Diagnostic Contact Lenses for Ophthalmic Examination

Greg Heacock PhD and Louise Culham PhD MCOptom

Rayne Institute, St Thomas' Hospital, London
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Introduction

We are fortunate that the eye can readily be examined both externally and internally with the globe intact. In contrast to other medical disciplines, eye care professionals may view internal structures of the eye using relatively simple, non-invasive instrumentation. As the optometric profession plays an increasingly essential role in the detection and management of ocular abnormalities, it is important that practitioners are equipped with a broad skill set and a range of instrumentation. Practitioners are familiar with the head-mounted indirect ophthalmoscope and non-contact indirect biomicroscopic lenses for use at the slit lamp. Many optometrists elect to use one or both of these techniques in addition or in preference to direct ophthalmoscopy. At present uncommon in optometric practice, direct and indirect contact lenses offer an alternative means of ophthalmic examination. Our medical colleagues use contact lenses routinely for diagnosis and treatment and there are clear reasons for doing so. The main advantages of contact lenses, compared with non-contact lenses, include: (1) the improved image quality (Bock 1977); (2) the ability to view more of the fundus and in particular the peripheral fundus (Lobes et al. 1981); and (3) the ability to view the internal anterior segment and, specifically, the anterior chamber angle (Fankhauser et al. 1996, Ritch 1985). Although contact lenses will not displace the more traditional methods of examination, they may be a useful addition to an optometrist's repertoire. The purpose of this paper is to review the optics of direct and indirect-viewing devices, to consider applicable designs of common contact lenses and to outline their uses and advantages.

Review of Direct and Indirect Viewing

As with all optical systems for examining ocular structures, there are two essential categories of contact lenses: those for direct viewing and those for indirect viewing (Mainster et al. 1990, Rol et al. 1988). Brief revision of ray traces describing each lens type will be useful for understanding their optical design.

Direct viewing

Figure 1 shows the position of the image of the patient's fundus (in the virtual image plane) relative to the contact lens and the practitioner. This image is virtual and upright. It is presented to the optometrist without any intermediate image plane and observation of the image occurs by bringing the biomicroscope's plane of focus coincident with the region of interest, ie the slit lamp must be focused on the virtual image and in practice this means moving the slit lamp towards the patient. For interpretation of the image centrally, no reversal is required. When a mirror is employed, the practitioner must remember that the region being observed is opposite from the location of the mirror, as seen in Figure 1.
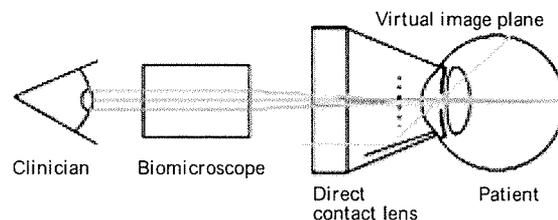

Figure 1 Ray trace of direct viewing.

Indirect viewing

When using an indirect contact lens the practitioner must move the focal plane of the biomicroscope to a location that is coincident with the real image produced by the lens (Figure 2); this means moving the slit lamp further away from the patient. As the image is inverted and reversed, turning the paper upside down when drawing the clinical picture is an easy method of recording the image orientation correctly.
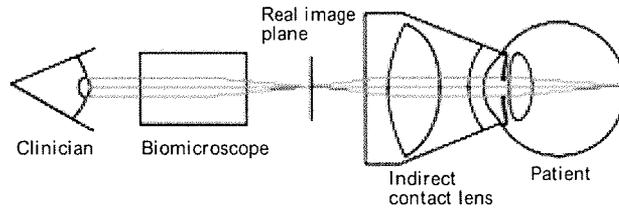
Address for correspondence: Dr G Heacock, Light Sciences Corporation, 34931 SE Douglas Street, Suite 200, Snoqualmie WA 98065, USA.
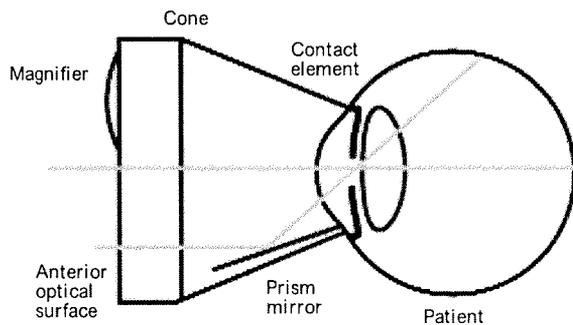
Figure 2 Ray trace of indirect viewing.

