrich C.F., vonHerbay A., Friedrich-Rust M., and Bernatik T., "Tumor-specific vascularization pattern of liver metastasis, hepatocellular carcinoma, hemangioma and focal nodular hyperplasia in the differential diagnosis of 1349 liver lesions in contrast-enhanced ultrasound (CEUS)", Ultraschall in der Medizin 2009;30(4):376-382.

[10] Westwood M.E., Joore M.A., Grutters J.P.C., Redekop W.K., Armstrong N., Lee K., Gloy V., Raatz H., Misso K., Severens J., and Kleijnen J., "Contrast-enhanced Ultrasound Using Sonovue® (sulphur hexafluoride microbubbles) Compared with Contrast-enhanced Computed Tomography and Contrast-enhanced Magnetic Resonance Imaging for the Characterisation of Focal Liver Lesions and Detection of Liver Metastases: a Systematic Review and Cost-effectiveness Analysis", Health Technology Assessment 2013;17(16).

[11] Wilson S.R. and Burns P.N., "An Algorithm for the Diagnosis of Focal Liver Masses Using Microbubble Contrast-enhanced Pulse-inversion Sonography", American Journal of Roentgenology 2006;186:1401-1412.