BCLA CLEAR Presbyopia: Management with contact lenses and spectacles

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ABSTRACT

This paper seeks to outline the history, market situation, clinical management and product performance related to the correction of presbyopia with both contact lenses and spectacles. The history of the development of various optical forms of presbyopic correction are reviewed, and an overview is presented of the current market status of contact lenses and spectacles. Clinical considerations in the fitting and aftercare of presbyopic contact lens and spectacle lens wearers are presented, with general recommendations for best practice. Current options for contact lens correction of presbyopia include soft simultaneous, rigid translating and rigid simultaneous designs, in addition to monovision. Spectacle options include single vision lenses, bifocal lenses and a range of progressive addition lenses. The comparative performance of both contact lens and spectacle lens options is presented. With a significant proportion of the global population now being presbyopic, this overview is particularly timely and is designed to act as a guide for researchers, industry and eyecare practitioners alike.

1. Overall purpose

Almost two billion people are currently presbyopic [1], and this figure is set to grow as populations live longer. At the same time, people are working until later in life (and therefore deeper into presbyopia) and typical work and home settings in many parts of the world are more visually complex and demanding than for previous generations with the almost universal use of digital devices. In this context, the optimum correction of presbyopia is of key importance to successful human life and this report has been designed to provide an overview and to explore evidence for various considerations related to the two most widely adopted approaches: contact lenses and spectacle lenses. For both of these main interventions, history and market information are presented and issues related to clinical management, product performance and future directions are described.

1.1. Terminology

Table 1 outlines the key terms used in this paper and is largely based on ISO 18369-1:2017 [2] and ISO 13666:2019 [3]. Note that less-commonly used terms are defined in the relevant section of the paper.

Table 1
Terminology adopted in this paper.

Term	Definition
Addition power, addition, add	The difference between the average vertex power of the most plus (or least minus) portion and the average vertex power of the least plus (or most minus) portion of the lens.
Bifocal contact lens	A multifocal contact lens having two optic zones, usually for distance and near-vision correction.
Centre distance contact lens	A multifocal contact lens or progressive power contact lens where the maximum minus (or minimum plus) power is found in the central optic zone of the lens.
Centre near contact lens	A multifocal contact lens or progressive power contact lens where the maximum plus (or minimum minus) power is found in the central optic zone of the lens.
Degressive-power lens	A power-variation spectacle lens with a primary reference point for near vision, generally designed to provide clear vision from near to further distances.
Extended depth of field and extended depth of focus (EDOF)	Both terms are used in the contact lens literature. Some contact lenses are designed to deliver an extended depth of focus and in doing so, the wearer experiences an extended depth of field. Both terms are inherently correct for this lens type. In line with its more widespread use in the literature, the term 'extended depth of focus' is employed in this paper.
Eye care professional (ECP)	An eye care health professional, generally indicating an optometrist, optician or ophthalmologist. Both the scope of practice and training of these professionals varies internationally.
Multifocal contact lens	A contact lens designed to provide two or more zones of different corrective powers. **Note that for contact lenses, the terms 'bifocal' or 'progressive' or 'varifocal' are subsets of 'multifocal lens', with the latter term generally preferred in this paper.**
Power-variation lens	A spectacle lens with a smooth variation of focal power over part or all of its area, without discontinuity, designed to provide more than one focal power.
Progressive or varifocal power contact lens	A contact lens designed to provide correction for more than one viewing range in which the power changes continuously, rather than discretely, over a part or the whole of the lens.
Progressive-power lens and progressive-addition spectacle lens (PAL), varifocal	A power-variation spectacle lens with two reference points for focal power, generally designed to provide correction for presbyopia and clear vision from distance to near. **Note that the term progressive-addition lens (PAL) is generally preferred in this paper.**
Simultaneous image multifocal contact lens	A contact lens that performs in a manner that does not primarily depend on contact lens movement for different viewing distances.
Translating (alternating) bifocal contact lens	A contact lens that performs in a manner that depends primarily on the movement of the contact lens to position either the near or the distance portion in front of the pupil.

Table 2
Reports of prescribing percentages of different contact lens types for presbyopia.

Contact lens type	1987/88	1991	2004	2018–22
	Australia [21]	UK [22]	UK [23]	World[a]
Multifocal - soft	15 %	15 %	17 %	41 %
Multifocal - rigid	2 %	8 %		3 %
Monovision - soft	30 %	25 %	47 %	9 %
Monovision - rigid	4 %			1 %
Non-presbyopic[b] - soft	45 %	52 %	36 %	34 %
Non-presbyopic[b] - rigid	4 %			12 %

a, Present report; b, single vision lenses (neither multifocal nor monovision).

2. Contact lenses for presbyopia correction

2.1. History

Although scleral contact lenses were first fitted in 1888 [4], it was another half a century before the idea of bifocal contact lenses was proposed. In his patent entitled "Contact Lens", filed on August 21, 1936, United States (US) optometrist William Feinbloom suggested, among other ideas, the manufacture of " … contact lenses whose corneal sections are made with two or more different refractive powers" [5]. He described three designs – bifocal (Fig. 1A), trifocal (Fig. 1B) and multifocal (Fig. 1C). Feinbloom did not discuss whether these contact lenses were intended to be used as simultaneous or alternating designs, and it is difficult to envisage any of them working effectively. This patent was awarded on September 6, 1938; however, there is no record of Feinbloom ever having successfully fabricated and fitted such lenses [6].

It is unclear who performed the first successful fitting of bifocal scleral contact lenses. Bowden noted that, in 1950, United Kingdom (UK) ophthalmologist Frederick Williamson-Noble produced several scleral lenses with a small reading zone in the centre of the optic zone [7]. Lamb and Bowden also mention that UK-based ophthalmologist Josef Dallos fitted bifocal scleral contact lenses around the same period, and they published images of two of these contact lenses [8].

The first person to fit a rigid bifocal corneal contact lens is also unclear. Koffler claims that 'in the 1950s', Tsuetaki and Camp developed the first bifocal polymethyl methacrylate contact lens utilising a half-round segment [9]. On November 18, 1957, UK optometrist John de Carle filed a patent application entitled "Bifocal corneal contact lens", in which he described a rigid bifocal corneal contact lens of concentric design with a centre portion focused for distance correction, surrounded by the reading portion [10]. The invention was patented on June 5, 1962. The first scientific paper reporting the fitting of rigid bifocal corneal contact lenses was published in 1960 [11]. In that paper, Jessen reported having fitted over 500 patients with rigid bifocal corneal contact lenses of various designs, including the de Carle bifocal, which he described as being 'ingenious in design'.

The concept of monovision correction of presbyopia – whereby one eye is corrected for distance vision and the other for near vision – was first suggested by United States (US) ophthalmologist Richard West-smith in 1958 [12]. Westsmith – who was emmetropic – reported being unable to adapt to bifocal spectacle lenses, so he fitted a +1.50D rigid
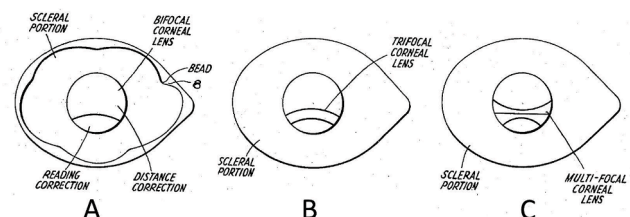

Fig. 1. Bifocal scleral contact lens designs proposed in the 1938 Feinbloom patent. (A) bifocal, (B) trifocal, (C) multifocal.

spherical contact lens to his left eye. He claimed that he had worn the contact lens successfully for one month, with good near vision, and was undisturbed by the slight blur in his left eye for distance vision.

It is difficult to ascertain the first instance of soft bifocal contact lens fitting, as during the 1970s, many small custom laboratories had emerged around the world which were capable of generating novel designs by lathe-cutting xerogels in any form, prior to hydration and forming a hydrogel lens. In 1977, KL Rowley in the UK reportedly designed and fitted a truncated soft translational bifocal lens with prism ballast [7]. The first published report of soft bifocal contact lenses was that of Hirst in 1980 [13]. The first soft bifocal contact lenses approved by the US Food and Drug Administration in 1981 were the Bausch & Lomb PA1 (for 'progressive addition #1') spin cast aspheric bifocal soft contact lens and the Wesley-Jessen Durasoft Bifocal Contact Lens [14]. The Bi-Soft lens – a bifocal soft contact lens – was launched by CibaVision in June 1982 [14].

In 1982, Pilkington produced the Diffrax rigid corneal bifocal contact lens [7]. This was a simultaneous-focus bifocal design which used a diffraction grating to create distance and near foci simultaneously. The gratings produced interferometry patterns with good resolution, similar to the technology used to produce holograms. A hydrogel version of this lens – the Echelon Diffractive Bifocal Contact Lens – was developed by Hydron in 1989 [15].

A more recent optical construct for contact lens presbyopic correction is the 'extended-depth-of-focus' lens. This approach, which was first described in the Griffin patent granted in 2002 [16] and later discussed by Zlotnik et al. in 2009 [17], involves generating an optical design on the front surface of a contact lens that is capable of extending the depth of focus of the lens by 3.00D. The authors conducted clinical trials and claimed to have achieved good visual acuity and contrast sensitivity for both distance and near vision [17].

Highlighted above is an historical overview of the major pioneering developments in multifocal contact lenses in terms of contact lens material (soft/rigid), contact lens form (scleral/corneal) and optical principle. Historical developments in respect of the various forms of simultaneous/translating designs are not considered here. At the time of writing, 101 different multifocal contact lenses – in a variety of different brands, optical and physical designs, materials and replacement frequencies – are available, comprising 12 soft daily disposable, 42 soft reusable spherical, 12 soft reusable toric, 31 rigid, and four hybrid (rigid centre/soft skirt) multifocal contact lenses [18,19]. The remainder of Section 2 in this paper will consider these current options.

2.2. Fitting trends and market information

Contact lens prescribing surveys conducted towards the end of the 20th century and early 21st century serve as important indicators of the initial level of practitioner activity in contact lens fitting of presbyopes, and in particular, interest in early-generation soft multifocal contact lens designs. Practitioner surveys conducted in Australia in 1980 and 1983/84 revealed that bifocal contact lenses constituted 0.5 % and 1.0 % of soft contact lens fits to presbyopes, and 2 % of rigid contact lens fits to presbyopes, respectively (the extent of monovision fitting was not reported) [20]. Subsequent surveys conducted in Australia in 1987/88 [21], and in the UK in 1991 [22] and 2004 [23], revealed higher levels of contact lens fitting for presbyopes (Table 2).

Contemporary data on contact lens prescribing for presbyopia can be derived from a large bank of data that has been collected from annual surveys that commenced in the UK in 1996, expanded to other markets from 1998 and which have continued to the present day [24]. A network of 97 members of the International Contact Lens Prescribing Survey Consortium supports this annual effort; the consortium is comprised of a network of academics, industry representatives and clinical colleagues who have agreed to manage the survey in their country or geographic region.