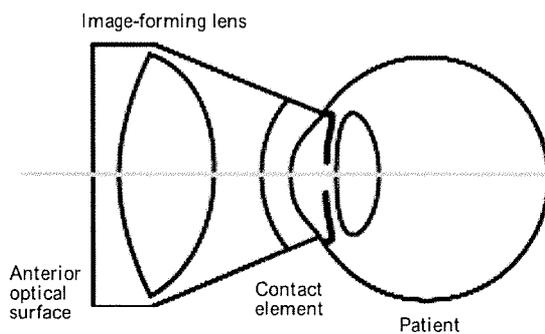Figure 3 Basic components of a direct contact lens.

Figure 4 Basic components of an indirect contact lens.

Generic Design of Contact Lenses

All types of contact lenses share basic components. They all have a housing cone, an anterior optical surface (commonly referred to as anterior optic or anterior surface) and a contact element (or endpoint) (Figure 3). A direct contact lens usually has one or more mirrors, and in some designs a magnifier (Figure 3). Indirect lenses have an image-forming lens (Figure 4), and in some cases an intermediate field lens.

The housing cone serves as a hermetic seal for the optics, and offers a textured finger grip for use during procedural manipulations. The anterior optic presents an additional optical surface that may be shaped to alter image magnification.

There are three styles of contact element geometry: (1) standard; (2) flange style; and (3) a further development, no methylcellulose required (NMR) (Kapetansky 1988). A standard contact element comprises two different curves, the base curve and the scleral curve. The base curve usually has a radius of curvature of approximately 7.5mm. This curvature is slightly steeper than the average corneal curvature of 7.8mm. When this steeper base curve is surrounded by a scleral radius of curvature of 12.25mm (which closely fits the sclera), a geometric gap of 0.3mm is formed with respect to the vertex of the cornea.

Goldmann taught that the contact element should be filled with methylcellulose or water, and when the contact lens is placed on the cornea, a portion of the interface fluid would be forced from the geometric vault (Goldmann 1949, Kapetansky 1988). The resulting hydraulic forces act to suck the cornea into the base curve, thus increasing contact lens to eye coupling and decreasing the possibility of air bubbles at the optical interface. Further benefits provided by this geometry are the reduction of wrinkles in the cornea and a fluid buffer to protect the corneal epithelium.

Flange-style contact element geometry is also based on the teachings of Goldmann; however the peripheral edge of the contact element is extended 2mm, forming an annular lip around the endpoint. This lip increases the stability of the contact lens and makes it nearly impossible for the patient to squeeze the eyelids and force the lens away from the cornea.

NMR contact element geometry is a modification of the Goldmann design. The NMR base curve has a radius of curvature that is approximately 8.0mm. The scleral curve is the standard 12.25mm radius. This endpoint geometry is designed to match closely the patient's corneal profile, thus using only the patient's tear as the interface fluid.

Basic Design of Direct Contact Lenses

In the most simplistic form, a direct contact lens comprises only two optical surfaces, one matching and reversing the power of the patient's cornea, and another that is planar (ie a flat surface with no optical power). A contact lens with such a basic design is commonly referred to as a fundus lens (Fankhauser et al. 1996, Mainster et al. 1990, Rol et al. 1988). But often, optical power is introduced either by adding a positive curvature to the anterior surface or by bonding a plano convex magnifying lens to the anterior surface. Extra power means that the magnification is increased from the basic value (for a fundus lens) of 0.93× to a maximum of 7× (Peyman 1984, Wise et al. 1986). Of course, higher magnification is only gained at the expense of the field of view.

In the most complicated form, direct contact lenses have additional positive power and also mirrors. These mirrors allow the clinician to observe eye structures away from the central axis of the eye. Contact lenses that have three mirrors and a fundus lens are usually referred to as 'Goldmann-type lenses'. In nearly all contact lenses, the mirrors are actually planar surfaces formed from prisms. These mirrors use total internal reflection (TIR) to redirect the observation axis to the internal eye tissues of interest.

