All-Optical Ultrasound for Real-Time, Video-Rate Imaging of Radio Frequency Ablation Lesions

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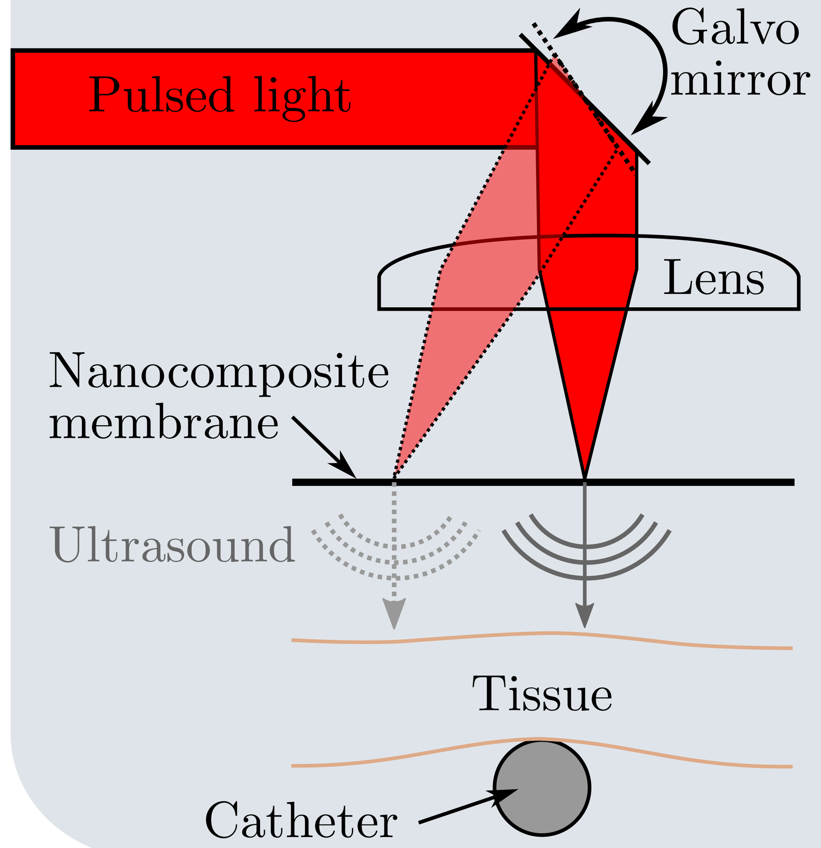
1. Introduction

Real-time imaging of the formation of **radiofrequency (RF) ablation** lesions is challenging. Conventional modalities (MRI, CT) are severely limited by RF noise, electronic interference, low resolutions and poor tissue contrast, and only yield images pre- and post-ablation. Here we present a novel, high resolution **all-optical ultrasound imaging** system that employs laser light to generate and receive ultrasound. Insensitive to electromagnetic interference, this system is ideally suited to real-time visualisation of RF ablation lesion delivery, as is demonstrated here on *ex vivo* tissue samples.

2. Methods

All-optical ultrasound imaging is an emerging modality exhibiting **high resolutions** and a **high sensitivity**. This sensitivity is retained upon probe miniaturisation, which enabled real-time, minimally invasive *in vivo* M-mode imaging [1]. Here, we present a novel benchtop all-optical ultrasound imaging system that for the first time allows for video-rate, real-time B-mode imaging.

The benchtop system comprised a pulsed laser that was focussed onto a nanocomposite membrane optimised for **photoacoustic ultrasound generation** [2], and a tunable laser interrogating a miniature (diameter: 125 µm) **fibre-optic ultrasound receiver** [3]. Scanning the pulsed light permitted synthesis of an optimised, broad aperture, and **real-time processing and image reconstruction** were performed in parallel processes.



RF ablation was performed (max. 30W, 65°C, 60 s) on both homogeneous (chicken breast) and inhomogeneous (pork belly) samples, while continuously acquiring and displaying 2D images.

