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Introduction

Pediatric cornea patients present unique challenges in terms of both diagnosis and management. Obtaining an accurate and complete history and examination is especially challenging with younger patients. Fortunately, an ever-increasing array of ophthalmic imaging tools can assist in making correct diagnoses, explaining pathology to both patient and family members, and managing many corneal conditions. This chapter will discuss when to consider various ophthalmic imaging modalities, including photography, specular or confocal microscopy, anterior segment optical coherence tomography, ultrasound, ultrasound biomicroscopy (UBM), topography, and keratometry.

Photography

When to use: Detailed slit lamp examination is critical for the diagnosis and management of most corneal pathology. This can be especially challenging in pediatric patients, who may not be able to position appropriately or remain still (Figs. 2.1a and 2.2a). High-resolution photographs, which are useful to document findings and monitor progression, are especially useful in pediatric patients, though they are not always possible. A length standard can be included in the image to facilitate corneal diameter measurements, which is especially useful in patients with small (microcornea or microphthalmos) or large (megacornea or congenital glaucoma) corneas (Puvanachandra and Lyons 2009). To provide the highest quality images, the examiner should select a camera based on both patient characteristics (age, level of cooperation, and degree of photophobia) and level of detail needed.

Options available: Slit lamp cameras can be used with cooperative children who are able to sit at the slit lamp and focus at a specific location. Children as young as 3 years of age, who are cooperative, can often position at the slit lamp, as long as the chair and headrest are adjusted properly.

A video capture technique, which will tolerate a degree of motion greater than is acceptable for standard flash-based slit lamp imaging systems, can be useful in children who are unable to maintain focus (Mireskandari et al. 2011). The video capture technique can also be used to image

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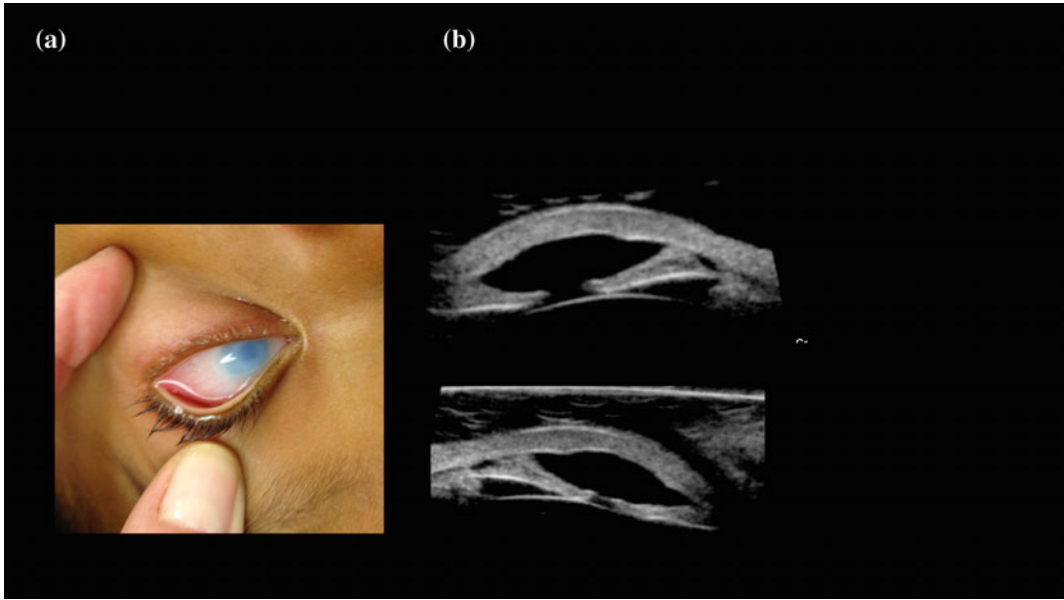