By varying the angulation of the TIR prism surfaces, the viewing axis offered by a mirror in a contact lens may be designed for the observation of specific regions of the eye. For example, mirror angles of 59–64° offer views of the trabecular meshwork and other structures in the periphery of the anterior segment of the eye (Ritch 1985). Steeper mirror angles such as 67–80° allow visualisation of equatorial to arcade regions in the posterior segment of the eye (Bock 1977, Goldmann 1949).

Often, manufacturers bond a thin glass cover slip to the anterior surface of the contact lens. This bonded cover glass has two advantages. Firstly, the glass is much more resistant to scratching than the optical plastic substrate which comprises the main element of the anterior aspect. Secondly, the glass is often coated with materials that reduce reflections from the slit-lamp biomicroscope illumination (Hill et al. 1988). Such special coatings must be applied at high temperatures that would destroy the plastic substrate, therefore they are deposited on to the glass cover, and this cover is then bonded into place.

Basic Design of Indirect Contact Lenses

Indirect contact lenses share the common basic components with direct lenses. The contact elements are of the same design and the cone, which acts as the optic fixture and hermetic seal, is similar. However, the similarities between direct and indirect contact lenses end there. The internal optical elements of indirect image-forming contact lenses employ significant positive optical power to form a real image of the fundus (Mainster et al. 1990). This is in contrast to the direct-viewing lenses which serve primarily to subtract or negate the optical power of the patient's cornea.

In their simplest form, indirect contact lenses have two essential optical components: the contact element and the image lens. The contact element is shaped on its posterior surface to fit the cornea (as previously described) and curved on its anterior surface to add 40–60D of optical power. The image lens is very similar in design to those used with a binocular indirect ophthalmoscope. The contact element and the image lens work together to form a real image of the fundus.

In another difference compared to direct-viewing lenses, off-axis viewing of eye tissues with indirect lenses is accomplished by increasing the field of view and not by the addition or angular adjustment of mirrors. A 'field' lens is inserted between the contact element and the imaging lens, collecting peripheral image light and directing it toward the image lens, thus presenting a fundus image with a larger field of view.

As mentioned above, antireflection coatings deposited on to the optical surfaces of contact lenses are important for the control of unwanted or dazzling reflections from illumination beams and lasers. The real image in an indirect lens is formed near the anterior of the lens and reflections from the front surface are particularly troublesome and must be minimised. Typically for these lenses, coatings are applied directly to the optical components before assembly.

Examination of Different Regions of the Eye

Selection of the type of contact lens to use in practice depends upon the structures to be studied. Direct-viewing contact lenses may be used to observe tissues in both the anterior and posterior segments of the eye. Indirect-viewing lenses are used for posterior eye-imaging only. Figure 5 shows the regions of the eye that may be visualised with each type and Table 1 indicates the best lens for viewing each zone (Fankhauser et al. 1996).

For direct-viewing lenses the mirror angle determines the region of view. Gonioscopy (region 6) is achieved with mirror angles of 59–64°, with 59° displaying more anterior structures, and 64° displaying those more posterior (Ritch 1985).
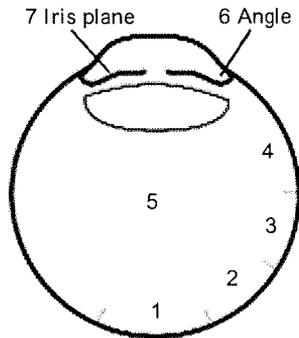
Figure 5 Regions of view within the globe.

Region 1 may be seen through the centre of the direct-viewing contact lens without employing any mirrors (Fankhauser et al. 1996, Yannuzzi & Slakter 1986). If the anterior surface of the contact lens has a concave shape, both regions 1 and 2 may be seen (Rol et al. 1988, 1999). With designs of this type, the optical magnification of tissues is approximately 0.62:1. For example, an optic nerve head with a diameter of 1500µm would appear smaller, ie a diameter of 900µm. Hence detail is lost, as the negative power of the optical surface minifies the image, but field of view is gained.

Region 2 may be viewed with mirror angles in a direct lens of 76–80°. Although this zone is difficult to observe with Goldmann-style contact lenses (because the most posterior-viewing mirror has an angulation of 76°), it is possible if the lens is tilted. Optimal direct viewing of area 2 is accomplished with the 80° mirror of a four-mirror Karachoff-style contact lens (Fankhauser et al. 1996). Mirror angles of 67–72° offer good views of region 3, the equatorial zone.

