Country	CET/CPD information	Audience	Competencies	MCQs
UK	This article offers 1 non-interactive CET point (C-74923) or 1 interactive point (C-75516). (For instructions on how to complete the interaction see the end of this article.) INTERACTIVE	General Optical Council Approved CET For Optometrists; General Optical Council Approved CET For Dispensing Opticians	STANDARDS OF PRACTICE; OCULAR EXAMINATION; OCULAR DISEASE; STANDARDS OF PRACTICE; OCULAR EXAMINATION; OCULAR ABNORMALITIES	6
ROI	All articles are CPD accredited in the Republic of Ireland			6

Corneal thickness measurement: Pachymetry a practitioner's guide

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Even before COVID-19 infections control and waste disposal in clinical practice were essential. Whilst the guidance we adhere to is changing in response to the pandemic this article is vital learning. Please do ensure you and you colleagues stay up to speed with the guidance on a daily basis.

Outline

Corneal thickness is particularly important as it affects the measurement of IOP, with thin corneas resulting in underestimated IOP readings, and thick corneas with overestimates. Corneal thickness is also an independent risk factor for the development of glaucoma. Central corneal thickness can be easily measured using a handheld ultrasound pachymeter. This article provides an overview of the methods of corneal pachymetry and the interpretation of the results.

About the author

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Introduction

Corneal pachymetry is the process of measuring the thickness of the cornea. Pachymetry is from the Greek words pachos (meaning 'thick') and metry (meaning 'to measure'). The measurement is most commonly taken prior to performing refractive surgery and in the screening of patients suspected to be developing glaucoma. Corneal thickness is particularly important in relation to the measurement of intraocular pressure (IOP); thin corneas tend to result in tonometry readings that underestimate IOP, while thick corneas tend to result in overestimations. Independently of this, corneal thickness has been found to be a risk factor for the development of glaucoma.

The normal cornea varies in thickness. It is thickest in the periphery at the limbus at around 700–900μm and thinnest centrally at the corneal apex at around 544μm (approximately ½ a millimetre); this measurement is known as central corneal thickness (CCT). The CCT can vary significantly as a variation of normal; it is generally found to be higher in men, individuals with diabetes, Caucasians and younger populations.[1] Moreover, a number of corneal pathologies can affect corneal thickness, and where corneal refractive surgery has been performed the CCT may be significantly reduced.

Central corneal thickness, an artefact or independent risk factor

The importance of CCT in the management of glaucoma and ocular hypertension (OHT) was established as a result of the Ocular Hypertensive Treatment Study (OHTS).[2] The study found that CCT is a crucial measurement in relation to the diagnosis and management of glaucoma in two respects: first, because it affects the accuracy of applanation tonometry in measuring IOP; and secondly, but more importantly, because it is the single greatest risk factor predictive of which subjects would develop glaucoma.

CCT has been found to affect the accuracy of applanation tonometry in the measurement of IOP, with thin CCT leading to misleadingly low IOP readings and thick CCT to misleadingly high ones. Thus, it is important to consider IOP in the context of the CCT measurement; it may, for example, be unjustified to classify a person as having OHT on the basis of high IOP alone, where the CCT is thick and no other glaucoma-related findings are present.

However, it is vital to understand that a thin CCT measurement is also the most important risk factor for the development of glaucoma in its own right. A person with a thin CCT measurement has a higher risk of developing glaucoma than one with a thick CCT measurement, irrespective of the impact of CCT upon measurement of IOP. The OHTS found that applying a correction factor to the underlying IOP data did not improve the performance of the modelling and that the power of the risk factor from CCT was much greater than through a calibration error alone. Thus, CCT is much more than a contextual measure for IOP; its ability to stratify risk is of utmost importance. Moreover, since publication of the OHTS, it has been found that CCT can impact upon the progression of glaucoma once established. These findings were later supported in the longer term results of the Early Manifest of Glaucoma Trial[3] and separately in the European Glaucoma Prevention Study.[4]