2.2.1. Conduct of the contact lens prescribing survey

Details of how this survey is conducted have been published previously [24], and so will not be repeated here in full. In essence, in each country each year, a paper or electronic (e-mail) survey form is sent to up to 5,000 contact lens practitioners (opticians, optometrists and/or ophthalmologists, depending on the market). The survey forms (locally translated if necessary) are distributed together with a request that they be completed and returned within three months of receipt. The survey is conducted at approximately the same time of year in all countries. Throughout the 25 years of the survey in up to 71 countries, 11 features of each of 406,859 fits were obtained (that is, 4.5 million data points). The results of this survey have been published previously [24]; however, for the purposes of this work, an updated analysis is presented of data relating to the contact lens correction of presbyopia.

2.2.2. Current modes of contact lens correction of presbyopia

To ascertain current trends in contact lens prescribing for presbyopia, data relating to all contact lens fits to presbyopes (that is, those $\geq$ 45 years of age) from 2018 to 2022, inclusive, were analysed. This comprised 21,326 fits (69 % to females) undertaken in 47 countries.

The distribution of types of fit is displayed in Fig. 2 and tabulated in Table 2 for comparison with historical data. The majority of presbyopic fits are with multifocal contact lenses (44 %), of which 31 % are with silicone hydrogel materials and 10 % with hydrogel materials. Multifocal rigid contact lenses comprise 3 % of fits to presbyopes. Monovision comprises 10 % of presbyopic fits.

It is evident from Fig. 2 that 46 % of presbyopic contact lens wearers are being fitted with a 'non-presbyopic fit' (typically distance correction only) and are presumably relying upon intermittent use of supplementary reading spectacles for close work. This high rate of non-presbyopic contact lens fits to presbyopes has not changed appreciably over the past 30 years (Table 2).

The reason for this apparent reluctance of practitioners to provide a contact lens correction for presbyopia in a large proportion of those over 45 years of age is likely to be multifactorial. First, a lack of fitting skills, technical knowledge or product awareness may serve to undermine confidence among practitioners who may contemplate prescribing these lens types. Second, some practitioners may be of the view that the perceptual compromises of multifocal contact lenses are too great [25] and that prospective patients are likely to fail wearing trials with such contact lenses, leading to a loss of confidence in the prescribing practitioner. Third, the absence of availability of a 'perfect' multifocal contact lens, which provides good comfort and uncompromised simultaneous optical imagery for all distances, may preclude attempts by some
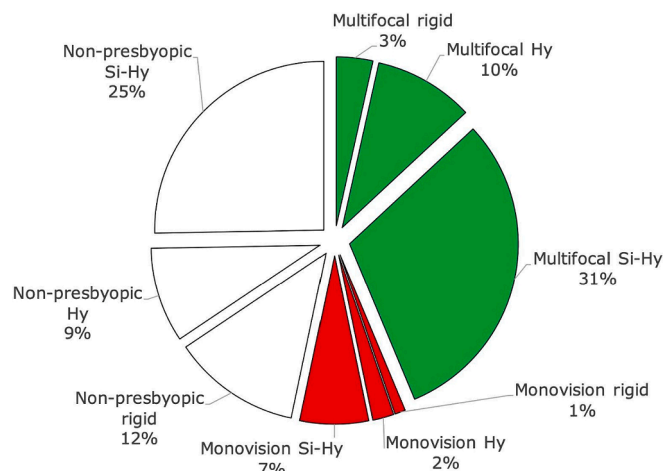

Fig. 2. Proportion of presbyopic and non-presbyopic contact lens fits conducted in 47 countries between 2018 and 2022, inclusive. Si-Hy: silicone hydrogels; Hy: hydrogels.

practitioners to correct presbyopia with contact lenses. Such perceptions can only be overcome by accelerated professional education in presbyopic contact lens fitting, delivered by academic and professional institutions and the contact lens industry, and continued research and development into optimised multifocal contact lens designs.

2.2.3. Trends in contact lens correction of presbyopia

Trends in contact lens prescribing for presbyopia over the past 20 years (2003 to 2022, inclusive) are displayed in Fig. 3, with fits stratified by soft and rigid multifocal, and soft and rigid monovision. Data for this figure were derived from 78,160 lens fits in 70 countries. It is evident from Fig. 3 that there has been a gradual increase in the extent of contact lens fitting to presbyopes, with virtually all of this increased activity attributed to soft multifocal lens fits.

The rising use of multifocal soft contact lenses over this 2-decade period can be attributed to a combination of (a) increasing availability of multifocal lenses types [18,19], (b) expanding parameter ranges [18,19], and (c) advances in optical designs that offer more acceptable vision with multifocal contact lenses than with previously-available lenses [26].

2.2.4. International differences in contact lens correction of presbyopia

To examine differences between nations, the percentage of soft lens multifocal and monovision contact lens fits to presbyopes was determined for all countries returning data on ≥ 500 such fits between 2018 and 2022, inclusive. The results of this analysis are shown in Fig. 4. A total of 17,398 lens fits conducted in 28 countries are represented in this figure.

There are clear differences between countries in the extent of contact lens fitting to presbyopes. A number of factors can contribute to this, such as differences in population demographics; differences in the onset and rate of progression of presbyopia [27]; availability of brands and specific types of bifocal lenses; regulatory constraints; types of prescriber/seller (that is, optometrist, opticians, ophthalmologists or unregulated lens sellers); and the nature of practitioner training in respect of presbyopic contact lens correction.

A possible factor that could potentially explain international differences in the prescribing of multifocal contact lenses for the correction of presbyopia is national affluence. Multifocal contact lenses can also be considered as discretionary in that lens wearers have alternative and perhaps less expensive – albeit less desirable – options for correcting their presbyopia, such as (a) monovision single vision contact lenses, or (b) the use of reading spectacles over single vision contact lenses. For equivalent lens designs, multifocal lenses tend to be more expensive than single vision lenses; for example, it has been shown that the annual cost of daily disposable hydrogel multifocal contact lenses is 45 % more

than that of daily disposable hydrogel spherical contact lenses, and the annual cost of 2-weekly replacement silicone hydrogel multifocal contact lenses is 24 % more than that of 2-weekly replacement silicone hydrogel spherical contact lenses [28]. It might be expected that presbyopes in less affluent nations are less inclined to purchase more expensive multifocal contact lenses.

This idea was recently investigated by determining if there is a correlation between the extent of multifocal contact lens prescribing and national affluence (as measured by national gross domestic product); no correlation was found [28]. The authors of that work suggested that multifocal contact lenses are generally fitted to persons over 45 years of age (that is, presbyopes) [24] – a demographic that has, on average, a higher annual disposable income than those under 45 years of age (that is, pre-presbyopes) [29]. The higher disposable income of presbyopes is thought to mitigate against any impact of national affluence.

2.3. Preliminary clinical examination

2.3.1. Understanding patient needs and how this informs lens choice

It is important that eyecare professionals (ECPs) educate their patients about presbyopia and the various correction options available [30,31]. In general, both pre-presbyopic and presbyopic patients are not familiar with the term 'presbyopia' and do not understand what it means [30,32]. The need for presbyopic correction is generally viewed negatively as a sign of decline or of old age [30]. Furthermore, patients not yet needing a presbyopic correction are reported to be sceptical, reluctant or even worried at the prospect of having to do so [30,33].

This analysis explains why pre- and early presbyopes may deny their need for near vision correction and why pre-presbyopes may need to receive more information about their correction options than more established patients [30]. Interestingly, presbyopes are generally aware of visual symptoms some time before seeking advice from an ECP [34,35].

Overall, the criteria for selecting the contact lens material, replacement frequency and wearing schedule for contact lens options are similar for a presbyope as for a non-presbyopic patient. The ECP should seek to optimise contact lens comfort, vision, convenience and cost, and with minimal impact on ocular physiology [30], although cost is by far the least important despite ECPs believing that patients consider this to be paramount [36]. Indeed, there appear to be various mismatches between patient and ECP when considering the aims of and needs for contact lens fitting. Practitioners tend to emphasise the clinical, anatomical and technical aspects of the decision-making process, [35,37] whereas patients are more concerned about convenience and comfort [30]. Patients have reported that they prefer to be more involved in their choice of correction type but believe that they do not get adequate information for making informed decisions [38].

Determining patient needs prior to contact lens fitting is best practice [36]. To accomplish this goal, one option here is to adopt presbyopia impact and coping questionnaire(s) or patient-related outcome measures (PROMs) to reveal patient coping mechanisms, such as using a mobile phone to take pictures with subsequent enlargement or simply needing to increase font sizes or using the zoom function on the computer displays, tablets or smartphones [33]. Such questionnaires can evaluate how satisfied patients are with their current correction option [33] and can ask patients to outline their current vision requirements. This information should guide the ECP in considering available correction options.

Patients not yet wearing contact lenses before becoming presbyopic generally do not consider them as an option [30] and tend to be more open to them when offered by an ECP rather than raising the option themselves [39]. However, those already in distance vision contact lenses are typically much more enthusiastic about correcting presbyopia with contact lenses [30].

Understanding the degree of motivation for contact lens correction of presbyopia is a useful clinical step. Key elements of this are to identify
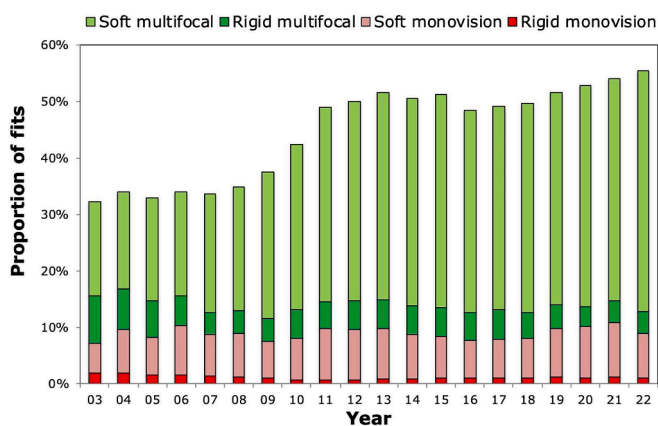