Fig. 2.1 A 1-week-old boy presented with a cloudy left cornea (a), noted at birth. On exam, the left cornea was opacified, the intraocular pressure was 9 in the right eye and 10 in the left eye, and the vision was blink to light in both eyes. At age 10 months, an exam under anesthesia with ultrasound biomicroscopy was performed to

determine the extent of the pathology. The ultrasound biomicroscopy showed a thickened cornea, extensive iridocorneal adhesions without any lenticular corneal adhesions and an atrophic ciliary body consistent with Peter's anomaly (b). The decision was made not to proceed with corneal surgery

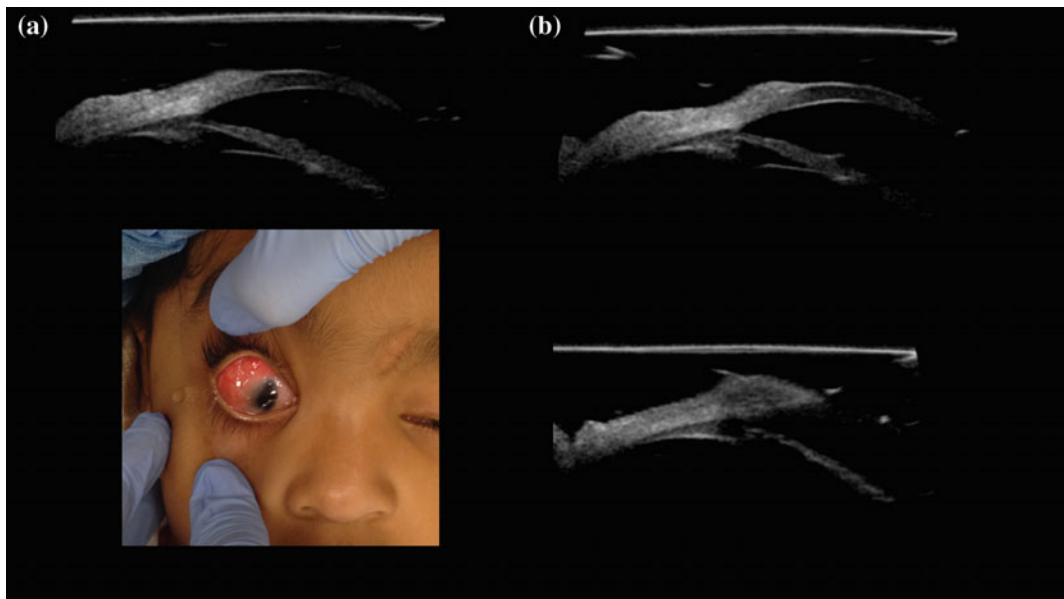


Fig. 2.2 A 4-year-old boy presented with a diffuse dome shaped lesion, covering part of the left cornea (a). A UBM was performed, which revealed a diffuse dome-shaped elevation of the corneal/scleral interface measuring approximately 0.97 mm. There appeared to be a

demarcation line identified but the lesion did appear to extend into the corneal interface (b). The lesion was removed and the pathology report came back as “conjunctiva lining dense connective tissue with hair follicles, adipose tissue, and nerves, consistent with a dermoid”

dynamic phenomenon such as Seidel tests, phacodonesis, and subtle eye movement anomalies.

Children who are photophobic and unable to tolerate the minimum light requirement associated with slit lamp photography can sometimes be imaged using simple digital single-lens reflex cameras with medium telephoto macro lenses with a ring flash setting to minimize shadows (Mireskandari et al. 2011).

An increasing number of adaptors are now available for various smartphones, most specifically the iPhone® and these can be used to obtain ophthalmic images. Some of these adapters are specifically designed for use in conjunction with the slit lamp, the indirect ophthalmoscope, or the direct ophthalmoscope, but others allow the smartphone itself to be used as the primary device, often with a relatively low level of light (Myung et al. 2014). These are especially useful in children since many children feel more comfortable with a smartphone than with traditional ophthalmic imaging systems.

