



Assessment of the Tear Film

KEY POINTS

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Tear film assessment should be undertaken with minimal invasion of the structure – non-invasive techniques should be used whenever possible

Assessment must be made both prior to and during contact lens wear. Tear film quality should be assessed both with the lens *in situ* and without the lens

Use of the Tearscope in clinical practice allows a more detailed examination of the tears to be undertaken

Symptoms, not just signs, are an important aspect of overall tear film assessment

As soon as a contact lens is placed on to the eye, the lens becomes bathed in the tear film. The ability of the tear film to maintain its integrity in the presence of the lens is a fundamental prerequisite of successful contact lens wear. Deficiencies in the lens/tear interface are arguably the most common reasons for contact lens failure. The most common symptom reported by contact lens wearers is 'dryness', which implies a deficiency in the tear film.

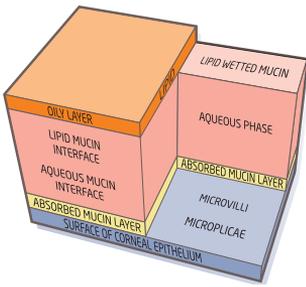


FIGURE 1 Structure of the tear film

The importance of the tear film in maintaining comfortable contact lens wear means the contact lens practitioner must be able to assess the tears, both before and during contact lens wear. This article will review the clinical examination of the tear film in contact lens practice.

The normal tear film

The tear film is, typically, considered to be a three-layered structure, comprising a mucoidal basal layer, an aqueous component and a superficial lipid layer (Figure 1). This classic description has been challenged in recent years with some modifications proposed by Nichols *et al*, and by the work of Pyral, who believes the tear film is significantly thicker and has more mucus than previously thought.

Functionally, the three major components of the tear film work together to maintain the overall form. Their functions and origins are summarised in Table 1. The lipid and mucus layers have the most influence on the quality of the tear film, while the aqueous layer provides the quantity of tears needed. Both quality and quantity of tears are important to maintain the bulk hydration and surface hydration of a soft contact lens.

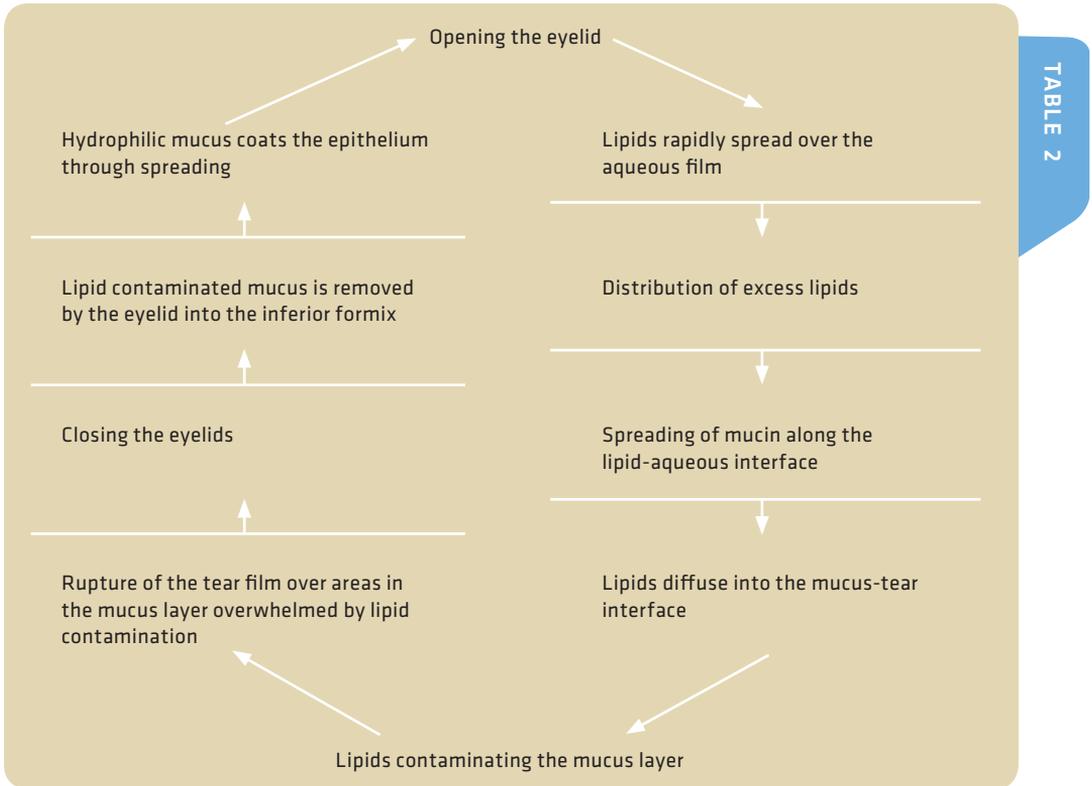
The tear film is formed and maintained by blinking. As the eye closes during a blink, the lipid layer is compressed between the lid margins. The mucin, contaminated by lipid from the tear film breaking up, is moved to the upper and lower fornices from where it is excreted through the tear duct. It is replaced by a new layer, which is created by the lids pushing against the eye surface.