Fig. 3. Trends in contact lens prescribing for presbyopia over a 20-year period (2003 to 2022, inclusive) in 70 countries, stratified by soft and rigid multifocal, and soft and rigid monovision fits.
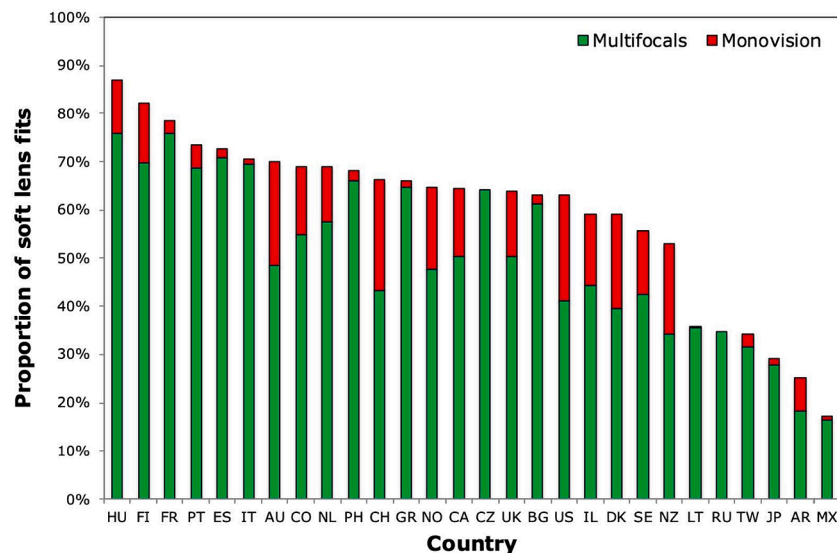
Fig. 4. Percentage of soft lens multifocal and monovision fits to presbyopes for 28 countries returning data on ≥ 500 such fits between 2018 and 2022, inclusive. Country codes: AR, Argentina; AU, Australia; BG, Bulgaria; CA, Canada; CN, China; CO, Colombia; CZ, Czech Republic; DK, Denmark; ES, Spain; FI, Finland; FR, France; GR, Greece; HU, Hungary; IL, Israel; IT, Italy; JP, Japan; LT, Lithuania; MX, Mexico; NL, Netherlands; NO, Norway; NZ, New Zealand; PH, Philippines; PT, Portugal; RU, Russia; SE, Sweden; TW, Taiwan; UK, United Kingdom; US, United States.

the distances that are important for the patient, how they spend their time during the day, and which visual tasks are important and time-consuming [35,37]. Myopic spectacle wearers, of course, can have adequate near vision without correction [30,31], although they may tire of the repeated lifting of spectacles if this is their typical practice. Discussion on the inconvenience of such behaviour should form part of the overall patient discussion.

2.3.1.1. Monovision. Monovision is seen as a fast and easy option for early presbyopes [40]. However, ECPs should note that multifocal contact lenses tend to perform better than monovision in many situations [41,42], possibly due to a reduction in stereopsis with monovision [43]. As such, ECPs should query patients with depth perception requirements (for example, machine workers, craftspersons, golfers and tennis players) carefully before considering monovision contact lenses [44].

2.3.1.2. Multifocal contact lenses. Compared to the generally quick fitting process with monovision, multifocal contact lens fitting may take longer [35,37] as there are more variables to consider, including, for example, pupil centration and multiple power options [45]. As such, ECPs should advise patients that a successful outcome may require the fitting of more than one contact lens pair, although recent data show that some contemporary multifocal contact lens options have high success rates with just one pair of contact lenses [46,47]. For soft contact lenses, many daily disposable and reusable brands feature a multifocal option so many existing single vision lens wearers can move seamlessly into multifocals, retaining the same replacement schedule and material and likely maintaining similar levels of wearer comfort. Multifocal contact lenses are likely to be better received than spectacles for many occupations and pursuits [48] – notably, any role which requires good distance and near vision at multiple directions of gaze, and just about any sport. A number of reusable multifocal toric soft contact lenses are now available for astigmatic presbyopes. Perhaps more than for other contact lens designs, patient motivation has been identified as a major requirement for success with multifocal contact lenses [37,49,46,50,51] which should be factored in when ECPs are considering contact lens choices.

2.3.2. Clinical assessment

2.3.2.1. Clinical examination prior to contact lens fitting

2.3.2.1.1. Capture of patient history and symptoms. A comprehensive recommendation of points to cover when obtaining a contact lens history and inquiring about symptoms, was provided as part of the BCLA CLEAR report on evidence-based contact lens practice [52]; these are summarised in Table 3.

For presbyopic patients several additional, specific, considerations may be warranted:

2.3.2.2. Presenting symptoms. Aside from difficulties with both reading and use of digital devices, presbyopic onset may be accompanied by epiphora and asthenopia [54]. Patients may report the use of temporary solutions such as over-the-counter reading glasses, magnifiers or increased lighting [54].

2.3.2.3. Ocular health and patient history. Use of topical ocular medications is not necessarily a contraindication for contact lens wear but ECPs may wish to consider contact lens replacement frequency, modality, timing of the drops, and whether the drops are preservative-free [52].

Eyelid surgery is now extremely common and was the most common cosmetic procedure in Asia (and the third most common procedure requested by Asian Americans) in 2009 [55]. Given the potential impact on lid tautness and the subsequent implications on contact lens fitting (translating rigid lens designs, toric lens rotation) the relevance of this growing trend may be of increased importance to contact lens prescribing and any prior ocular surgery ought to be recorded, in particular for rigid lens wearers.

2.3.2.4. General health. Both multifocal spectacles and monovision contact lens correction have been associated with an increased risk of falling in some population groups [56–59]. ECPs may, therefore, wish to consider the presence of other risk factors for falls when making prescribing decisions, for example, age, poor mobility, impact of existing medication on balance, or working at elevated heights [60].

Various general health conditions which affect the ocular surface, meibomian gland dropout, or otherwise impact the tear film may lead to increased susceptibility to infection or reduced comfort and wearing

Table 3

Summary of typical contact lens history and symptom topics. As with most contact lens wear, it would be useful to ensure the patient has a backup spectacle correction in case of infection [based on Wolffsohn et al 2021 [52]]. CLDEQ-8: contact lens dry eye questionnaire-8; HIV: human immune-deficiency virus' MK: microbial keratitis; VDU: visual display unit.

Point of discussion	Notes
Reason for visit	While cosmesis is the most commonly cited reason for contact lens wear, a recent survey of over 40-year-olds found 'sports and fitness' and 'work purposes' to be the main reasons [53]
Patient age	
Ocular symptoms, ocular history	● Previous contact lens wear, reasons for discontinuation [37] ● CLDEQ-8 for existing wearers ● Previous history of corneal infiltrative events (CIEs)s associated with an increased risk of future CIEs in contact lens wearers ● History of blepharitis, meibomian gland dysfunction (MGD), allergies
General health	● Diabetes – check for presence of ocular surface disease, for example, recurrent corneal erosions ● Individuals with conditions such as HIV may be more vulnerable to infection and MG dropout ● Thyroid eye disease more common in individuals with contact lens related MK ● Upper respiratory tract infections associated with contact lens related corneal infiltrates
Medication	● Consider use of ocular medication, preservatives used, timing and dosage. ● Check side effects of any medications used for potential impacts on ocular surface or tear film
Family history	For example, keratoconus, corneal dystrophies
Lifestyle/occupation/ environment	Swimming, video games, driving, smoking, VDU work, exposure to dust, water, air conditioning, low humidity etc Understand vision needs for distance versus intermediate versus near - time spent on viewing each distance and quality of vision needed for each

time. Discussing the potential risks with the patient can help them make informed choices [52], in addition to providing options to help maintain comfortable lens wear with a potentially compromised ocular surface and tear film.

2.3.2.5. Occupation and hobbies. Since presbyopia correction options may lead to compromising on certain aspects of visual performance, it is useful to gain an understanding of specific visual task demand such as tasks, font sizes, piece sizes, working distances and duration of activity.

With respect to driving, performance between progressive addition lens spectacle lenses and multifocal contact lenses appears to be similar [61]. Monovision wearers may, however, experience problems with blur suppression when driving at night [25].

2.3.2.6. Baseline measurements. Contact lens fit relies upon contact lens back surface geometry and its interaction with the anatomy of the eye. While initial contact lens selection is commonly preceded by measurement of several ocular parameters, the rationale underlying this practice, particularly for soft contact lens fits, is not always supported by the scientific literature [52].

2.3.2.6.1. Horizontal visible iris diameter, white-to-white. In a study of individuals aged 40–64 years, linear regression showed white-to-white diameter to be larger in younger participants [62].

2.3.2.6.2. Visible palpebral aperture OR vertical visible iris diameter. The evidence base supporting visible palpebral aperture measurement, with respect to lens fitting, is weak [52], and visible palpebral aperture is not considered a major correlate of ocular surface disease or dry eye. Nevertheless, there are several instances where recording visible palpebral aperture may be beneficial when fitting the presbyope, such as, for bifocal translational rigid contact lens designs which rely on

appropriate interaction with the eyelids, or as a baseline measure for future monitoring of either lens-induced or age-related ptosis.

2.3.2.6.3. Lid tension and lid pressure. Eyelid tension and pressure may contribute to contact lens fitting, tear film maintenance and corneal astigmatism [63,64]. While upper eyelid tension is believed to reduce with age [65], a pilot study investigating the link between age and lower lid tension failed to show a significant relationship [66]. Yet, it is noteworthy that advancing age has been linked to lower lid conditions such as ectropion [67].

With respect to lens fitting, presbyopic individuals with flaccid lids are generally considered poor candidates for rigid translating design lenses [37,68,69].

2.3.2.6.4. Corneal shape. A change towards against-the-rule astigmatism for the anterior cornea and, to a lesser extent, with-the-rule astigmatism for the posterior cornea has been linked to advancing age [70]. Age-related differences in rate of corneal shape change have also been reported between males and females [71]. Some, but not all, corneal higher-order aberrations are found to significantly increase with age. These include vertical coma, vertical trefoil, and primary and secondary spherical aberrations [72].

2.3.2.6.5. Pupil size. Whilst it is potentially useful to measure pupil size in prospective contact lens wearers, usually for back optic zone calculation (especially for rigid lens fitting), this parameter holds additional significance when fitting the presbyope.

The interplay between pupil size and multifocal contact lens design determines the relative proportions of near and distance optical powers available to the patient [73,74]. Pupil diameter, as well as individual aberrations, have been identified as the main participant-dependent factors affecting quality of vision [75]. Given the potential changes in pupil size by both age and refractive status [76], it has been suggested that multifocal lens designs ought to be adapted to account for such differences; however, a well-controlled study found neither pupil size nor pupil decentration away from the visual axis to be significant influencers on patient soft multifocal contact lens preference [77]. Nevertheless, recent work has shown that centre-distance multifocal contact lenses (with a central optic zone extending to approximately 80–100 % of the photopic pupil size may offer visual advantages (see section 2.7)) [78].

The presence of large pupils (>5mm in room lighting) in patients may need to be carefully considered when fitting aspheric rigid design lenses due to the potential for glare and image ghosting [37]. There remain cases where multifocal contact lens designs are independent of pupil dynamics, for example diffractive design lenses [37,51,79] (see also section 2.4.1.5); however, the commercial viability of such contact lenses has so far been limited [51].