When used to image the anterior segment, fundus cameras lead to images with peripheral distortion, so their usefulness is limited in this setting. However, in patients with posterior segment pathology, the convenience of imaging both the anterior segment and the posterior segment with a single device may be worth sacrificing some peripheral details.

Microscopy

When to use: Confocal and specular microscopy can be used both to establish an initial diagnosis and to monitor patients over time. This high-resolution imaging modality is indicated when there is need for detailed imaging of a specific cell type, most commonly the endothelial cells. Specular microscopy can be used to assess endothelial cell counts both pre- and postoperatively.

This is especially useful in cases of congenital hereditary endothelial dystrophy (CHED). Patients with CHED have traditionally been treated with penetrating keratoplasty (PKP) for replacement of damaged endothelium, a technique associated with multiple long-term

complications, including need for suture removal (often under anesthesia in children), risk of neovascularization, rejection, and loss of structural integrity of the cornea. However, Descemet's stripping endothelial keratoplasty (DSEK) is becoming an accepted treatment for CHED and may lead to lower complications, relative to PKP, in pediatric cases (Busin et al. 2011). As DSEK becomes more commonly performed in children, long term studies comparing the complication rates and endothelial cell loss between these two techniques will be critical to help determine the best surgical choice for these patients. Specular microscopy is critical to follow the endothelial cell count and morphology in these patients pre and post operatively.

Confocal microscopy provides extremely high-resolution imaging of specific regions of the cornea and is a useful tool in management of complex corneal infections, especially fungal and acanthamoeba infections. Though the gold standard for diagnosis of corneal ulcers, especially fungal and acanthamoeba, remains microbial culture, there is debate over the ideal culture medium for specific microorganisms (Boggild et al. 2009). Additionally, not all ophthalmic offices are equipped with onsite microbiology laboratories, so turn around time for these cultures can be significant. Therefore, in centers where confocal testing is available, it can provide a useful adjunct to microbial cultures. It can also be used to follow patients over time, and is especially useful when the infection is located in the deeper layers of the cornea (which often occurs with both fungal and acanthamoeba infections) (Oldenburg et al. 2011; Keay et al. 2011).

Confocal microscopy can also be used to assess morphological changes in the epithelium and stroma following corneal cross-linking in patients with keratoconus (Mazzotta et al. 2001). As corneal cross-linking becomes more widely performed, this will become increasingly relevant. Also, as this treatment modality is relatively new, data regarding the long term (greater than 10 years) effects on the morphology as well as the topography of the cornea will be critical to access the safety as well as the efficacy of the treatment.

Options available: Though only available in large, primarily academic centers, the confocal microscope allows the clinician to examine and image individual cells in all layers of the cornea. The specular microscope, is more readily available and allows for a similar level of high-resolution imaging, but is limited to the endothelium. Endothelial cell counts can be followed using specular microscopy in children who are able to maintain position in camera chinrest and who are able to focus. Though the confocal microscope is able to image a wider range of cell types and cell layers, it is much more challenging to use in children. The scan times are significantly longer for confocal microscopy versus specular microscopy and many models require the use of a coupling gel, which further limits tolerability in children.

Anterior Segment Optical Coherence Tomography (OCT) Ultrasound Biomicroscopy (UBM) and Posterior Segment Ultrasound

When to use: Both anterior segment OCT and UBM are useful for imaging the structures of the anterior segment, including all layers of the cornea, the iris, and the morphology of the angle. Therefore, they are useful in imaging patients with both congenital and acquired anomalies of the anterior segment, including tumors (Fig. 2.2b), Peter's anomaly (Fig. 2.1b), ICE syndrome, congenital glaucoma, and following ocular trauma (Cauduro et al. 2012). Both anterior segment OCT and UBM can be useful in the pre and postoperative management of patients (Nesi et al. 2012). Vengayil et al. reported the use of OCT to enable visualization of a retained host Descemet membrane following PKP for CHED, before and after surgical removal (2008).