As the eye opens, a new aqueous layer spreads across the now hydrophilic epithelial surface. As it is formed, the lipid, which

TABLE 1

Major components and functions of tear film layers

STRUCTURE	ORIGIN	MAJOR COMPONENTS	FUNCTIONS
Lipid layer	Meibomian glands	Cholesterol esters Ester waxes	Avoids evaporation Provides optically smooth surface
Aqueous layer	Lacrimal glands	Water Protein Salts	Bacteriostasis Debris flushing Maintenance of epithelial hydration
Mucus layer	Conjunctival goblet cells Glands of Moll and Krasse	Glycoprotein	Renders epithelial surface hydrophilic for aqueous to wet



has been squeezed into a thick layer during lid closure, spreads out, producing a new monolayer across the aqueous to reduce tear evaporation.

The new tear film is a relatively unstable structure. Despite the presence of the lipid layer, there is still some tear evaporation that reduces its thickness. As this occurs, lipids begin to diffuse towards the mucus. The mucus, now contaminated by the lipid, begins to lose its hydrophilicity, and the tear film begins to rupture, leading to isolated islands of tear break-up. This is the stimulus for the blink and the cycle to be repeated. Table 2 summarises the mechanism. A normal tear break-up time can be longer than the usual inter-blink period.

Under non-contact lens wearing conditions, the structure of the tear film can be affected by systemic or ocular medication, general health and a number of ocular conditions, such as keratoconjunctivitis sicca. The tears are also affected by age, with changes in both the volume of tear production and stability of the tear film.

Assessing the normal tear film is made difficult by it being transparent, small in volume ($7\mu\text{l}$) and relatively thin ($7\mu\text{m}$), and, moreover, by the reflex nature of tear, often induced by the method of assessment. A normal tear flow rate can be increased by more than 100 times if reflex tearing is stimulated.

A change to tear composition can also be effected. Any method to collect tears must involve some mechanical trauma to the eye that, in turn, leads to reflex tearing and to questions about how normal the sample was. For a fuller summary of the structure and biochemistry of the tear film, see reviews by Bright and Tighe¹ and Lydon and Guillon.²

Tear film in contact lens wear

RGP lens wear

Inserting a RGP lens into the eye causes a major disruption to the tear film, which, in turn, is the major reason for lens discomfort. Classical assessment of the non-invasive break-up time (NIBUT) of an RGP lens shows a significant decrease from the NIBUT of the tear film before lens wear to the pre-lens NIBUT. This, together with other observations, shows it is difficult for the tear film to maintain a lipid layer over the surface. The rapid evaporation of the tears can be seen in sclerotic scatter through the biomicroscope. The situation can be worsened if the patient does not fully blink, as this prevents the whole of the lens being wetted adequately. Over time, the accumulation of deposits on the surface of an RGP lens leads to further disruption of surface quality and increases the difficulty for the thin pre-lens tear film to cover the lens adequately, leading to areas of non-wetting and a sequelae of problems.

Deposition characteristics can vary between RGP materials. The fluorosilicone acrylates family tend to deposit more lipid than their silicone acrylate predecessors, the latter having a higher propensity for protein deposition. Practitioners should be mindful of these differences when choosing the most appropriate surfactant cleaner for the lens material.

Soft lens wear

The insertion of a soft lens into the eye provides new challenges for the tear film. Once again, while there is a need to provide a wettable front surface, there is also a need to maintain the hydration of the lens, which may comprise as much as 70 per cent water. As with RGP lenses, NIBUT is significantly reduced over a soft lens compared with when the lens is not in place. Investigations, however, have shown the lipid layer is more stable over a soft lens than a hard lens.

