High-frame rate multi-meridian corneal imaging of air‑puff induced deformation for improved detection of keratoconus

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**Abstract:** Corneal biomechanics plays a fundamental role in the genesis and progression of corneal pathologies, such as keratoconus. It also contributes to corneal remodeling after corneal surgery, and it affects the measurement accuracy of glaucoma biomarkers, such as the intraocular pressure (IOP).  Air-puff induced corneal deformation imaging reveals information that potentially differentiates normal and pathological corneal response to a non‑contact mechanical excitation. However, current commercial systems are limited to monitoring corneal deformation only on one corneal meridian, reducing their sensitivity to keratoconus, as the weakened region is often eccentric. Here, we present a novel air‑puff induced corneal deformation imaging system, based on a high-frame rate swept source optical coherence tomographer. The system is capable of detecting deformation on planes distributed over the corneal surface. We designed two scan patterns covering a transverse field-of-view of up to 15 mm, at a pattern repetition rate of 1 kHz, afforded by a galvanometer scanning mirror system with extremely low coil impedance. We provide nearly unobstructed views of the corneal surface through a modified collinear piston‑based air‑puff unit. We set the air‑puff duration and maximum pressure, by controlling the piston’s speed through custom electronics. We validate the need for such an instrument via numerical simulation of both healthy and keratoconic corneal deformations with FEA models. We introduce and obtain metrics of deformation and asymmetry in *ex vivo* keratoconus-mimicking *ex vivo* porcine eye, where the treated inferior area was made deliberately softer than the untreated superior cornea. Firstly, we confirmed the strong influence of IOP on corneal deformation parameters. Secondly, we detected deformation asymmetries in air-puff deflected areas up to 0.50 mm2 for the vertical meridian, otherwise missed on a single meridian. Moreover, we present first results of the system in a pilot clinical study on both healthy human eyes and a keratoconic eye *in vivo.* We believe that our novel multi‑meridian corneal deformation imaging system will substantially aid in corneal biomechanics diagnostics and pathology screening.