2.3.2.6.6. Ocular dominance. Establishing the dominant eye allows designation of distance and near-biased lens powers when fitting monovision and simultaneous vision contact lens designs. The process is believed to facilitate blur suppression and therefore contact lens adaptation. However, some researchers report that, at least for monovision, the impact of selecting one eye over the other may be minimal [80,81]. Further discussion of the process of establishing ocular dominance is provided in section 2.6.1.

2.3.2.6.7. Stereopsis. Loss of stereoacuity with monovision tends to worsen with higher near addition powers [25,43,82]; furthermore, practical tasks requiring depth perception are performed less well with monovision [83–85]. Compared to spectacles, researchers have found stereoacuity to be reduced with soft multifocal contact lenses [86], while others find performance to be retained at a similar level [87].

2.3.2.6.8. Slit lamp examination and tear film assessment. Age-related physiological changes mean additional considerations when fitting contact lenses to the presbyopic eye. Together with a standard slit lamp examination, a thorough evaluation of the tear film quality and quantity and anatomical features, such as lid tautness, may be required. The prevalence of dry eye disease increases with advancing age, with prevalence higher in women compared to men [88]. Notably, signs of dry eye

disease may increase more per decade than symptoms [89]. The prevalence of meibomian gland dysfunction specifically has been estimated to increase by 5.3 % per decade [90]. See Table 4 for details of a slit lamp examination according to Wolffsohn et al (2021) [52].

2.3.2.7. Lens fitting and evaluation. Although baseline measurements may be important for empirical fitting, rigid lenses, monitoring change, troubleshooting, or for medico-legal purposes, most soft contact lenses fitted today are mass-produced with few opportunities for ECPs to manipulate parameters such as back optic zone radius, back optic zone diameter and total diameter. Multiple other lens properties (for example, materials, wetting agents, surface treatments, tints, power options, design), replacement frequencies and wearing modalities can, however, be selected by the ECP and may subsequently influence patient satisfaction [91].

Typically, it will take 1–2 multifocal contact lenses at the screening/fitting visit before an appropriate lens is found [47]. Most multifocal lenses will be accompanied by fitting guides tailored to the specific lens in question and the use of trial frames rather than a phoropter is generally advised to allow a more natural head position [92].

When evaluating visual performance, task-oriented assessment may be beneficial [32,51,83–85,93], with some researchers advocating a more comprehensive approach of generating defocus curves to evaluate visual performance [32] although such advice may be impractical in clinical practice. Recommended clinical assessments for presbyopes include reading, asking about subjective benefits, and assessing vision performance. Additionally, for simultaneous images/translating designs, measuring aberrations, straylight and glare, and contrast sensitivity have been recommended [32].

Some researchers advocate informing presbyopes being fitted with contact lenses of the potential impact on quality of life [51]. Specifically, they argue that patients should be advised of a possible compromise in visual quality, and that differences in refractive correction (extra plus or extra minus) may be required for specific tasks such as detailed work at near or driving at night. However, there is little published evidence to support any particular counselling approach and indeed, there is little

correlation between objective consulting room tests and successful presbyopic contact lens fitting [41]. Furthermore, if there is any visual compromise, this needs to be balanced against the general improvement in quality of life offered by contact lenses over spectacles [94]. Contrary to conventional wisdom, lens decentration is reported to neither significantly impact visual performance in presbyopes nor affect overall contact lens preference [45,77].

2.4. Soft lenses

2.4.1. Simultaneous imaging lenses

2.4.1.1. General principles. In their simplest form simultaneous imaging contact lenses have two different optical powers that, when placed in front of the entrance pupil of the eye, facilitate viewing of objects situated at both far and near distances. More complex arrangements are possible, such that multiple, continuously varying, or non-refractive optical elements can be incorporated, but all have in common that the distribution of light on the retina results from the simultaneous contribution of all relevant elements of the contact lens. While primarily designed for application in presbyopia, similar optical arrangements are increasingly being adapted and adopted for use in myopia control.

2.4.1.1.1. Retinal image quality. The retinal light distribution created by a simultaneous imaging contact lens is the feature that both permits it to function as a presbyopic correction and its main weakness. While light coming from an object of regard is brought to a relatively sharp focus on the retina by the corresponding optical portion of the lens, that image is overlaid by out-of-focus light that has passed through the remaining optical elements. Thus, the desirable in-focus image suffers a degree of contrast reduction caused by the out-of-focus images superimposed upon it [95]. Inevitably, this situation impacts visual function to an extent which depends on a range of factors, acting both individually and in combination. These include the optical design of the contact lens, its centration, pupil size [96], residual accommodation and astigmatism, individual ocular aberrations [97] and the contrast and brightness of the visual scene [98–100]. Associated visual phenomena that wearers may report include poor vision, especially in low illumination, ghosting, haloes and flare. Dealing with these problems is the major focus of post-fitting, follow-up care and unsuccessful outcomes are the major reasons for dropout [101].

2.4.1.1.2. Pupil dependence. The fact that many simultaneous imaging contact lens designs place multiple optical zones in front of the eye, means that different focal properties are imparted to light entering the pupil, depending on which portion of the contact lens it has previously passed through. Changes in pupil size can therefore affect the contribution made by each contact lens element in forming the retinal image, a phenomenon known as pupil dependence. Taking the example of a concentric, centre-near bifocal shown in Fig. 5, as the pupil constricts, relatively less light is admitted through the distance optics, and the ratio of distance to near light reduces. In the extreme case where the

Table 4
Anterior eye examination based upon Wolffsohn et al. (2021) [52]. MGD: meibomian gland dysfunction; OCT: optical coherence tomography.

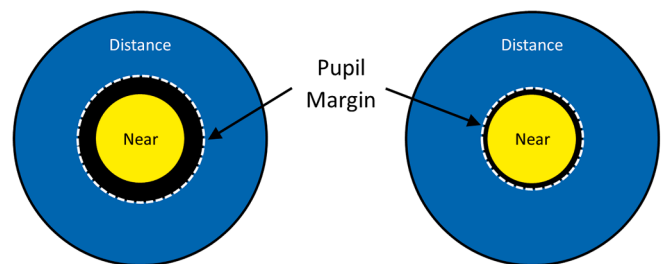| Examination	Notes
Slit lamp biomicroscopy	
Tear film	Non-invasive examination precedes invasive approaches
Grading scales and photography	● Grading to the nearest 0.5 step ● Change of > 1 unit is clinically significant ● Specify scale used ● Record: blepharitis, MGD, bulbar and limbal hyperaemia, corneal neovascularisation, palpebral conjunctival redness (white light) and palpebral roughness with fluorescein sodium ● Draw corneal/conjunctival staining, record depth
Lid eversion	Upper lid eversion is considered to be best using a silicone rubber everter
Palpebral conjunctiva	White light examination ought to precede fluorescein sodium and blue light/yellow filter examination
Lid margins	Check for anterior blepharitis, MGD, lid-parallel conjunctival folds, lid wiper epitheliopathy
Ocular surface damage (using ophthalmic dyes)	● Fluorescein sodium for tear film, corneal staining. Examination under blue light with a yellow filter ● Lissamine green for conjunctival and lid margin staining
Use of other anterior eye techniques where appropriate	For example, meibography, OCT

Fig. 5. Effect of pupil size on Distance:Near ratio for a centre-near bifocal. Left: Large pupil allows roughly equal (50:50) amounts of light through distance and near portions. Right: Small pupil allows relatively little light (25:75) through the distance portion.

pupil is smaller than the near optical zone, the lens tends towards monofocality.

Pupil size is dynamic and influenced by multiple factors [102], including the flux density at the cornea (that is, field illuminance x area subtense), target distance, age, binocularity and emotional state. Therefore, it is neither surprising that pupil-dependent contact lenses can be prone to performance variations, nor that individual wearers may experience differing outcomes with the same contact lens type. Consequently, several design proposals have been made in an effort to avoid the issue. Initially, these involved geometrically arranging the lens optics to maintain equality between the distant and near focal regions as pupil size varied. Some of these are shown in Fig. 6; however none has achieved wide acceptance. More recent approaches have used multiple concentric zones, diffraction and extended depth of focus (EDOF) principles, as discussed in subsequent sections.

2.4.1.1.3. Adaptation. During fitting, it is common practice for ECPs to explain the potential visual complications to wearers as a means of managing expectations during the early stages of wear. The further suggestion is often made that individuals will adjust to the new visual situation after a period of adaptation [105,106]. While this may be entirely reasonable in terms of wearer management, the evidence for adaptation to the optical realities of simultaneous vision is not strong. In fact, during the first week or so after fitting, it appears that wearers tend to become more, rather than less, aware of the associated visual decrements, as shown by significant worsening across a range of subjective ratings, including ghosting, haloes, visual fluctuation, facial recognition and visual quality [107]. Whether this trend then reverses with further exposure is uncertain.

Possible recovery of other abilities has been observed, however. For example, at eight weeks post-fitting, performance on simple tasks such as placing cocktail sticks into straws, card filing, and letter editing improves slightly, though not for all simultaneous imaging designs [108]. Crucially, acuity-based metrics do not substantially change during the post-fitting period [107–110], which reinforces their lack of sensitivity as useful clinical indicators of visual function in this context [107].

While neural adaptation to sustained, constant, refractive blur has been demonstrated [111], the relevance of this phenomenon to the complex and dynamic retinal image environment created by a multi-focal contact lens remains uncertain.

2.4.1.1.4. Clinical implications. From a practical point the phenomena discussed in the previous sections have several consequences. First, obtaining an optimum result for a given individual may require trialling more than one design, or even a mixture of designs within the same person. Second, the optimum contact lens type will vary from person to person. Third, the best achievable visual outcome will differ between individuals and in some cases, may ultimately prove to be unacceptable. Fourth, visual acuity is a poor indicator of success. Awareness of these factors can usefully inform clinicians in crafting their fitting approach and associated routine and paying attention to the manufacturer fitting guide is often a useful starting point.

2.4.1.2. 'Centre Near' contact lenses. The bulk of contemporary presbyopic contact lens fitting uses some kind of centre near design. These contact lenses are typically manufactured with an aspheric power profile so that there is a transition zone between the two nominal, principal powers [112]. In principle at least, this affords the wearer some useful vision at intermediate distances, as well as at near and far. For this reason, the term multifocal, rather than bifocal, is generally applied to these designs. Most manufacturers offer a product of this type, often in both reusable and daily disposable versions. Toric multifocal contact lenses are also available to cater for astigmatic presbyopic prescriptions.

Several factors bear upon the performance of this contact lens type. Pupil constriction with convergence for near targets is relevant and potentially helpful with centre near lenses. As mentioned previously pupil dependence is a factor, as are lens centration relative to the pupil centre and ocular aberrations [75], and since power profiles vary from manufacturer to manufacturer, it is not uncommon to discover that a design which works well for one individual is less successful in another [42]. Willingness to switch designs during the fitting process is therefore a helpful strategy for achieving subjective success.