Region 4, the far periphery and ora serrata, is extremely difficult to visualise with any contact lens. To observe tissues in this area of the eye, external manipulation of the globe is required. The technique of physically displacing the tissue to a position where it may be seen (scleral depression) is typically undertaken by ophthalmologists searching for a peripheral retinal hole or tear. Once indented, an acceptable image of the far periphery is achieved by direct viewing with a mirror of approximately 67°.

Region 7 (the iris) is optimally observed with simple direct-viewing optics. Often these designs have plano convex magnifying lenses incorporated in the anterior surfaces (Abraham 1981, Schirmer 1983, Wise et al. 1986). The magnifiers may be located centrally or peripherally on the anterior lens surface depending on the imaging task for

Table 1 The optical features of common contact lenses and their application

Contact lens	Type	Image magnification[a]	Field of view	Region of view
Goldmann three-mirror style	Direct	0.93×	36° [b]	1–3, 5, 6 [c]
Fundus lens	Direct	0.96×	37°	1, 5
Karachoff four-mirror style	Direct	0.93×	37° [b]	1–3, 5, 6 [c]
Haag-Streit CGRL	Direct	0.6×	44°	1, 2
Kreiger	Direct	0.65×	42°	1, 2
Single-mirror gonio	Direct	0.93×	37°	1, 6
Four-mirror gonio (Zeiss style)	Direct	0.94×	37°	1, 6
Magna view gonio	Direct	1.3×	6°	6
Haag-Streit CGAL	Direct	1.4×	5°	6
Abraham style	Direct	1.5×	2°	7
Mainster standard	Indirect	0.96×	90°	1, 2
Area centralis	Indirect	0.96×	90°	1, 2
Mainster wide field	Indirect	0.67×	125°	1–3
Quadraspheric	Indirect	0.5×	130°	1–3
Mainster hi magnification	Indirect	1.25×	68°	1

[a] Emmetropic eye.   [b] Posterior pole field of view through lens centre.   [c] Region 4 with scleral depression only.

which the lens was designed. Centrally located magnifiers with optical powers of 15–30D are useful for viewing tissue or delivering laser therapies to the posterior capsule and crystalline lens (Peyman 1984). With the magnifier optic displaced to the edge of the anterior lens surface, the iris plane may be observed. Commonly, the optical power of these iris plane magnifiers is 30–80D. Some contact lens designs have magnifiers of up to 103D in power (Wise et al. 1986). Although high magnification of up to 7.8× may be helpful, optical aberrations may degrade image detail, reducing optimal imaging and dramatically affecting the field of view. With magnifiers of powers 2–15D integrated into the anterior direct-view lens surface, region 5 (the crystalline lens) is well observed (Peyman 1984).

In the case of indirect-viewing contact lenses, total optical power defines the maximum field of view. The optical power of an emmetropic eye is approximately 58D and this represents a magnification factor of 1. Indirect lenses having approximately 60D of total optical power generate images with approximately 1:1 magnification and display regions 1 and 2 (Mainster et al. 1990). When lower optical powers are employed – 30D, for example – image magnification is increased, field of view is reduced and only region 1 can be visualised. Indirect lenses with higher optical powers – 90D, for example – enable viewing in regions 1, 2 and 3 (Fankhauser et al. 1996). Fine image detail will be lost however, as the magnification will be reduced.

Selecting a Contact Lens

More than 150 contact lenses are available to eye care professionals. Selecting the optimal lens for a diagnostic investigation (or in a medical situation, therapeutic procedures) is a difficult task, often exacerbated by the limited and conflicting specifications published by lens manufacturers.

In selecting a contact lens for a particular purpose, the clinician must consider the region of the globe to be studied and the required magnification and field of view (Table 1). Ophthalmologists must also consider the influence of the contact lens on any therapeutic laser beam entering the eye. The optical power of a given contact lens has an effect on the size of features presented in the image, and also on the geometric size of laser beams focused on to eye tissues (Fankhauser et al. 1996, Mainster et al. 1990, Rol et al. 1988, 1999). Generally, contact lenses that produce images which minify the detail produce images with larger fields of view, and magnify the size of the laser beam on the target tissue. Conversely, contact lenses that generate images with a highly magnified detail provide smaller viewing fields, and minify the spot size of

therapeutic laser beams. Therefore the size of a therapeutic laser treatment spot is inversely related to the image magnification factor.