Silicone hydrogel materials tend to deposit more lipid and less protein than hydrogels. The appearance of lipid can vary between silicone hydrogel materials, appearing as a sheet of lipid over the entire lens surface or as discreet focal deposits. Research has shown that a rub and rinse step is effective in reducing lipid deposition with silicone hydrogels.

The geometry, fit and movement of a soft lens on the eye will also influence the pre-lens tear film stability. Lenses with less movement favour the formation of a more stable pre-lens tear film.

All soft lenses dehydrate to some extent when placed on the eye, with the dehydration generally being greater as the water content increases. Lens dehydration and subjective dryness and comfort are not shown to be correlated.³ If excessive dehydration occurs, this can manifest itself as punctate corneal staining, often in the lower quadrant of the cornea — the ‘Smile’ stain (Figure 2).

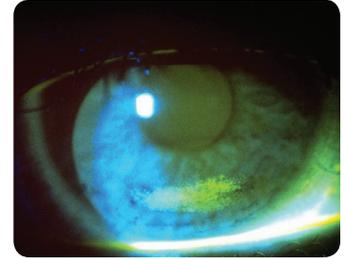


FIGURE 2 ‘Smile’ stain

While ocular lubricants have been advocated to resolve the problem of dry eye in hydrogel lens wearers, no one has yet shown the effect of any significant change on either the quality or the quantity of the tear film.⁴

More recently, soft contact lens manufacturers have incorporated wetting agents into both hydrogel and silicone hydrogel materials and/or packaging solution in an attempt to improve ongoing lens wettability and surface characteristics of the lens, and hence achieve longer lasting comfort.

Having established the characteristics of the normal tear film and the pre-lens tear film, we now review methods to assess these in relation to contact lens wear.

Instrumentation

Assessing the tear film can be achieved through a variety of methods. Consistent with many aspects of contact lens practice, the slit lamp is the key piece of instrumentation. High magnification and excellent optics are required to observe the structures and integrity of the tear film, using specular reflection and the interference colour phenomenon associated with them. A keratometer can also be employed to assess tear stability by observing the clarity of the mires between blinks.⁵

For detailed tear film assessment, additional equipment may be used with the slit lamp, such as the Tearscope. In clinical practice, existing equipment can also be modified to help to assess the tear film. The adaptation of a Keeler keratoscope to the use of the Loveridge grid,⁶ and the adaptation of a Bausch & Lomb keratometer to the use of the HIR-CAL grid,⁷ are prime examples of this. Both of these instruments can be used to assess NIBUT.

Technique

There are numerous and varied techniques, which continue to expand and develop, particularly in clinical research, for assessing the tear film. Only those techniques suitable for

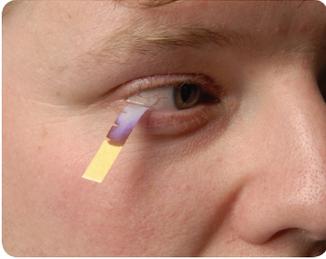


FIGURE 3 Schirmer tear test strip in use



FIGURE 4 Phenol red thread in use

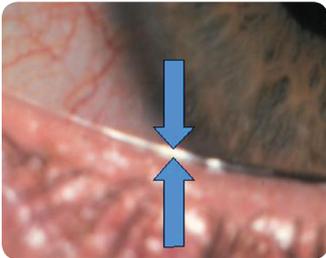


FIGURE 5 Inferior tear prism as seen with the slit-lamp biomicroscope

routine use in contact lens practice will be reviewed here. Tear film evaluation can be divided into two areas — assessing tear volume or quantity, and assessing tear stability or quality.

The appointment time for assessment of contact lens wearers is an important aspect to consider. The common symptoms of dryness and discomfort worsen with increased length of contact lens wear, hence an appointment towards the end of a day will best identify symptomatic wearers.⁸

Tear quantity

Schirmer test

Since its introduction in 1903, the Schirmer test has been widely used in clinical practice for assessing tear production. There has been extensive criticism of the effectiveness of this technique, which has been well documented in the literature. The invasive nature of this technique results in excessive reflex tearing, and hence a lack of sensitivity and repeatability limits the value of the test in clinical practice.

Although it is becoming less popular in contact lens practice, there appears to be a reluctance to discard this test, which is partly due to the fact that it is still the simplest, fastest and least expensive diagnostic test available for assessing tear production. The authors believe the only value of this test is in confirming which patients have severe dry eye; keratoconjunctivitis sicca is indicated where there is less than 5mm of wetting.