In terms of fitting, emmetropes are regarded as being more difficult to satisfy than those with higher refractive errors [113]. Although centration has been viewed as an important parameter due to predictions of induced coma when lenses with high amounts of spherical aberration are decentred [114,115], this may be of limited practical significance, at least in younger presbyopes [75]. The natural progression of presbyopia inevitably means that higher additions are required in older wearers and achieving this can involve adjusting the lens design to increase the rate at which plus power increases across the contact lens. This in turn tends to reduce the area associated with near viewing. Both these situations are likely to reduce image quality and so prescribing the lowest addition power in any given case is usually advisable. As an associated procedure, it is highly recommended to arrange the prescription so that the maximum amount of positive power is included in the distance portion. Frequently this can be achieved, without compromise to binocular distance vision, by loading plus power in the non-dominant eye.

2.4.1.3. 'Centre Distance' contact lenses. Centre distance contact lenses have maximum plus power located towards their peripheries and are less commonly prescribed for presbyopia than centre near designs. When they are used, it is often in a combination that places a centre distance contact lens in one eye and a centre near contact lens in the other. This hybrid approach offers a means of utilising the strengths of each lens type to maximise distance and near performance and one study has shown it to be preferred over either binocular centre near, binocular multizone or monovision alternatives, in about one third of cases [77].

The defocused point spread function formed by the peripheral portion of a centre distance contact lens forms an annulus around the distance image which is often perceived as a "halo" effect. This is most problematic where the ratio of stimulus to background luminance is high, as commonly occurs when oncoming headlights approach during night driving. While decreasing the addition power may help, this is likely to reduce performance in other situations, particularly near work. As an alternative, some designs have extra positive spherical aberration to the addition zone. Somewhat counter-intuitively this increases the blur, but as it also increases the size of the halo it tends to reduce its
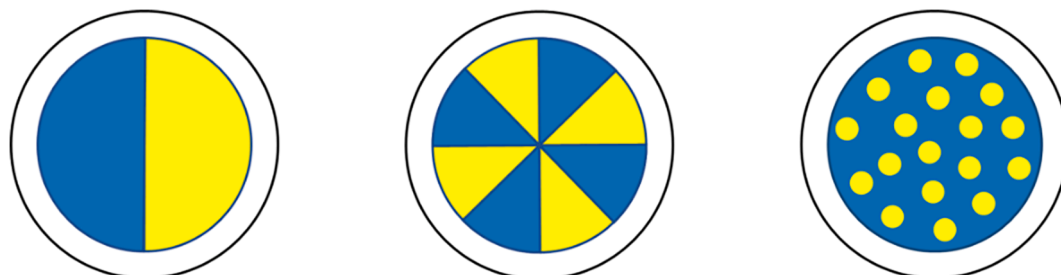

Fig. 6. Theoretically pupil-independent bifocal contact lens designs. Left: Baron, Hoefer & Schwind [103]. Middle and Right: De Carle [104].

contrast [116].

2.4.1.4. Multizone lenses. The multizone design consists of a series of concentric rings of varying power. Theoretically, the central ring can have power appropriate for either distance or near objects and the concentric arrangement is not as affected by pupil diameter changes as conventional concentric designs. As shown in Fig. 7, increasing the number of zones increases the resistance to pupil dependence [75]. The visual performance experienced by a given wearer depends on the combination of their ocular aberrations and the contact lens design, such that bifocal effects may be minimal [117]. This may explain the relatively poor performance of this contact lens type in a comparative wearing study [77].

2.4.1.5. Diffractive contact lenses. Diffraction is an alternative to the conventional refractive zones method of producing multifocality. Here, an element on the lens back surface, usually referred to as a phase or zone plate, alters the phase of incident light so that it constructively interferes at two main locations, arranged to correspond with the required distance and near foci. The profile of the zone plate typically resembles a series of annular steps, with a triangular cross-section, having a maximum height of a few micrometres. The number of annular rings increases with the desired addition power [118].

As the division of light takes place evenly across the whole zone plate, diffractive contact lenses are theoretically pupil independent. While modulation transfer function measurements have largely confirmed this to be true, the effect tends to break down at larger pupil sizes [79].

The extent to which light deviates due to diffraction depends on wavelength and so chromatic aberration is a feature of diffractive contact lenses. Usefully however, the sign of aberration is opposite to that which exists in the uncorrected eye, which generally results in some degree of compensation [119].

Despite these advantages, diffractive contact lenses have the drawback that while most light is directed into the two primary foci, these correspond to only the zero and first orders of diffraction. Higher orders must exist and light directed into these does not usefully contribute to image formation. Up to 20 % of total incident light may be lost in this way [118] and retinal image contrast inevitably reduces as a consequence. Subjectively, this affects visual quality [82] with wearers sometimes reporting that vision appears hazy or smoky.

Both rigid and soft diffractive bifocal contact lenses have been marketed in the past, with success rates in non-controlled studies being as high as 49 % in neophytes and 66 % in those with prior experience [120].
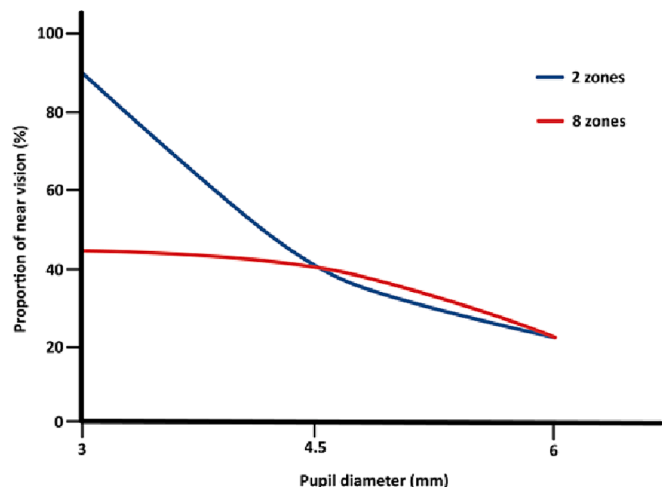
No diffractive contact lenses are currently available for presbyopia applications, but intraocular lenses based on these principles are in regular use [121 122]. It may be that the relative success of surgically implanted devices is at least partly due the fact that removal of their cataractous crystalline lens renders such patients less likely to perceive contrast losses associated with diffractive optics.

2.4.1.6. Extended depth of focus (EDOF). All simultaneous imaging lenses attempt to extend the depth of field so that useful vision is obtained at more than one and typically two, working distances. However, one subset of contact lenses seek to do so over a continuous range of vergences and are able to offer this 'extended depth of field' for wearers by their 'extended depth of focus' (EDOF) design. Both the *field* and *focus* terms are correct for such lens types, with extended depth of focus used more widely in the contact lens literature.

The most familiar way to achieve this is with pinhole viewing, which restricts incident light rays to a bundle close to the visual axis and reduces the diameter of the retinal blur circle for all object distances. Visually, this results in the effective elimination of refractive errors, including presbyopia.

Using pinhole contact lenses to correct presbyopia is a long-standing practice [123], but not one that has been widely adopted due to concerns over low light level performance and visual field restrictions [124], as well perhaps, as cosmesis.

Pinhole optics are an example of how field depth can be extended by modifying the amplitude distribution of light across the wavefront produced by the lens. Mimicking this behaviour without rendering parts of the lens opaque is an attractive goal and one that has precipitated several design proposals. For example, a virtual pinhole can be created by rapidly increasing plus power with radial distance from the lens optical centre [16]. Little objective information is available on how such lenses perform, however.

Since all amplitude modifying strategies involve some loss of light and thus reduced retinal illumination, manipulation of the phase component of the wavefront is an attractive alternative. Diffraction is an example of one such approach and a more recent development relies on manipulation of the higher order aberrations of the lens so that image quality is maximised over a range of vergences [125], rather than being concentrated into the two discrete peaks of a bifocal. While this redistribution of light energy may provide useful vision across a wide range of object distances, image quality is inevitably reduced at locations corresponding to the true bifocal peaks. Although contact lenses using this approach are commercially available, their clinical performance has not been evaluated, other than in prototype form [126].

Other phase manipulation design proposals have also been described [127,128], but not, so far, commercialised.

2.4.1.7. Translating lenses. Translating contact lenses are the only current design that allows true single vision at both distance and near. These lenses rely on the tension of the lower lid to support the lens while the eye rotates downwards behind it. In soft contact lens form, however, successful translation is affected by the coupling between the contact lens and the eye, which tends to reduce their relative motion. The problem is exacerbated by the age-related loss of elasticity of the lids, as well as the decrease in palpebral aperture width [129].

Attempts to achieve adequate movement have relied on manipulating the thickness profile of the lens so that the lower lid encounters some kind of ridge, or prism on downgaze. If adequate movement is not achieved, portions of both near and distance optical zones can cross the pupil margins, degrading the point spread function on the retina and giving poor vision [95]. Apart from having questionable efficacy, features intended to aid translation also typically interfere with subjective comfort. This can be further compromised if contact lenses are not rotationally symmetric, as may occur if there is a need to counteract the natural nasal rotation of the contact lens with blinking. To-date,

Fig. 7. Effect of increasing number of zones on pupil dependence [75].

therefore, soft translating bifocal contact lenses have not been widely utilised as a viable option for most presbyopes.

2.5. Rigid lenses

Rigid corneal multifocal lenses provide excellent optics since, compared to a soft lens, a rigid corneal contact lens has less flexure during a blink and aids masking corneal astigmatism with the post-lens tear film layer. These designs provide improved visual outcomes compared to soft bifocal contact lenses [99] and binocular high and low contrast acuity comparable to spectacle progressive addition lenses [130].

Corneal rigid multifocal contact lenses are a beneficial option for individuals who experience unstable vision in soft toric multifocal contact lenses and they provide a straightforward transition for habitual corneal contact lens wearers. These contact lenses naturally move more following each blink compared to soft contact lenses. Other good candidates are new contact lens wearers who are motivated to be spectacle-independent with more complex astigmatic prescriptions.

Multifocal rigid contact lenses are typically from one of two lens designs - simultaneous imaging or translating - and share some of the design considerations and optical features described in the soft contact lens section above. Overall contact lens fitting is similar for the two design types. Settling of 15–20 min after application is recommended prior to evaluating the lens-cornea fitting relationship. The patient should be asked to view different distances and simulate their everyday visual tasks by looking at their phone, reading a book, and switching to view distant objects [37]. Topography of a corneal contact lens on the eye has recently been reported to be a useful method by which to assess centration [131].

2.5.1. Translating versus simultaneous imaging designs

Rigid multifocal contact lens models use two different design principles: translating and simultaneous images [26,51,132]. A translating image occurs when a movement of the contact lens in a down gaze results in viewing through an area with a different refractive power.