Variation in CCT

Biomechanical properties of the of the cornea

The elasticity of the cornea is thought to have a potentially greater effect on error in IOP measurement than either corneal curvature or CCT.[5] It is known that the cornea becomes stiffer as a person ages, but currently it is uncommon to measure corneal elasticity. Some tonometers such as the 'ocular response analyser' provide an approximate measure of viscoelasticity, corneal hysteresis and corneal resistive factor, but none of these can accurately be described as elasticity.[6] CCT is not thought to be affected by elasticity. Procedures such as corneal cross-linking will increase the cornea's rigidity and affect IOP measure. More research is needed in this area, but an awareness of the potential effect of elasticity on the cornea ensures CCT is viewed in context as one of a number of parameters which can affect IOP.

Physiological central corneal thickness variation

Some population studies have reported that the cornea becomes thinner as a person ages, although other studies have found no change.[7,8] If there is a decrease in thickness over a lifetime, it is not thought to be dependent on ethnicity, sex or refraction and is likely to be small.[9] Practically, it is recommended that repeat pachymetry measurements are taken every 5–10 years, to ensure an appropriate risk applied. There is no preferred time of the day to perform pachymetry. The corneal swells slightly overnight and some practitioners recommend waiting two hours before taking the measurement. Similarly, it is advisable to remove contact lenses two hours prior to performing pachymetry; however, it is unlikely to make a clinically significant difference.

The corneal thickness of a person will vary in numerous pathologies, such as in keratoconus, Fuchs endothelial dystrophy or corneal oedema. Some report subtle changes in the corneal thickness measured throughout the day, although these changes are not considered clinically significant.

Central corneal thickness variation amongst different racial groups

There are numerous population studies that have reported a variation of CCT based upon ethnicity (Table 1).[10] Most significantly, the OHTS found that African American participants had thinner corneas and that the reduced CCT identified wholly accounted for the increased risk of developing glaucoma.[11] As such, race is not thought to be the primary risk factor for some groups; it is now thought that CCT variation explains why some racial groups are more or less likely to be at risk of developing glaucoma. South Asian and African populations were found to have the thinnest CCT, with averages in the region of 518–531nm, compared to Caucasian populations with CCT in the region of 546–548nm.

Ethnicity	Studies	Population size	Mean CCT ± SD (μm)
Australian aboriginal	2	280	513 ± 31.5
South Asian	6	8437	527.9 ± 33.2
Native Asian	6	1320	524.5 ± 35.6
South East Asian	4	2459	525.6 ± 32.4
African migrant	11	1905	530.8 ± 35.8
Caucasian migrant	16	5040	546.2 ± 34.2
Hispanic	5	2071	546.7 ± 33.7
European Caucasian	9	5588	548.6 ± 34.5
East Asian	13	3528	*551.4 ± 33.5*

Table 1: Population-based surveys. Adapted from Dimasi et al.[10]

Central corneal thickness variation following refractive surgery

The process of corneal refractive surgery results in both a thinning of the cornea and a change in IOP. However, the relationship between the two is complex and you cannot predict the change in IOP based on CCT alone.[12] The refractive surgery procedure affects the entire biomechanics of the cornea and, as such, the IOP found post-surgery is as a result of a change in corneal curvature, CCT and elasticity. Broadly, a decrease in IOP is found post-surgery, with LASIK reducing IOP to a greater extent than PRK, and myopic procedures more than those for hypermetropia. Independent of

CCT, the creation of a LASIK flap reduces IOP by around 1mmHg.[13] The greatest predictor of postsurgery IOP reduction is the pre-surgery IOP; the higher the IOP, the greater the decrease in IOP post-surgery, independent of the CCT.