The technique involves hooking the 5mm folded end of an absorbent strip of paper over the margin of the lower lid. Although variations have been produced, the most commonly used is the Schirmer tear test strip, which comprises absorbent strips of paper of 35mm x 5mm (see Figure 3). The length of the wetting from the bend is measured in millimetres after five minutes. A normal tear film should produce a wetting length of more than 15mm.

Phenol red thread test

This method of assessing tear quantity has the advantage of being less invasive than the Schirmer test, utilising a two-ply cotton thread impregnated with phenol red dye (Figure 4). Phenol red is pH sensitive and changes from yellow to red when wetted by tears, due to the alkaline nature of tears (pH 7.4).

To undertake this test, the crimped end of a 70mm long thread is placed in the inferior conjunctival sac on the temporal side. The patient is instructed to close his/her eyes and the thread is removed after 15 seconds. The length of the colour change on the thread, indicating the length of the thread wetted by the tears, is measured in millimetres. Wetting lengths should

normally be between 9mm and 20mm. Values of less than 9mm have been shown to correlate with subjective symptoms of dryness.

Inferior tear prism height

Measuring the tear meniscus formed on the lower lid margins gives a useful guide to tear volume. The authors believe this test should be an integral part of the pre-assessment of potential contact lens wearers. This simple technique employs the slit-lamp biomicroscope. Excessive or prolonged use of illumination should be avoided to prevent artificial drying of the tear prism. With experience, the approximate prism is graded as minimal, normal or excessive. Grading is not accurate in the presence of reflex tearing.

Figure 5 shows the appearance of the tear prism through a slit lamp. For precise measurement, a graticule can be employed in the slit-lamp eyepiece.

An alternative technique is to compare the tear prism height with the illuminated slit width by setting the slit horizontally in alignment with the lower lid margin, altering the slit width until it appears to match the height of the tear prism. A value in millimetres can be obtained by a one-off calibration of the knob rotation controlling the slit width, using a microscope scale.

Guillon proposes a clinical routine to incorporate the measurement of the tear film prism height in these positions:

- Immediately below the pupil centre
- 5mm nasally
- 5mm temporally.

Figure 6 shows the normal distribution of tear prism heights, peaking at 0.22mm.⁹ It is important to ensure the patient is in a primary position of gaze, as the apparent height of the meniscus can depend on this. In addition to the volume of the tear film, this approach allows the evaluation of the regularity of the tear prism, with the presence of any scalloping indicating a dry eye.

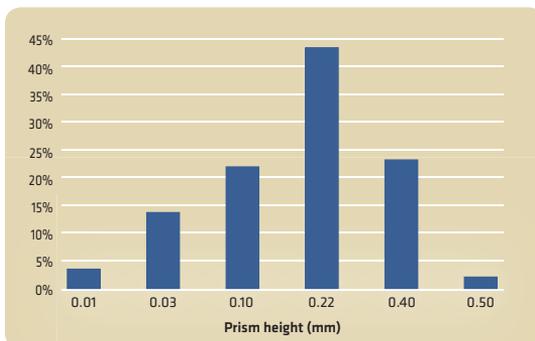


FIGURE 6 Inferior prism height distribution⁹



FIGURE 7 Fluorescein instillation
(a) minimal ideal (b) excessive



Tear quality

The difficulty in assessing the quality of the tear film is in developing a system to observe accurately a transparent structure.

Fluorescein BUT

Traditionally, tear break-up time has been measured by staining the ‘transparent’ tears with fluorescein to assist with observing and viewing the dyed tear film under cobalt blue light. Additional use of a yellow ‘Wratten’ filter further improves observation of any fluorescence. The dye is usually applied by wetting a fluorescein-impregnated strip with saline, then shaking off any excess liquid and gently touching the lower conjunctiva with the strip tip (Figure 7). Using a drop of a 1 or 2 per cent fluorescein solution from a Minim is not recommended, as even one drop can instill more than three to six times the original tear volume, causing excessive destabilisation of the tear film. A BUT of 20 seconds is considered a normal value for tear film stability, measured with fluorescein, although wide ranges have been reported in the literature.

It should be noted that this technique is invasive. Touching the eye with the paper strip will induce a degree of reflex tearing and instilling 20–30ml of fluorescein solution from a Minim swamps the normal 7ml tear film. Furthermore, the addition of fluorescein to the tear film alters the physical interactions between the tear film layers, which reduces the surface tension and, hence, affects the BUT value. It should also be remembered that the fluorescein dye stains soft lenses and this precludes its use in assessing the pre-lens tear film with a soft lens *in situ*.