A simultaneous image is where the concurrent projection of images emerging from multiple target distances are displayed to the eye at the same time at different focal planes. Simultaneous image contact lens designs can be comprised of (a) zones of two different optical powers (bifocal, two-foci) so that light is focused when viewing at distance or near or (b) a smooth transition between the powers necessary to focus light when viewing at distance and near (multifocal, multiple foci) [132].

Rapid transitions in optical powers are often difficult to manufacture and may create a smoothing of optical power delivering some multi-focality [132]. The retina obtains both in-focus and out-of-focus images simultaneously in either the simultaneous image design bifocal or multifocal lenses [95,132].

Neural adaptation is necessary with a simultaneous image to choose the sharp image depending on the visual target [26]. Simultaneous-image correction can be fabricated in various ways: diffractive, zonal, concentric or annular, aspheric, or EDOF. Each contact lens may be constructed as a centre-near or centre-distance design [37,49,51;97;132,133].

2.5.1.1. Simultaneous imaging contact lenses. Simultaneous image contact lenses offer a range of powers across the optic zone. The performance of typical lens designs is highly dependent upon pupil size with a desired pupil size of less than 6 mm in standard room illumination [134]. Aspheric progressive lens designs include three options: back-surface aspheric, front-surface aspheric, and dual- aspheric.

Back-surface aspheric rigid contact lenses have a spherical front surface and aspheric back surface. The aspheric back surface offers a progressive flattening from the centre to the periphery to produce the near addition effect. Most designs are fitted like a spherical corneal contact lens; however, to improve centration, the flattest corneal meridian is fitted approximately 1.00D (0.20 mm) steeper than alignment [37]. Corneal rigid contact lens binding or adherence should be avoided. Back-surface aspheric multifocal contact lenses are primarily indicated for early presbyopes who require a near addition less than 1.50 D, or current corneal rigid lens wearers with intermediate visual needs due to the confines of higher amounts of addition power [37].

If further near addition power is needed, other designs alter the aspheric front surface to achieve this. Front surface aspheric designs can be fitted with corneal alignment, unlike back surface designs which are generally fitted 'steeper than K' which can result in corneal adherence and distortion. Dual-aspheric lenses have both front-surface and back-surface aspheric optics to optimise the addition power. For presbyopes post refractive surgery, a front multifocal surface in combination with a reverse geometry back surface is also available [134].

If loose lids or low inferior eyelids are present, an individual is a better candidate for an aspheric multifocal rather than an alternating design [37]. Aspheric simultaneous-image designs are better for individuals with a smaller pupil diameter and are not typically indicated for those with a pupil diameter greater than 5 mm in standard room lighting, since distance vision may be compromised in low illumination [37]. To ensure the optics are within the visual axis, simultaneous lenses should have minimal movement of less than 1 mm with each blink.

Aspheric multifocal contact lens troubleshooting is similar to rigid corneal contact lenses. If inferior decentration or excessive movement is present, the base curve radius can be steepened by 0.50D (0.10 mm). For lateral decentration, lens diameter can be increased to improve lens centration. For superior centration, a back-surface only aspheric design can be considered as these lenses are fit steeper.

2.5.1.2. Translating contact lenses. Translating (also termed 'segmented') lenses are a good option for individuals with high visual demands or larger pupils. During primary gaze, the distance zone is fitted to align with the pupil; in a downward gaze, the lower near segment of the lens is forced up by the lower lid to align with the pupil.

The position of the segment line should be at or within 1 mm inferior to the lower pupil margin and should not move more than 1 mm into the pupil when blinking [37]. Ideal candidates for segmented/translating lenses include those with good lid tonicity for lens stability.

These contact lenses necessitate a prism ballast in the near zone or slab-off technology for the contact lens to position at or near the lower lid [134]. Some designs incorporate inferior truncation to improve the alignment of the lens with the lower lid to assist translation.

The contact lenses are fitted slightly flatter than the flattest central corneal meridian to allow for rapid translation of the lens to the lower lid [37]. To problem solve, if distance vision is poor, evaluate lens centration and movement to ensure that the segment height is not within the pupil during primary gaze, affecting distance vision. If there is poor near vision, an individual may not be viewing through the near zone. Evaluate the segment height to determine if the lens is too low during downward gaze. To improve near vision, increase the lens diameter or raise the segment line [134]. With excessive lens movement, fluctuating vision may occur; steepen the base curve of the lens or increase the amount of prism to help stabilise the lens.

Excellent distance and near vision can be obtained with the appropriate power in front of the pupil [95]. Lens designs are available with different bifocal segment shapes such as the curved upswept, D-shape, executive-style segment line, or with an up-decentred distance zone surrounded by a near concentric periphery.

2.5.2. Hybrid multifocal contact lenses

Hybrid contact lenses with a rigid centre attached with a peripheral soft hydrogel or silicone hydrogel skirt provide the optics of a corneal contact lens with the comfort of a soft contact lens. Compared to

standard corneal contact lenses, hybrid contact lenses are more comfortable and easier to adapt to, provide more constant visual quality and correct anterior corneal higher-order aberrations compared to soft toric contact lenses, are easier to handle compared to piggyback and scleral contact lenses, and do not have post-lens tear reservoir fogging compared to scleral contact lenses [135].

Hybrid contact lenses are ideal for individuals with high visual demands who desire crisp optics for precise vision or for those who notice blur due to soft toric lens rotation. Hybrid contact lenses are also a good alternative for those whose work requires them to look above their head (ex. mechanics, carpenters, or medical technicians) since hybrid contact lenses can rotate freely without causing blurry vision.

Hybrid contact lenses may be fitted empirically with either raw topographical data or specific values such as axial keratometry readings and eccentricity. Alternatively, diagnostic lenses may be used. Conventional hybrid contact lenses are designed as centre-near or centre-distance, with multiple near zone diameters. Most modern hybrid multifocal contact lenses have an EDOF design [132].

2.5.3. Scleral multifocal contact lenses

For eyes that are unsuccessful with conventional contact lens modalities, scleral contact lenses are one of the best options for vision correction. Contemporary scleral contact lenses are also utilised for the correction of simple refractive errors, including presbyopia, especially when other modalities fail due to issues with vision or comfort [136]. Advancements in the manufacturing process, lens designs, lens materials, and increased knowledge of scleral anatomy has heightened scleral lens fitting.

Scleral contact lenses have been observed to typically decentre infero-temporally due to the effects of gravity, eyelid morphology, and scleral shape [136,137]. Inferior decentration can generate a minor base down prismatic effect due to an asymmetric fluid reservoir [138], which can create challenges to those who wear a single scleral lens [136]. Residual astigmatism may occur as a result of lens flexure, usually associated with thinner lenses that have a rotationally symmetric landing zone fitted on a non-spherical sclera [139]. These optical effects can be decreased by using a toric or customised landing zone to reduce the amount of decentration [136]. Fluid reservoir thickness can also be reduced to minimise vertical decentration [140].

Multifocal scleral contact lenses are fitted with the same technique as conventional scleral contact lenses. Many scleral contact lens manufacturers have proprietary designs for multifocal contact lenses and offer the option to include multifocal optics in scleral lens designs [141]. Scleral multifocal design options include near centred, distance centred, aspheric and periscopic alternatives [141]. The majority of scleral contact lens multifocal fittings are based on fitting a monofocal scleral contact lens first; however, a few manufacturers offer specific diagnostic fitting sets for multifocal scleral contact lenses. Each contact lens design is different and requires different approaches for troubleshooting. Thus, it is pertinent to follow the recommendations of the manufacturer for enhanced success, laboratory consultant recommendations, and to follow the fitting guide if available.

Toric peripheral curves may aid scleral contact lens centration; certain manufacturing laboratories now provide customisation in the positioning where the multifocal optics are created on the lens. These decentred multifocal optics then align with the visual axis of the patient to improve multifocality.

2.5.4. Rigid material considerations

Contact lens material considerations include oxygen permeability, mechanical properties in relation to flexure, scratch resistance and surface wettability. The wearing modality, daily or overnight wear, refractive error [142,143] and ocular surface disease [132] are also considerations when selecting lens material. Corneal lenses for daily wear should have a Dk/t of at least 20 x 10^{-9} units to avoid inducing corneal oedema [144].

Highly oxygen permeable rigid materials (more than 100 units) provide increased oxygen transmission, may be prone to on eye flexure [145], do not increase bacterial adhesion to the corneal epithelium following overnight lens wear, and may reduce the possibility of adverse hypoxic complications [146]. However, higher Dk materials may require more frequent replacement (for extended wear regimes [147] since they are less scratch resistant [148].

The wettability of the surface of rigid lenses denotes the extent to which water, serving as a proxy for the tear film, uniformly spreads over or adheres to the front surface of the lens. This characteristic significantly influences the deposition of substances on the surface, patient comfort, and visual acuity [149].

Wettability is influenced by various factors, including the presence of residue due to manufacturing, the quantity, quality, and chemistry of the tear film, blinking efficiency, conditioning solution, and the contact lens material [150,151].

With plasma treatment, the lens surface is ionised with oxygen plasma to create a hydrophilic rigid lens surface. Plasma treatments are not permanent, and the benefits of increased contact lens wettability and comfort decrease after weeks of lens wear. According to in-vitro studies, plasma treatment can improve wettability by 40 % (Shin et al., 2009) and decrease bacterial adhesion [152].

A different option to increase rigid lens surface wettability is through the application of polyethylene glycol (PEG) polymer coating after plasma treatment [153]. In-vitro studies suggest this process can significantly increase rigid lens surface wettability by 50 % and reduce protein and lipid deposition, without affecting the optical properties of the lens [153]. Modern PEG can be covalently bonded to the lens surface to improve lens wear and comfort [154].

2.6. Monovision and modified monovision

Monovision is an optical correction method for presbyopia where one eye is optimally corrected for distance and the other for near. It is a well-used strategy for contact lens correction and used rather less commonly for spectacles, refractive surgery or intraocular lenses.

The use of monocles in the 1800s was possibly the first documented application of monovision and the first documented use of a contact lens for this purpose was by Westsmith in the 1960s [155]. There are certain advantages and disadvantages of monovision correction for presbyopic patients; these are listed in Table 5.

Several clinical studies have looked at the success of monovision; however, there appear to be no long-term, randomised, masked, placebo-controlled, clinical trials which have investigated the success of monovision in contact lenses. The reported success rates with monovision contact lenses are heavily dependent on the methodological design of the study including patient characteristics such as level of presbyopia, motivation, the difference between binocular and monocular stereoacuity scores and perseverance for contact lens wear

Table 5

Advantages and disadvantages of monovision correction for presbyopia using contact lenses [32,42,156–158].