The reduction in IOP post-refractive surgery must be due to exaggerated corneal flattening as well as corneal thinning or changes in biomechanical properties. Practically, this means that CCT should always be measured post-surgery, and results viewed in the context of pre-surgery risk. It is still unclear how a refractive surgery procedure alters a person's risk of developing glaucoma. However, it is widely acknowledged that it is more challenging to detect glaucoma following refractive surgery.

Classification	Corneal thickness	Effect on IOP measurement
Very thin	510µm or less	Underestimated IOP
South Asian	535µm or less	Underestimated IOP
Native Asian	540–560µm	Roughly correct IOP
South East Asian	565µm or more	Overestimated IOP
African migrant	600µm or more	Overestimated IOP

Murray Fingeret[14]

Table 2: CCT tonometry reading

Methods of pachymetry

There are three different groups of pachymeter: ultrasound, optical and novel (Table 3). There are two main approaches to recording corneal thickness: the first is to create a topographical map of thickness across the whole corneal surface; the second is to record one central corneal thickness measurement. Which method you choose will be dependent on why you are taking the measurement and which instrument you are using.

All the various methods give broadly similar results. For the purposes of establishing a patient's glaucoma risk, all methods do consistently group patients with thin, average and thick corneas. However, in some situations there may be a difference that may be significant in a refractive surgery context, so it is recommended that you are consistent in which method you use for each patient to ensure you are comparing like with like.

Instrument	Methodology	Category
Acutome Pachpen	Ultrasound	Handheld ultrasound
Haag-Streit slit lamp attachment	Manual optical	Optical
HGG Pachmate	Ultrasound	Handheld ultrasound
OCT (Carl Zeiss Heidelberg, Nidek, Topcon)	OCT	OCT
Oculus Pachycam	Confocal microscopy	Novel
Ocular response analyser	Built in 20Mhz ultrasound pachymeter	Mounted ultrasound
Orbscan II (B&L)	Scanning slit pachymetry	Novel
Pentacam	Confocal microscopy	Novel

Table 3: Types of pachymeter

Ultrasound pachymetry

Today, ultrasound pachymetry is the most commonly used method; it is considered to be the gold standard. The measurement relies upon on the reflection of ultrasound waves from the anterior and posterior corneal surfaces. A simple formula is used to calculate corneal thickness[15]: Corneal thickness = (transit time x propagation time)/2. The sound velocity through a normal cornea is 1640m/sec.

Ultrasound pachymeters are typically small, lightweight and handheld. When performing the measurement, the probe tip has to make contact with the surface of the cornea. To ensure accuracy, the tip must be held perpendicular to the cornea, as displacement will result in an artificially increased thickness reading. The probe tip is normally around 1.5mm in diameter, and must be keep in good condition to ensure it does not damage the cornea. The resultant measurement is called a spot thickness measurement, as only the corneal thickness directly perpendicular with the probe has been measured. The advantages and disadvantages of this method are provided in Table 4.

Advantages	Disadvantages
Fast	Contact with cornea so local anaesthetic is required
Small, lightweight and portable	Accuracy is dependent on probe position and ensuring it is perpendicular
Objective, good intra-observer repeatability	Reproducibility relies on probe placement on the centre of the cornea
Relatively cheap	Low resolution
No coupling gel required	Less effective in oedematous corneas

Table 4: Ultrasound pachymetry summary

Optical coherence tomography (OCT)

There are various types of optical pachymeter available with a mix of contact and noncontact devices. The two most common are slitscanning (Orbscan II) and, more recently, anterior segment optical coherence tomography. Most commonly available OCTs now have the ability to measure corneal thickness. The key advantages of using OCT for measuring corneal thickness are that it is non-contact, and performs objective wide area mapping, rather than a single spot thickness. However, the instruments are large and expensive and it takes longer to set the patient up to perform the measurement.