Lissamine green

While fluorescein highlights epithelial cell loss, other dyes such as lissamine green or rose bengal highlight devitalised or dead cells. Unlike rose bengal, lissamine green has the advantage of not causing irritation in dry eye patients. A normal eye will show no staining with lissamine green. Use of a red-free filter (Wratten 25) aids observation of this staining.

Practitioners should be aware of all the limitations with invasive techniques using dyes, and therefore consider other, more reliable and non-invasive options for assessing tear stability.

Non-invasive break-up time

This is the measurement, in seconds, of the time that elapsed between the last complete blink and the appearance of the first discontinuity in the tear film. A pre-rupture phase, known as the tear thinning time (TTT), can also be observed with some techniques. A number of different instruments can be employed to measure NIBUT. A summary of those that are

Techniques to measure NIBUT

INSTRUMENT	TARGET	BACKGROUND	ADDITIONAL COMMENTS	AUTHOR
Keratometer	Mire	Dark field	Only shows reflected disturbances on 3mm circumference	Patel 1985
Modified keratometer	HIR-CAL grid	Dark field	Normal use of keratometer restricted	Hirji <i>et al</i> 1989
Hand-held keratoscope	Loveridge grid	Dark field		Loveridge 1993
Tearscope		White field	Also allows evaluation of tear structure	Guillion 1986

TABLE 3

suitable for use in routine contact lens practice is given in Table 3. All techniques listed can be used with and without contact lenses.

All these methods are optical in nature and measurement is achieved by observing the distortion (TTT) and/or break up (NIBUT) of a keratometer mire, the reflected grid image of changing interference patterns. The practitioner views the first Purkinje image and records the time taken for the image to distort and/or break up. Figures 8 and 9 show undistorted and distorted reflected grid images.

Well documented research papers confirm that NIBUT is, typically, longer than fluorescein BUT, and is often greater than 30 seconds (Figure 10). Abnormal values are those of less than 15 seconds. These methods are considered more patient-friendly and, furthermore, more repeatable and precise. As with most clinical methods of tear assessment, measurements are not reliable if reflex tearing is observed.

Specular reflection observation

This is a method for observing the tear film in specular reflection that does not require the instillation of a dye. Two techniques can be employed.

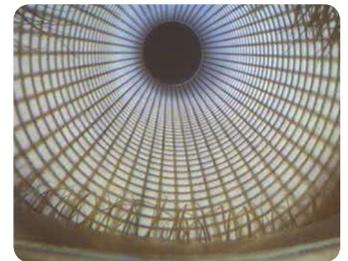


FIGURE 8 Undistorted reflected grid images



FIGURE 9 Distorted reflected grid images

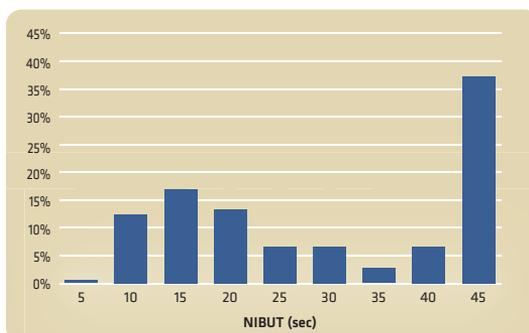


FIGURE 10 NIBUT distribution⁹



FIGURE 11 Tearscope Plus instrument



FIGURE 12 Tearscope in use with slit lamp

Narrow-field specular reflection

Locate and focus on the bright reflection from the slit beam through a slit lamp utilising high magnification (30-40X). It is important to reduce the light intensity to avoid artificially drying the tear film and to subtend as large an angle as possible with the light source. Although it is a relatively easy technique to undertake, its greatest limitation is that it permits only a very small area to be observed at any one time (1mm x 2mm-zone maximum).

Tearscope

Tear interferometry is increasingly being used in research settings to observe the tear film. In clinical practice, interferometric observation can be achieved using a hand-held instrument designed to be used in conjunction with a slit-lamp biomicroscope. The Tearscope (Keeler) developed by Guillon in 1986, comprises a 90mm hemispherical cup and handle with a central 15mm diameter observation hole (Figure 11). The inner cup surface is illuminated by a cold cathode ring light source, which was specifically designed to prevent any artificial drying of the tear film during an examination. The light emitted is diffuse and, as such, does not need to be in focus to observe the tear film.