Though the structures imaged by the UBM and anterior segment OCT are similar, there are some differences between the two modalities. The primary difference is that OCT requires a relatively clear cornea and media, since it relies on light for imaging. This precludes its use in patients with opaque corneas. Since ultrasound relies on sound

waves, this imaging modality is especially useful when corneal opacities limit the view to the anterior and posterior segments. In complex diagnostic cases with co-existing anterior segment dysgenesis, the UBM can be used to assess the need for additional procedures and surgical approach prior to corneal transplantation, including cataract extraction, intraocular lens implantation, iris reconstruction, and glaucoma procedures. UBM is also helpful in planning tumor excision. For anterior segment tumors, the UBM offers overall better anatomic resolution, especially of posterior tumor margins. The anterior segment OCT, however, demonstrates better resolution of anterior tumor margins (Bianciotto et al. 2011).

The contact B-scan is used to scan the posterior segment of the globe to identify pathology. Examples of this would be vitreous debris or various types of choroidal lesions, excavation of the optic nerve head, and orbital pathology. In pediatric patients, B-scan often visualizes the superior ophthalmic vein within the intraconal space.

Options available: Anterior segment OCT is a noncontact device and can thus be more readily employed when examining children, provided they are able to position and fixate. Anterior segment OCT uses a superluminescent light-emitting diode with a wavelength of 1310 nm to image the cornea (Izatt et al. 1994). The anterior segment OCT can penetrate 3–4 mm and has a resolution of 18 μ m.

UBM is a high-frequency, 20–50 MHz, and has an axial resolution of approximately 30 microns depending on the frequency. Higher frequency ultrasound leads to shallower penetration of the ultrasound wave and better resolution of the image. There are a number of commercially available UBM systems with transducer ranges between 20 and 50 MHz.

There are two UBM scanning techniques, both require contact to the eye either with saline use as a standoff or gel as a contact medium.

The Immersion Method

To perform an immersion scan, the eye is anesthetized, a scleral shield is placed securely under

eyelids. The shield is then filled with a coupling solution, usually sterile saline. Since this is an open system the transducer can be moved closer or further away from the eye, allowing the area of interest to be kept within the focal zone. For safety reasons it is important the immersion technique only be performed during an examination under anesthesia (EUA) for the pediatric population.

The Contact Method

Standoff caps are available in 4 depths, the most common is the 3.5–4.5 mm. The standoff cap is inserted over the transducer, filled with saline/distilled water, then covered with a thin barrier such as Tegaderm (3 M). Tegaderm is a sterile transparent dressing which is waterproof and a viral barrier used often as over IV sites. A generous amount of coupling agent such as Genteal gel[®] is then used between the probe cover and the cornea. There is no contact of the transducer to the cornea since the transducer is on the surface of the gel.

The ClearScan Probe cover system (ESI, Inc) is a similar technique, in which the sterile probe cover is filled with saline/distilled water and the transducer is placed into the probe cover. A coupling agent such is then used between the probe cover and the cornea. However, there is direct contact to the cornea with this technique.

Images through closed lids can be obtained with the contact methods, with limited diagnostic information.

The primary difference between UBM and conventional B-scan technology is the frequency of the ultrasound. B-scan uses 10–12.5 MHz frequency, which is primarily used for imaging of the posterior segment due to its deeper penetration and lower resolution. However, B-scan systems can be modified with a standoff to allow anterior segment scanning. The focal zone of the B-scan transducer typically starts approximately 15 mm from the scanning surface. Therefore, it is important that the area to be examined be within the focal zone.