The rapid increase in the number of OCT devices in primary care practice with the ability to measure cornea thickness will mean practitioners are likely to rely on OCT. Many papers have been published looking at the reliability and repeatability of the various instruments and methodologies. Repeatability and accuracy are very important for a device to be introduced into clinical practice. Repeatability is the ability of an instrument or technique to give similar values on different occasions while accuracy describes how close the measurement is to the true value being measured. It has been found that, although there may be small differences between ultrasound and OCT pachymetry, the differences are not clinically significant. It is recommended that the devices are not used interchangeably and to ideally stick with the same instrument for repeat measurements. When using the thin, thick and average categories, little difference will be found between the methodologies.

Novel methods

Novel methods include the use of topographic assessment, scanning slit or Scheimpflug principle to derive corneal thickness. As with OCT, these methods require large expensive devices that are normally reserved for refractive surgery, research, or hospital anterior segment clinics.

Taking the measurement with a handheld ultrasound device

Handheld ultrasound pachymeters are currently the most commonly used in the UK. Before you use the instrument, check it is in good working order, the probe in good condition, the battery charged and it has been recently calibrated. As the probe makes contact with the cornea you need to ensure it has been correctly disinfected before use. The exact process of disinfection will depend on your clinic type and local protocol; there is more information on this in both the College of Optometrists[16] and Royal College of Ophthalmologists[17] disinfection guidance. In all cases, the probe tip should be handled carefully, rinsed with saline, disinfected and dried before each use. Despite some manufacturer's instructions, all clinical experts agree that you should NOT use alcohol wipes to clean the probe tip.

To prepare your patient, explain what you are about to do and, as this is a contact procedure, you should obtain their verbal consent before you proceed.[18] Both corneas will require a local corneal anaesthetic. The patient should be instructed to look straight ahead at a distance target with both their eyes in primary gaze, with the instrument turned on and ready. The probe should be placed gently onto the central apex of the cornea; it should be at a tangent to the front surface and you should never move the probe on the corneal surface. You will see the cornea depress slightly and the instrument and, as this happens, your patient may notice a temporary distortion in their vision.

If the practitioner requires near correction, this should be worn so the probe tip can be clearly seen; there should also be adequate room illumination. The instrument will bleep once after each reading is taken. Keep the probe in place until you hear a long beep indicating all the readings have been taken, then remove the probe and repeat again on the other eye. You are presented with the continuous average CTT and its standard deviation for each eye. Record your results and check your patient's cornea. If the standard deviation is high, or there is a large difference (greater than 10) between the two eyes you may wish to repeat the measurements. It is normal to see superficial epithelial staining where the probe was in contact. The measurement itself takes seconds and the whole procedure around one to two minutes. You should follow local protocols as to how often you repeat pachymetry. Normally this will be on every patient at their first assessment and once every five or ten years thereafter, or after any subsequent eye surgery. Most clinicians feel there is little value to repeating pachymetry at every appointment, as any physiological change in thickness will be gradual.

Interpreting the central corneal thickness result

The OHTS found that CCT is an independent risk factor for the development of glaucoma. As such, if you find a patient has a thin cornea, you can conclude they are at a greater risk of developing glaucoma. An ocular hypertensive with thin corneas may require treatment before a person with thick corneas. Many conversion tables have been produced which calculate a modified IOP value based on the corneal thickness found. However, you should not make a conversion of IOP as this is not clinically helpful and may be misleading. A robust and simple approach is recommended, in which you classify the cornea as either thin, average or thick, with a corresponding increased or decreased risk of developing glaucoma.

At the time of diagnosis of ocular hypertension (OHT), assess the risk of future visual impairment, taking account of risk factors such as: level of IOP, CCP, family history and life expectancy.[19]

Summary

Central corneal thickness is important as it affects the measurement of IOP, with thin corneas resulting in underestimated IOP readings, and thick corneas with overestimates. Corneal thickness is also an independent risk factor for the development of glaucoma. Central corneal thickness can be easily measured using a handheld ultrasound pachymeter. The instrument must be correctly prepared and disinfected prior to use; the patient should give their verbal consent prior to the procedure; and a local corneal anaesthetic is required in order to perform the test. The final measurement for each eye is useful as it helps form a more reliable classification of a person's risk of developing glaucoma when considered alongside the other key glaucoma findings of IOP, disc and nerve assessment, anterior angle assessment and visual fields.