Advantages	Disadvantages
Quick and easy to prescribe	Lack of binocular balance and discomfort due to engineered anisometropia
Generally cheaper option	
Easier to fit conventional single vision contact lenses	Reduced stereopsis and depth perception
	Compromised intermediate vision
Easier to explain to patients	Reduction of contrast sensitivity
Only one eye contact lens is changed	Impaired complex spatial motor tasks
	May not work for established presbyopes where more than 1.50D near addition is required
Patients understand chance of success relatively quickly	Can be challenging to judge an object size, colour, converging lines and shadows
Minimum ghost images	
Not dependent on pupil size	Can be prohibitive for certain professions such as pilots and night drivers
Can use astigmatic lenses	
Readily adjustable	

[25,159,160].

The success rate for experienced contact lens wearers with presbyopia trying monovision can range between 67 and 80 % [25,32,44,160–162], but may drop to 8 % with neophytes trying monovision with contact lenses for the first time [25]. Maintaining binocular disparity within clinically acceptable limits is important for successful monovision contact lens practice. This is supported by the fact that in monovision binocular acuity decreases by one letter for every dioptre of increase in addition power [163].

Despite various compromises, monovision is still relatively common in contact lens practice. As stated in section 3, the share of multifocal and monovision contact lens fit for patients more than 45 years of age is 44 % and 10 % respectively. Among the 10 % monovision contact lens wearers, 7 % are with silicone hydrogel lenses, 2 % are with hydrogel lenses and 1 % wear rigid lenses. The design and materials of monovision contact lenses are not different from single vision contact lenses, unless modified monovision with multifocal contact lenses is attempted.

In conventional practice, the dominant eye is typically corrected for distance vision, whereas the non-dominant eye is corrected for near work [164,165]. It is also important that low levels of astigmatism are fully corrected to maximise distance visual acuity [166]. Most of the literature indicates that tests of sensory dominance and blur suppression are the most relevant although there is evidence that different types of ocular dominance may not agree and that normal visual system sensory dominance is 'insignificant' in most individuals with normal vision [167]. Furthermore, ocular dominance is not permanent, but a subjective and adaptive phenomenon in most patients [25].

2.6.1. Ocular dominance

Ocular dominance can be broadly classified into three types (1) motor, (2) sensory, and (3) sighting dominance (Fig. 8).

Various methods are available to determine ocular dominance and many are used in clinical practice. In general, ocular dominance tests can be classed into three types: (1) sighting dominance test (2) binocular rivalry test and (3) sensory dominance test [165]. Although sighting dominance or 'hole in the card' test is the simplest method and continues to be used by many ECPs [43], sensory dominance test such as '+1.50D blur' is often the most preferred method to determine ocular dominance in monovision contact lens practice.

Modified monovision combines multifocal optics in one eye with a single vision or multifocal correction in the fellow eye, with the multifocal lens(es) being any of the available design options (for example, simultaneous or alternating). The modified monovision approach tends to work better with higher patient satisfaction [168]. There are a number of approaches combining various contact lenses that could be used to provide modified monovision, including:

- The dominant eye is prescribed with a single vision distance lens, and the nondominant eye is prescribed with a multifocal contact lens. The multifocal contact lens in the non dominant eye can have (1) centre-distance correction for early presbyopes and (2) centre-near correction for established presbyopes.
- The dominant eye is prescribed with a multifocal contact lens and the non-dominant eye prescribed with optimum near correction. The multifocal contact lens in the dominant eye can have (1) centre-distance correction for early presbyopes and (2) centre-near correction for established presbyopes.
- Modified multifocal contact lenses – different multifocal designs are prescribed in each eye – generally distance-centre correction in the dominant eye and near-centre correction for non-dominant eye.

2.6.2. Specific fitting considerations

While fitting, practitioners need to be mindful that monovision may provide great performance in the consulting room, but when tried with real-world tasks over a period of time, monovision contact lenses may result in poorer subjective responses [77,157]. However, in these projects, monovision was preferred by 37 % of participants when compared to one multifocal lens brand [157] and was chosen by 29 % of participants when compared to four other multifocal options (and was the second ranked option overall) [42], suggesting that ECPs should consider monovision as an option at least for some patients. Stereopsis is compromised in monovision which may cause binocular vision impairment, and this should be carefully considered during dispensing. Full adaptation of monovision contact lenses can take up to eight weeks [169].

While fitting monovision contact lenses (and the potential for compromised distance vision in one eye in particular), medico-legal aspects should be considered by the ECP, and a consent form can be administered.

The following are the key considerations for fitting monovision contact lenses:

- Careful selection of patients suitable for monovision is key to successful patient experience
- Patients should be given trial lenses for long enough to perceive real-world situations and lifestyle-specific tasks. This will also allow patients to determine preferred eye for near and distance. Arguably the adequate time could range between 30 min to half-a-day.
- Early presbyopic patients with 1.50D near addition are more likely to be good candidates
- Small amounts of astigmatism should be corrected for the distance eye [166]
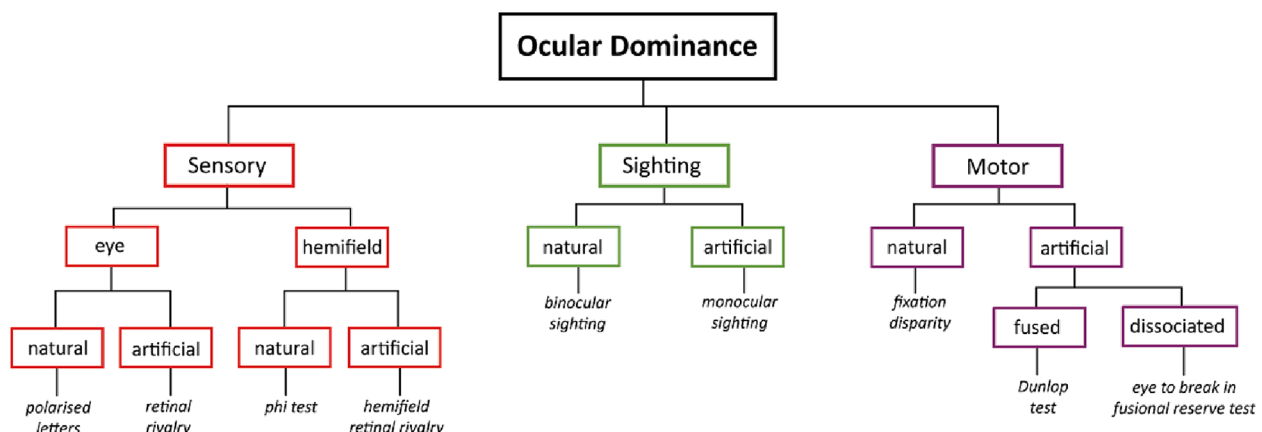- Existing single vision contact lens wearers adapt to monovision better than neophytes

Fig. 8. Classification of ocular dominance and tests of respective classifications are noted in italics. Based on Evans (2007) [25].

● Some of the major limitations of monovision include difficulty in suppressing the blurred image during night driving. Perhaps, monovision ECPs contact lens practitioners may consider an additional intermediate focal length for established presbyopes such as for computer use.

2.7. Comparative performance of contact lens options

In recent decades, there have been numerous comparative studies with contact lenses for presbyopia comparing single vision distance, monovision, multifocals and progressive addition spectacles lenses, in addition to studies comparing different multifocal contact lens designs (see Table 6 for details and references). The majority of these studies consider visual performance including visual acuity at distance, intermediate and near and in a range of light conditions, subjective vision performance, preference, stereoacuity, stereopsis, accommodation, contrast sensitivity, glare, ghosting, light disturbances and reading speeds. Wearer preference was also noted in some studies, along with willingness to purchase.

Further to this, there has been an evolution in studies since the early 1990s. Early investigations often compared monovision with earlier soft multifocal contact lenses, with the conclusions overall being that while objective performance was often similar (although some vision measures were better with monovision), subjective performance, stereopsis and stereoacuity were better with multifocal lenses [41,43,110,120,157,170]. Refitting monovision wearers into multifocal lenses was successful [171], and preference and real-world, functional vision were better with multifocal lenses [156]. It was suggested that a period of adaptation is often needed [110], including for light disturbances [172].

When comparing spectacle progressive addition lenses with multifocal contact lenses, one study demonstrated that while both lens types performed well, there was a preference for contact lenses and the functional vision they provided [61]. The same multifocal contact lenses were compared with progressive addition lenses while in a driving simulator, and looked at sign identification, distances and driving performance metrics [61]. There were no differences in sign identification distance between spectacles and contact lenses for most distances, and while signs at 70 m from the roadside showed differences in favour of progressive addition lenses, all the distances were greater than those required to safely stop a vehicle. However, these findings conflict with earlier work which found poorer driving-related vision in participants using multifocal contact lenses compared with progressive addition lenses [173]. It is notable that this latter study was conducted at night time, capturing measurements during driving on a controlled track. This discrepancy may relate to differences in the nature of the recruited participants, for example, one study used participants with previous progressive addition lens experience [61] and the other did not [173]; this discrepancy may also relate to the complexity of the tasks evaluated, but overall points to a need for ECPs to counsel new multifocal contact lens wearers about initial use of lenses when driving.

Vision performance with progressive addition lenses has been found to be similar to that with rigid contact lens multifocals [130], which in turn is superior to that with a soft multifocal design and monovision.

Comparisons of soft multifocal contact lens designs have shown improvements in objective and subjective vision performance over time, and with some differences between lens design types. Some of the designs included in studies are no longer commercially available, as noted in Table 6). One study noted some differences between two soft multifocal contact lenses (objective and subjective vision) [86], although both were acceptable alternatives to spectacles. Another study reported differences in stereoacuity between two soft multifocal lens types, although distance visual acuities were similar [174] and another compared three multifocals and found few significant differences between designs for vision performance (objective and subjective), accommodation and aberrations [175].

A study comparing four soft multifocal contact lenses and monovision, with a range of objective and subjective vision performance measures, found little differences in some measures, although defocus curve profiles, stereopsis, halo perception, the Near Activity Visual Questionnaire and quality of vision differed between lens types [42]. The authors concluded that although ocular aberration variation between individuals largely masks differences in optics between current multifocal designs, certain contact lenses outperform monovision, even in early presbyopes.

There have been a few studies comparing EDOF lenses with other multifocal designs showing similar performance for vision overall with some improvements with EDOF for intermediate and near vision, overall vision satisfaction, mean stereoacuity and for clarity-of-vision across most distances [126,176–179].

Improved vision performance with one multifocal design over another can be due to having more than one additional power zone and optimising pupil coverage [180]. Disability glare has been shown to vary between four different multifocal contact lenses [181] and on comparing centre distance, centre near and aspheric centre near designs, dissatisfaction is shown to be due to poor distance vision [182]. Comparison of three daily disposable multifocal contact lenses demonstrated that all performed well for vision, stereopsis and willingness to purchase, with some minor differences between lens designs [183].

Aberrations have been shown to affect vision performance (subjective and overall vision satisfaction) in presbyopes when comparing centre-near multifocal contact lenses, a centre-distance contact lens, a bifocal contact lens and a single vision contact lens [184]. Another study with multifocal contact lenses and a single vision contact lens found that monofocal correction provided better vision performance under low light conditions [185].