While any contact lens listed in Table 1 may be used for either diagnostic or therapeutic procedures, those used for laser treatment should be optimised by the addition of antireflection coatings on the optical surfaces. The coating needs to be specific to the laser wavelength and should exhibit a reflectivity of less than 0.5% at that wavelength (Hill et al. 1988). Alternatively, broadband coatings may be employed that offer less than 1.0% reflectivity across the entire visible spectrum (Ritch 1985, Ward 1986).

The single most important contact lens for an optometrist to obtain and become proficient using is the Goldmann three-mirror lens. With this instrument, every region of the eye may be visualised. Techniques learned with this lens are applicable to all other types of lenses. If the practitioner wishes to proceed further with contact lenses, the next one to acquire would be a fundus lens. This provides the best image of the posterior pole, macula and optic nerve head. For those wishing to specialise in conditions of the anterior segment, a four-mirror gonio lens or a single-mirror gonio lens would be ideal.

Contact Lens Use in Practice

Contact lenses offer notable advantages to the optometrist. The benefits include eye stabilisation for improved examination together with enhanced visualisation for better diagnostic precision. These lenses also provide a wider field of view and better access to peripheral regions of the fundus and anterior-chamber angle. Further, clinical evaluation often demands that depth information is available in the fundus image; superior depth discrimination is accomplished with a contact lens.

Contact lenses, however, have drawbacks from the patient's perspective. Having one of the lenses placed on the cornea is an uncomfortable experience. Interface fluids, such as methylcellulose, nearly always drip on to the cheek or clothing, and often blur vision for some time following the examination. Of course, non-contact indirect biomicroscopic lenses at the slit lamp do not have these disadvantages but they also cannot image areas within the anterior chamber and they offer less than optimal imaging of the posterior chamber. There may be some clinical circumstances where thorough examination needs to be balanced against patient comfort.

Discomfort can be minimised with the following procedure: the cornea should be anaesthetised and, while the drops are taking effect, the practitioner should position the

patient firmly on the chinrest of the slit lamp. If required, a drop of methylcellulose or other interface fluid should be placed in the endpoint of the lens. The patient should be instructed to look downwards, the upper lid should be lifted and the lens applied to the globe, inserting the lower aspect first, ensuring that the interface fluid remains within the endpoint. The patient should then be instructed to look up as the practitioner places the upper aspect of the lens on the superior cornea. Sufficient pressure should be applied to maintain the fluid interface. Removal of the lens is straightforward unless strong hydraulic forces act to hold the lens on to the cornea. If this happens, the suction needs to be released and this is best done by rocking the lens to lift the edge.

There are a number of safety aspects relating to the use of contact lenses that all clinicians need to consider. Factors relating to the contact element touching the patient's eye are of primary importance. Before applying a contact lens to the cornea of a patient, the endpoint must be clean and smooth. Any debris, dried methylcellulose or microbes must be removed. Cleaning any contact lens should begin by washing it with soap and water. All of the lenses are sealed to ensure that water and dust cannot adversely affect any of the internal optical components. After washing, the lens can be dried by wiping it with a soft cloth, or by blowing it dry using an air jet, which can be purchased from a photographic shop. Decontamination and disinfection should follow, taking into account the manufacturer's guidance and the College of Optometrists' recommendations (www.college-optometrists.org/professional/cjd.pdf). Disinfection must involve non-thermal processes since most of these lenses are made from plastic materials such as polymethyl methacrylate or styrene and they cannot withstand temperatures above 120°C.

It is important to inspect the surface of the contact element regularly. Accidental damage, for example from dropping the lens, could result in a sharp detail that could inadvertently scratch a patient's cornea. If defects are found, the contact element should be repolished, or the entire contact lens replaced.