Clinical pearls

- Think of any CCT result as falling into one of three categories: thin, average and thick
- Thin corneas are at a higher risk of developing glaucoma and glaucoma progression, thick corneas are at a lower risk
- Don't use conversion tables, record the actual Goldmann IOP measured and the CCT
- The CCT will generally be similar between both the right and left eye. If there is a big variation, double check the result as you may have not been centrally aligned
- One CCT measurement will not be good for life. Corneas may thin over a lifetime, it is recommended that an updated reading is taken every 5–10 years, and always following surgery
- Measure CCT before performing gonioscopy, as the goniolens may temporarily alter the shape of the cornea
- Remember CCT and IOP are just one of many measures to view in context. Consider everything like the pieces of a jigsaw; you need to look at all the pieces together before interpreting the glaucoma picture

Note relating to COVID-19 April 2020

COVID-19 has presented a number of challenges to the way we care for patients whilst we protect their best interests as well as the safety of our colleagues and ourselves.

Please read the Specsavers Guide to PPE in Optical Settings (April 2020) if you work for Specsavers Opticians, for regularly updated information about the use of PPE.

A useful summary of the correct PPE specification for UK primary care optometry is available at:

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/877599/T2_Recommended_PPE_for_primary_outpatient_and_community_care_by_setting_poster.pdf

Additional considerations for infection prevention and control relating to COVID-19 are available at:

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/877603/T4_Additional_considerations_of_COVID-19_poster.pdf

The College of Optometrists has provided guidance and frequently asked questions to inform our decisions. Understanding of pachymetry methods is vital at this time. Guidance relevant to practice can be found at:

https://www.college-optometrists.org/the-college/media-hub/news-listing/coronavirus-covid-19-guidance-for-optometrists.html

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14. http://www.healio.com/optometry/glaucoma/news/print/primary-care-optometry-news/%7B0c78f021-fde3-4826-a657-f22c13a7e3dd%7D/classify-corneas-simply-as-averagethin-or-thick

15. Shalini Mohan MS, Anand Aggarwal MD, Tanuj Dada MD et al. *Pachymetry: A Review. Delhi Ophthalmological Society Times* Vol 12, No 10. 2007

16. College of Optometrists guidance on disinfection of reusable devices

17. Royal College of Ophthalmologists guidance on disinfection of reusable devices

18. Section 3, GOC standards of practice 2016

19. https://www.nice.org.uk/guidance/ng81

Further resources

COVID-19 Guidance for infection prevention and control in healthcare settings DHSC PHE HPS PHA PHW (27/03/20)

College of Optometrists guidance (3/3/20)

https://www.college-optometrists.org/the-college/media-hub/news-listing/ppe-personal-protective-equipment-covid-19.html

https://www.college-optometrists.org/the-college/media-hub/news-listing/coronavirus-covid-19-guidance-for-optometrists.html

Royal College of Ophthalmologists guidance (03/4/20)

https://www.rcophth.ac.uk/wp-content/uploads/2020/03/NEW-PPE-RCOphth-guidance-PHE-compliant-WEB-COPY-030420-FINAL.pdf

Academy of Medical Royal College, PPE letter (28/03/20)

https://www.aomrc.org.uk/wp-content/uploads/2020/03/200328_Personal_protection_equipment_letter_NHSEI_PHE_AoMRC.pdf

NHS England Standard Operating Procedure (5/3/20)

HYPERLINK "https://www.england.nhs.uk/wp-content/uploads/2020/02/20200305-COVID-19-PRIMARY-CARE-SOP-OPTICAL-PUBLICATION-V1.1.pdf" \l "page=6" https://www.england.nhs.uk/wp-content/uploads/2020/02/20200305-COVID-19-PRIMARY-CARE-SOP-OPTICAL-PUBLICATION-V1.1.pdf#page=6

GOC's Enhanced CET Scheme

CET and CPD regulators require practitioners to reflect on their learning. Additional activities are required to gain CET for distance learning.