Frame rate:	9 Hz
Imaging depth:	15 mm
Resolution:	100 µm
Dynamic range:	30 dB

3. All-Optical Ultrasound Imaging Results

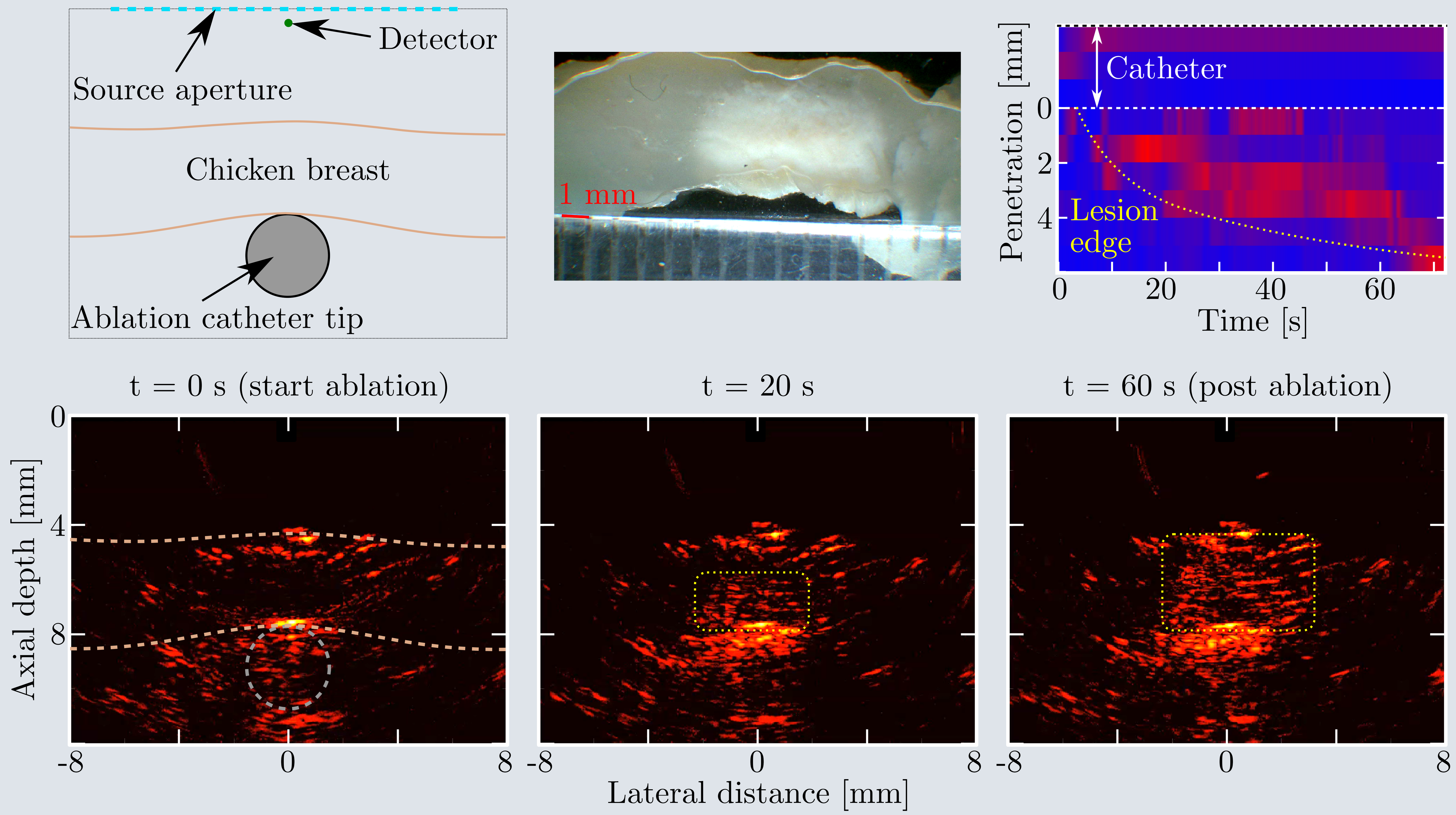


Figure 1 **Top:** schematic of experimental setup, photograph obtained post-ablation, and M-mode image acquired along the central lateral image line. **Bottom:** 2D B-mode images acquired in real-time, showing the ablation lesion at different time points as interpreted from the ultrasound images.

4. Discussion and Conclusions

A novel, all-optical ultrasound imaging system is presented that can acquire 2D B-mode images up to three orders of magnitude faster than the current state-of-the-art. This system is capable of real-time visualisation of lesion growth, up to a penetration depth of 8mm, despite the presence of strong electromagnetic fields and temperature gradients. RF lesions generated in *ex vivo* tissue samples were successfully imaged with the catheter placed either in front of or behind the tissue, and M-mode imaging allowed for tracking of lesion growth up to a penetration depth of 5 mm. Homogenous tissue samples exhibited isotropic lesion growth, whereas for inhomogeneous tissue samples anisotropic lesion growth was observed. These results demonstrate the viability of this technology for clinical implementation and *in vivo* RF ablation monitoring.

Ablation videos:

[1] Finlay *et al.*, Light Sci Appl 6(e17103), 2018
[2] Noimark and Colchester *et al.*, Adv Funct Mat 28(9), 2018
[3] Guggenheim *et al.*, Nature Phot 11(714), 2017

US generator:	50 µm thick composite of MWCNT-PDMS [2]
Source array:	200 sources, 200 µm source width, 13 mm aperture, 2 MHz high-pass filter
Optical excitation:	3 kHz pulse repetition rate, 76 µJ pulse energy, 5 ns pulse duration, 1064 nm
Optical detection:	40 Pa noise equivalent pressure, 1-80 MHz bandwidth, omni-directional sensitivity

This work was supported by an ERC Starting Grant [310970 MOPHIM], the EU project FAMOS [FP7 ICT, Contract 317744], the Innovative Engineering for Health award by the Wellcome Trust [WT101957] and the EPSRC [NS/A000027/1], the EPSRC Doctoral Prize [EP/N509577/1], the ESPRC Healthcare Innovation Challenge Award [EP/N021177/1], and the Ramsay Memorial Trust. The authors declare no conflicting interests.

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