Topography

When to use: Corneal topography is especially important for preoperative assessment and for postoperative management of pediatric patients undergoing corneal surgery. Children with keratoconus require serial topography for assessment of progression (Fig. 2.3a, b). Though collagen cross-linking is not yet FDA approved in the United States, several clinical trials evaluating its use are underway, and inclusion criteria are based largely on topographical parameters (Kankariya et al. 2013). Patients between the ages of 12 and 35 years with keratoconus may be candidates for one of these trials based on their corneal topography. Enrollment varies depending on the trial, but generally requires a minimum corneal thickness of at least 400 μm and a maximal keratometry of less than 60 diopters, as well as the absence of additional corneal pathology, including infection and visually significant scarring (Keating et al. 2010).

Among patients with irregular or opacified corneas, autokeratometers may be inaccurate and topography may therefore be a more reliable option for intraocular lens calculations, when indicated. Finally, topographic analysis of pediatric patients is important following corneal transplantation, to direct suture removal and assist in contact lens fitting when needed.

Options available: Optical, placido disc, or Scheimpflug topography can be used to access corneal steepening across multiple areas of the cornea and are widely available.

Keratometry

When to use: Keratometry is necessary to calculate optimal lens power and is thus essential prior to intraocular lens implantation, which is becoming a more accepted part of pediatric cataract surgery (The Infant Aphakia Treatment Study Group 2014). In rare instances, pediatric patients with anisometropic amblyopia who are unable to tolerate correction with glasses or contact lenses can be considered for refractive