There are light hazards associated with using a contact lens for therapeutic laser procedures. These hazards could have an effect on the clinician, persons in the laser treatment room or the patient (Blumenthal & Serpetopoulos 2000, Shiraki et al. 2000, Sliney & Mainster 1987). Literature reports have described several conditions that make it possible for a therapeutic laser to be reflected within and back out of a contact lens towards the practitioner (Hill et al. 1988). To reduce the possibility of any such occurrences, it is important that bubbles at the interface between the contact lens and the patient's cornea be kept to a minimum (Ward 1986). A bubble in the endpoint interface may provide an additional TIR surface that could reflect a laser beam. The best insurance against any eye hazard from reflections is the requirement that laser safety goggles be worn by all persons in the treatment room except the patient (Sliney & Mainster 1987).

Other aspects of light hazards relate specifically to the patient. The reports describe burns that may be unintentionally delivered to the cornea of a patient when wide field of view contact lenses are used in conjunction with laser therapies where the spot-size setting of the instrument is 1000µm or greater (Mainster et al. 1990, Shiraki et al. 2000). Under these conditions the energy level of the laser beam is higher at the corneal surface than at the retinal surface.

Conclusion

With increasing responsibility for patient care, optometrists should, at regular intervals, review the equipment they use and question whether their toolkit remains sufficiently comprehensive. Contact lenses may not be appropriate for everyday examination, but for certain circumstances, they provide the optimal means of investigation. Future developments in contact lens design may allow images to be sent via an electronic network to remotely located expert diagnostic centres. As shared care becomes mainstream, it may be important for optometrists to have the skills to utilise these lenses.

Note The authors have no commercial interest in any of the manufacturers or products discussed in this paper.

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Multiple Choice Questions

This paper is reference C-2409, event number EV-6768. Two credits are available. Please use the inserted answer sheet. Copies can be obtained from Optometry in Practice Administration, PO Box 6, Skelmersdale, Lancashire WN8 9FW. There is only one correct answer for each question.

1. Interpreting the image formed by a direct-viewing fundus contact lens requires the practitioner to:
(a) make no allowance as the image is the correct way round
(b) reverse and invert the image
(c) only reverse the image
(d) only invert the image

2. Indirect-viewing lenses produce images that are:
(a) real and inverted
(b) virtual and reversed
(c) real or virtual, depending on where the slit lamp is focused
(d) presented at infinity

3. In a contact lens with a contact element of the 'no methylcellulose required' (NMR) design, the radius of curvature of the contact element:
(a) is steeper than the cornea and tears will fill the geometric gap
(b) is flatter than the cornea and tears will fill the geometric gap
(c) is steeper than the cornea and methylcellulose will fill the geometric gap
(d) matches the corneal profile and tears act as the interface fluid

4. Usually the mirrors in contact lenses are:
(a) fully silvered
(b) partially silvered
(c) planar surfaces formed from prisms
(d) prisms with silver coatings

5. In order to view the trabecular meshwork, the mirror angle in a direct contact lens needs to be:
(a) below 5°
(b) between 5 and 20°
(c) between 20 and 50°
(d) more than 50°

6. Viewing tissues in the equatorial region is best accomplished by using a contact lens:
(a) with mirrors
(b) with a magnifier
(c) with a 'field' lens
(d) and rotating the globe

7. In order to observe tissues in the posterior chamber, the practitioner should select a:
(a) four-mirror gonio lens
(b) Goldmann three-mirror lens
(c) Abraham-style lens
(d) Magna view gonio lens

8. The single most important lens for the optometrist to become proficient at using is the:
(a) Abraham-style lens
(b) Kreiger lens
(c) area centralis lens
(d) Goldmann three-mirror style

9. For optometrists specialising in the anterior segment, a good lens to use would be:
(a) area centralis lens
(b) Mainster hi magnification lens
(c) four-mirror gonio lens
(d) quadraspheric lens

10. To avoid light hazards from therapeutic lasers, during laser activation all persons in the treatment room (except the patient) should:
(a) avert their gaze
(b) close their eyes
(c) use their sunglasses
(d) use laser safety goggles

11. Indirect-viewing lenses may be used to observe tissue:
(a) in the anterior segment only
(b) in the posterior segment only
(c) in both the anterior and posterior segment
(d) in the anterior chamber angle only

12. Indirect contact lenses with a total optical power of 60D will provide image magnification of:
(a) 0.5
(b) 1.0
(c) 10
(d) 60