Log into your CET dashboard via iLearn. On the menu you reach you can choose either interactive or non-interactive CET for this unit of learning.

If you choose 'non-interactive', you have to pass (>60%) a six-question multiple-choice quiz. If you choose 'interactive', you must pass the MCQ quiz and complete a further 30-minute discussion with a colleague, and upload a short summary of your discussion and reflections within 30 days. Note you must complete both tasks before your CET can be awarded. If you want the CET counted within a calendar year, make sure you submit the online record of discussion and remind your colleague to verify it online at least 2 weeks before the end of the year.

Further instructions for interactive learning are as follows:

The following steps must be completed within 30 days of completing the MCQ quiz:

1. Discuss the interactive questions below with a registered colleague. Note if you are an optometrist, the colleague must also be an optometrist. If you are a dispensing optician, the colleague may be a dispensing optician, a contact lens optician or an optometrist. The discussion should be in a quiet environment where you are not interrupted for at least 30 minutes. You should conform to any current social distancing requirements, and this discussion may take place by video call (eg Microsoft Teams) or face to face. Discuss the set questions and record a summary of the output of your discussion. Please ensure to create a paper copy of your record. Sign and date the document and keep it safely stored in case your CET is audited in future by the GOC.
2. In the event of an audit, we need to be able to show the GOC that the interaction has taken place in accordance with the instructions. Therefore, before you can be given points for this activity you must, within 30 days, record your answers to the set questions in the online Discussion Record and Reflection form (link provided on iLearn).
3. You will be asked for the GOC number, name and email address of the colleague who has completed the interaction with you, so please have those ready. Your colleague will be contacted by email (so please make sure you enter their correct email address) and will be sent a link to verify the interaction took place.
4. You can only be awarded interactive CET points if these steps are completed within 30 days.

The learning objectives for this article are:

3.1.1 Optometrists will have an enhanced understanding of how to conduct safe and accurate measurement of corneal centre thickness by ultrasound pachymetry

3.1.1 Dispensing opticians will have an enhanced understanding of the procedures used for safe and accurate measurement of corneal centre thickness by ultrasound pachymetry

6.1.8 Optometrists will have an enhanced understanding of how to interpret the results of pachymetry for clinical decision-making in patients with or at risk of glaucoma.

6.1.8 Optometrists will have an evidence based understanding of corneal centre thickness ranges associated with risks and management of ocular hypertension and glaucoma

8.1.2 Dispensing opticians will have an enhanced understanding of risk factors for glaucoma.

The discussion tasks for the interactive learning option are as follows:

1. Discuss with your colleague whether you have a tool that can measure corneal centre thickness and what the relevance of pachymetry might be to your practice.
2. **(Optometrists)** Discuss with your colleague how your glaucoma related decision making is influenced by knowledge of corneal centre thickness and how this relates to evidence and guidance.
   (Dispensing opticians) Discuss with your colleague what you have learned about risk factors for glaucoma, how corneal thickness affects interpretation of risk factors, what may influence corneal thickness, and how relevant this may be to the patients seen in your practice.
3. Discuss with your colleague the personal learning outcomes you have gained from this module and how you will apply this learning to practice. Consider the following questions (you will upload these reflections to iLearn and to myGOC within 30 days of completing the quiz).
   a. What are the main things you learned from the article?
   b. How will you apply this learning in your future practice?
   c. Has this module identified any areas in which you wish to pursue further learning?