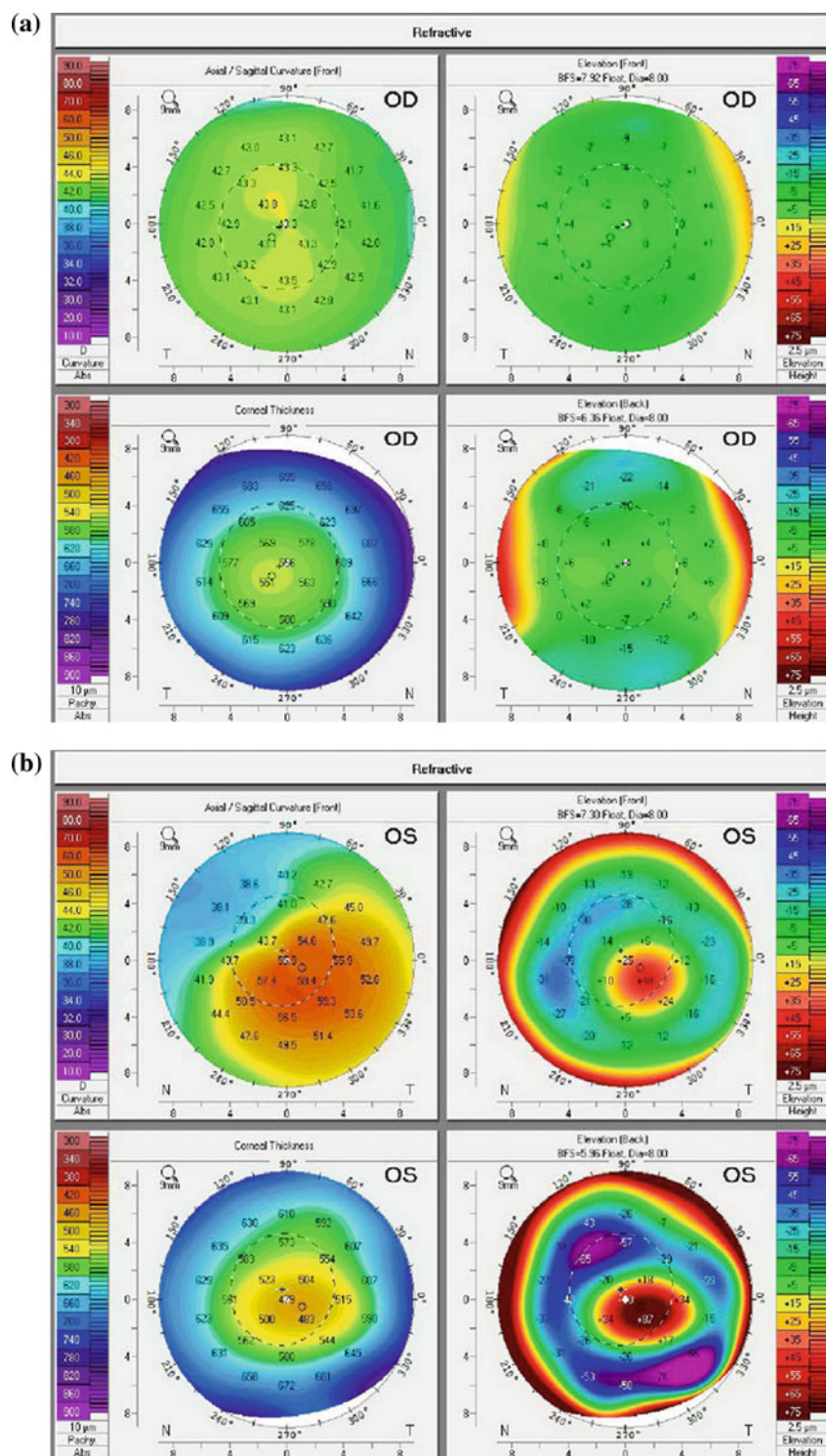


Fig. 2.3 A 14-year-old boy presented with blurry vision in his left eye, progressing over approximately 2 years. His vision was 20/20 in his right eye (a) without correction and counting fingers in his left eye without correction, and with a refraction of $-4.25 - 5.25 \times 146$. One year prior to our exam, he was seen by an outside optometrist and per those records, he was 20/20 in the right eye and 20/50 in the left eye without correction. At that time, the vision in his left eye had corrected to 20/20 with $+0.50 - 1.50 \times 115$. Tomographic imaging showed inferior paracentral steepening and associated thinning, typical of keratoconus, in the left eye only (b). Based on his topography, the rapid decrease in his vision, and his relatively young age, the decision was made to enroll him in a corneal cross-linking clinical trial

surgery, in the form of phakic anterior chamber intraocular lens implantation, refractive lens exchange, or corneal refractive laser ablations (Pirouzian 2011). Though refractive surgery for children remains controversial and is not FDA approved, it is an area of growing interest that will require accurate keratometry measurements.

Options available: Keratometry can be performed as part of a complete exam under anesthesia using a handheld autokeratometer (Capozzi et al. 2008). Older children who are able to sit at the slit lamp and focus may be able to have ocular biometry measurements performed using the IOLMaster (Carl Zeiss Meditec, Jena, Germany) or Lenstar LS 900 (Haag-Streit AG, Koeniz, Switzerland) (Sahin et al. 2011).

Discussion

Ophthalmic imaging has traditionally been used primarily to document exam findings, but as technology evolves, newer imaging modalities enable the ophthalmologist to view structures not visible on ophthalmic examination. This includes individual cells in the cornea, not visible with even the highest slit lamp magnification. Additionally, corneal opacification no longer precludes examination of anterior segment structures, as they can be imaged using UBM. Corneal topography allows quantification of corneal power and thickness, which facilitates both diagnosis and perioperative management.

For children, the appropriate use of these imaging modalities is especially important. For very young children, it is especially critical to acquire all necessary information to limit the number of examinations required since these examinations may need to be performed under anesthesia. Additionally, when surgical intervention is required in children, precise postoperative management is critical to reduce risk of amblyopia. Finally, these imaging tools can be a valuable addition to discussions with patients and family members, since an ophthalmic image can be worth more than a thousand words when explaining a complex ocular condition to a family.

Compliance with Ethical Requirements Christina Prescott, Lois Hart, and Kathryn Colby declare that they have no conflict of interest. No human or animal studies were carried out by the authors for this article.

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