With the patient's head positioned on the slit-lamp chin rest, the slit-lamp source should be positioned nasally and switched off. Alternative illumination is provided by the Tearscope itself (Figure 12). The Tearscope should then be held as close to the eye as possible and positioned to allow observation through the sight hole via one of the biomicroscope objectives. The closer the Tearscope is to the eye the better, so that the area illuminated can be maximised. The light reflected from the tear film can be observed as a white circular area, 10-12mm in diameter. Initially, set the magnification on low, although this can be increased up to 20-40X to examine the interference patterns in detail.

This device allows both the measurement of the non-invasive break-up time and the assessment of the lipid layer. Interpreting the interference patterns observed takes time to perfect, but excellent video training material is available. Figure 13 displays the patterns typically seen in the normal population. Table 4 outlines the classification, incidence and clinical interpretation of the various patterns.

Lids, lashes and blinking

Comprehensive tear film assessment is not a stand-alone examination. Importantly, all adjacent structures should be evaluated. This assessment should be undertaken using a slit lamp and diffuse illumination. Lashes, lid margins, the

Lipid pattern classification, incidence and clinical interpretation, adapted from Guillon & Guillon

DESCRIPTION	INCIDENCE (%)	ESTIMATED THICKNESS (NM)	APPEARANCE	CLINICAL
Open marmoreal	21	15	Grey, marble-like open meshwork pattern	Contact lens drying problems
Closed marmoreal	10	30	Grey, marble-like tight meshwork pattern	Stable tear film Possible contact lens candidate Possible excess lipid deposition
Flow	23	30-80	Wavy, constantly changing round shape	Generally stable tear film Possible contact lens candidate Possible excess lipid deposition
Amorphous	24	80	Blue/whitish appearance	Highly stable tear film Excellent contact lens candidate Occasional greasing problems
Colour	15	80-370	Yellow, brown, blue and purple fringes, grey background	Contact lens wear possible but excessive lipid deposition likely
Other	7	Variable	Variable coloured fringes with mucus strands	Contact lens wear contraindicated

TABLE 4

inner and outer canthus and meibomian glands should all be examined. Traces of make-up and blepharitis, among others, will impact on the tear film.

Observation of blinking frequency and completeness should also be considered — while listening to history and symptoms can be an ideal time to observe this. A typical blink pattern can be observed as approximately one blink every five seconds, ie 12 blinks per minute. Incomplete blinking can often be observed in contact lens wearers, and frequent blinking may be a result of an attempt to maintain a relatively thin lipid layer.

Furthermore, careful questioning of the patient provides important information in evaluating the tear film. Consideration of patient symptoms is paramount, and critical to the overall assessment.¹⁰ Using specific questionnaires to aid clinical judgement can be of benefit. The most established questionnaire — by McMonnies — is an excellent method of screening for dry-eye patients.¹¹ This questionnaire divides symptoms into primary/non-provoked (soreness, grittiness) and secondary/provoked (irritation from smoke, chlorine), and provides a score for a subject's potential for contact lens tolerance/non-tolerance.



FIGURE 13 Typical patterns seen through a Tearscope (a) meshwork and waves (b) waves (c) colour fringe

AUTHORS

Jane Veys MSc MCOptom
FBCLA FAAO, Education Director,
The Vision Care Institute™
Johnson & Johnson Vision Care,
Europe, Middle East & Africa.
Formerly in contact lens research,
optometric education and
independent practice.

John Meyler BSc FCOptom
DipCLP Senior Director
Professional Affairs, Johnson
& Johnson Vision Care, Europe,
Middle East & Africa. Formerly in
independent optometric practice.

Ian Davies BSc MCOptom DipCLP
FAAO, Vice President, The
Vision Care Institute™ Johnson
& Johnson Vision Care, Europe,
Middle East & Africa. Formerly
in contact lens research and
independent optometric practice.

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Conclusion

Examination of the tear film is one of the most important aspects of pre-selecting potential contact lens wearers and the aftercare of existing patients. The very nature of contact lens wear results in a tear film that is thinner and less stable than the pre-ocular tear film. The transparency of the tears makes it difficult to examine, and the challenge to the practitioner is in developing a technique to visualise the structure without causing disruption. Use of non-invasive techniques, or minimally invasive techniques (minimum fluorescein use and phenol red thread test) increases the accuracy of tear film assessment and should be employed where possible. No one test is sufficient, and a combination of tests to assess both tear film quality and quantity is recommended. In addition, consideration of patient symptoms is critical in the overall clinical assessment. ■

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