Real-time pupilometer implementation using three-dimensional volumetric ultrasound imaging

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Background, Motivation and Objective

Pupillary light reflex (PLR) is a useful diagnostic tool exploited in a wide range of clinical applications including assessment of traumatic head injuries. However, direct visual evaluation of PLR is time consuming, observer dependent, and difficult to be performed in a patient with hyphema or severe skin damage. Ocular ultrasound (US) could be an effective and safe method to assess PLR. Unfortunately, the coronal visualization of the pupil with traditional 2D US imaging is difficult and results in decreased accuracy and reliability of the measurements. Thus, this work investigates the feasibility of the volumetric US imaging for the PLR evaluation.

Statement of Contribution/Methods

Excised porcine eyes, embedded in a stiff gelatin substrate to mimic the tissue environment, were used for evaluation of multi-planar imaging capability. To investigate if real-time 3D US imaging can serve as a dynamic pupilometer, the motion of the stainless-steel iris diaphragm was used to mimic the pupil dynamics. A 1024-element 2-D matrix array in an arrangement of 32×32 grid was connected to a fully-programmable 256-channel Vantage system through the 4-to-1 high voltage multiplexer. Multiple diverging US waves (single cycle at 5 MHz) were emitted from 25 virtual sources and backscattered waves were coherently compounded to generate a single volume. Virtual sources were distributed over a spherical surface centered at the negative focal point beyond the transducer surface. Total 100 volumes were acquired at the speed of 30 Hz. For C-scan image reconstruction, the maximum intensity projection was used.

Results/Discussion

In multi-planar imaging, the anatomical features at different depths can be color-coded and superimposed to create a coronal image (Fig. 1A). Volume scan (Fig. 1B) provides more intuitive understanding of the anterior segment of the eye anatomy. In dynamic measurements, an artificial iris movement was captured over 900 ms (Figs. 1C-D). Overall, the developed 3D US imaging system and approach can capture and visualize the movement of the artificial pupil in real-time with sufficient temporal and spatial resolution to evaluate the PLR, and have shown potential to become an accurate, real-time, operator-independent ultrasonic pupilometer.

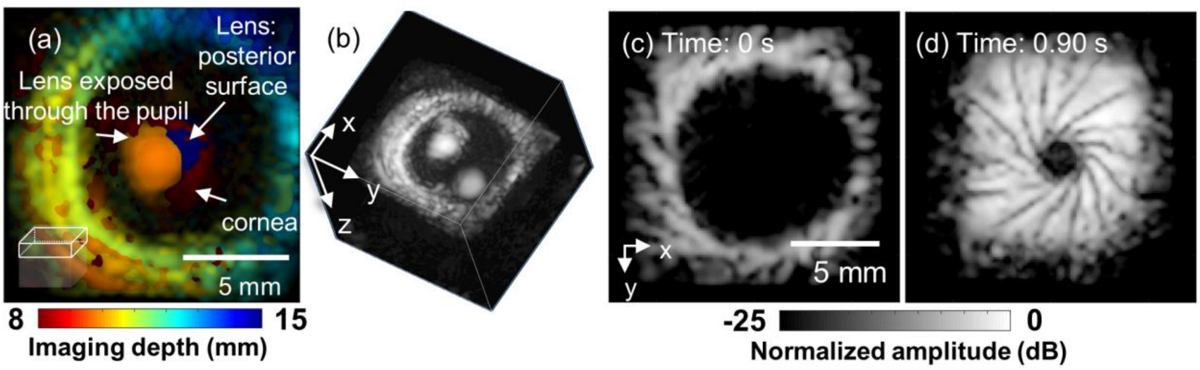

Figure 1. Multi-planar imaging of *ex vivo* porcine eyeball phantom and *in vitro* pupil mimic phantom. (a) The depth-color-coded maximum intensity projection image of the *ex vivo* eyeball rendered from (b) 3-D ultrasound image. Real-time (30 volumes per second) C-scan images of the artificial pupil movement recorded for (c) the initial open and then, 0.9 s later, (d) nearly closed iris.