A couple of studies have investigated different 'modified monovision' lens combinations. One early investigation compared monovision with a concentric centre near design, and then used a combination of centre distance and centre near [161]. Monovision performed the best, suggesting that disrupted stereopsis was not a reason for failure, and that the concentric bifocal design performance was negatively impacted due to vision compromises [161]. In another report, modified monovision was determined to be superior to a diffractive multifocal design and provided good stereopsis compared to monovision, although the advantages were only modest [186].

Whether early performance measures on fitting predict future performance have been studied several times. A study with four multifocal contact lens designs found that visual acuity measures on fitting are unchanged after a few days wear and do not predict performance, unlike subjective data (for example, level of ghosting) which are a better indicator [107]. A study with two multifocal contact lenses showed that initial performance did not predict final dispensing performance [109]. While objective visual acuity remained the same over the trial period, subjective performance declined, likely due to the enhanced consulting room visual environment at the initial fitting [109]. A retrospective analysis of 141 presbyopes found that subjective performance (overall vision satisfaction and vision stability) were key predictors of willingness to purchase rather than just using objective visual acuity [187].

A report of vision performance, contrast sensitivity and stereopsis in two multifocal contact lenses and a single vision lens [188] concluded that multifocal contact lenses continue to need improvements in design to enhance performance compared to single vision contact lenses, in particular for higher addition powers, although this was only measured after one hour of wear. A study to understand the impact of the pupil size and central optical zone diameter (COZD) relationship on visual performance in multifocal contact lenses used a range of bespoke aspheric designs with varying COZDs determined from pupil sizes measured under photopic light conditions to cover from 60 to 100 % of the pupil diameter [78]. It was demonstrated that vision performance was generally better with 80 % and 90 % COZDs compared to 60 %, and 90 % and 100 % COZDs provided better contrast sensitivity compared to those

Table 6

Comparative performance of soft contact lenses for the correction of presbyopia. (* = lens not currently available).

Authors	Age	Design	n	Lenses evaluated	Methods	Findings
Fogt et al. (2022) [193]	Range 45–63 years; 54.9 (4.7) years	2 weeks	20	1. MFCL (DAILIES TOTAL1, Alcon) 2. Habitual PAL spectacles	Functional vision tests (coincidence anticipation timing, peripheral search and hand-eye coordination, dynamic VA, preference with daily tasks)	MFCLs provide excellent and functional vision performance equal to PALs and patients may prefer them over PALs.
Woods et al. (2009) [41]	Early presbyopes	1 week prospective, double-masked, randomised, crossover, dispensing		1. MFCL (Air Optix Multifocal, Alcon) - Low Add 2. Monovision 3. Habitual correction 4. Optimised distance visual correction	High and low contrast LogMAR under high- and low-room lighting conditions, stereopsis, and critical print size	No differences in objective vision tests except low-contrast near VA in low light where MV performed better than MFCL and habitual options. Subjective data better performance with MFCLs vs. MV, especially driving tasks during day and night and associated haloes or glare. Preference for MFCL vs. MV and watching television and changing focus from distance to near. Predicting success should not be based on objective, consulting room tests alone.
Woods et al. (2015) [157]	Mean 52 years	Prospective, randomised, crossover, 2 week study	49	1. MFCL (Air Optix Multifocal, Alcon) 2. MV	High- and low-contrast logMAR VA and stereopsis. Participants performed specific tasks followed by subjective rating surveys and a general rating survey on dispensing and 2-week visits.	VA better with MV, stereopsis better with MFCLs on dispensing, although no difference after 2 weeks. Subjective ratings similar, trend for higher ratings on focus changing and driving with MFCLs and for near tasks with MV, with more preferring MFCLs.
Rajagopalan et al. (2006) [130]	Age range 42–65 years		32	1. Rigid MV 2. Rigid MFCLs (Essentials, Blanchard) 3. PALs 4. Soft bifocal (Acuvue Bifocal, Vistakon) *	Binocular low (18 %) and high (95 %) contrast Bailey-Lovie chart VA; binocular contrast sensitivity, monocular glare sensitivity at three luminance settings. Binocular near visual task performance.	MV VA lower than 3 other groups, especially high contrast. Rigid MFCL had least monocular disability glare, followed by soft bifocal CLs and then MV. Soft bifocals and MV had reduced binocular contrast sensitivity. Rigid MFCL contrast sensitivity was on par with PALs except highest spatial frequency. Error scores for binocular near visual task performance best with rigid MFCLs and PALs, followed by MV then soft bifocal. Evaluations contrast and glare sensitivity provide useful information in fitting presbyopes with CLs.
Fernandes et al. (2013) [110]	Range 45–57 years	Crossover study, 15 days; washout between	20	1. MFCL (Biofinity multifocal, CooperVision) 2. MV (Biofinity sphere, CooperVision)	Monocular and binocular high- and low-contrast logMAR VA distance and near, binocular distance contrast sensitivity function, near stereoacuity	MFCLs provided satisfactory levels of VA comparable with MV without compromising stereoacuity. Near vision significantly improved in dominant eye, and distance vision improved in non-dominant eye from 1 to 15 days with MFCL. Patients adapted to multifocality over time (not true for MV).
Richdale et al. (2006) [43]	Mean age 50.11 years (range 41–64)	Randomised crossover, 1 month	38	1. MFCL (SofLens Multifocal, Bausch + Lomb) 2. MV (SofLens 59, Bausch + Lomb)	Visual performance - high- and low-contrast VA at distance and near; near stereoacuity. Patient satisfaction - National Eye Institute Refractive Error Quality of Life Instrument	Majority preferred MFCL with excellent VA without compromising stereoacuity as MV.

Table 6 (*continued*)

Authors	Age	Design	n	Lenses evaluated	Methods	Findings
					questionnaire; patient final lens preference.	
Gupta et al. (2009) [194]	Mean age 55.0 years (range 49–67)	Crossover 1 month	20	1. MFCL (PureVision, Bausch + Lomb) 2. MV (PureVision sphere, Bausch + Lomb)	Distance, intermediate, and near VA, reading ability, distance and near contrast sensitivity function (CSF), near range clear vision, stereoacuity, subjective evaluation near vision ability (questionnaire).	MV performed better than CN aspheric MFCL for distance and near VA. MFCL better stereoacuity and near range clear vision, and little differences CSF, for better balance real-world visual function with minimal binocular disruption.
Ferrer-Blasco et al. (2010) [174]		Randomised crossover, 1 month	20	1. MFCL (PureVision Multifocal, Bausch + Lomb) 2. MFCL (Focus Progressives, Alcon) *	Spherical aberration measured under photopic conditions at 40 cm. Binocular high-contrast VA at distance and near.	Both MFCLs provided good VA preserving stereopsis. Focus Progressives slightly better near acuity and better SA than PureVision MFCL. Differences may be related to asphericity, near addition or VA differences between eyes.
Situ et al. (2003) [171]		Open label, 6 months	40 current MV wearers (completed; 9 discontinued due to vision)	1. Bifocal (Acuvue Bifocal, Vistakon) * 2. Habitual MV; first visit	Visual function and subjective vision ratings. Lens preference end of study and called 1 year later to repeat the lens preference questionnaire.	68 % preferred bifocal and 25 % habitual MV. High-contrast VA and contrast sensitivity at distance same but low-contrast acuity better with MV. Intermediate low- and high-contrast acuity and 3-metre and near stereoscopic acuity were better with bifocal. Near high- and low-contrast acuity were better with MV. All subjective ratings, except near vision in poor lighting, were significantly greater with bifocal lenses.
Fernandes et al. (2018) [172]	Mean age 48.7 years (range 45–57)	Randomised, double-masked, crossover. 15 days wear with 1 week wash-out.	20	1. MFCL (Biofinity Multifocal, CooperVision) 2. MV (Biofinity sphere, CooperVision)	Light distortion (Light Distortion Analyzer) under monocular and binocular conditions, LDI, %. Subjective quality of vision.	Light distortion increased all parameters both CLs and significant for MV in non-dominant eye. Increase in LDI with MFCL in non-dominant eye. After 15 days MFCL wear, decrease in LD parameters in the dominant eye. Binocularly, a significant improvement from 1 to 15 days was observed for LDI with MF. The QoV questionnaire showed no significant changes with neither CL. Adaptation to light disturbances induced by MFCL is more effective compared to MV.
Back et al. (1992) [195]	Mean age 57 years (range 51–63)		15 successfully wearing DIFF bifocal CLs	1. Soft diffractive bifocal (Echelon, Allergan) * 2. CN concentric bifocal design CL 3. MV CLs	LogMAR VA (distance and near, high and low illumination, high and low contrast), stereoacuity, subjective ratings	MV best VA distance and near. Both bifocals gave similar VA with more lines of acuity lost relative to spectacles at near compared to distance. Concentric bifocal induced more ghosting at near. Stereopsis compromised at distance with MV. All systems worse than spectacles at near.
Freeman and Charman (2007) [186]	Presbyopic		8	1. HEMA diffractive bifocals (Diffrax design); equal amounts light contributed to distance and near 2. Modified MV A; non-standard diffractive bi-focals. Dominant eye more light for distance; non-dominant eye a	Monocular and binocular high-contrast VA, contrast sensitivity and stereopsis at distance and near	Modest VA advantages, with better stereopsis vs MV, of modified MV did not compensate for greater complexity; expectations partly fulfilled.

Table 6 (*continued*)

Authors	Age	Design	n	Lenses evaluated	Methods	Findings
				greater fraction for near image 3. Modified MV B 4. Conventional MV		
Kirschen et al. (1999) [170]	Mean age 52.5 years (range 45–61)	1 week	19 MV patients	1. Soft bifocal (Acuvue Bifocal, Vistakon) * 2. MV	VA, stereoacuity, and suppression at distance and near.	Decrease in interocular difference in VA distance and near; improved certain aspects of binocularity with decrease in suppression and increase in stereoacuity
Jong et al. (2019) [187]	Presbyopes	Retrospective analysis from survey data on final visit two randomised, masked, crossover, dispensing clinical trials with simultaneous-image contact lenses after 5–14 days wear.	141	1. 9 prototype 2. simultaneous-image contact lenses 3. Simultaneous-image contact lenses (1-Day ACUVUE MOIST Multifocal, ACUVUE OASYS for PRESBYOPIA, AIR OPTIX Aqua Multifocal, SEED 1dayPure) 4. Multistage)	VA, subjective vision ratings, and willingness to purchase. Pearson correlation and area under the receiver operating characteristic curve determined correlations between variables.	Subjective vision ratings better indicator of simultaneous-image CL performance than VA. Overall vision satisfaction and vision stability are key predictors of willingness to purchase. Subjective vision ratings should be used to evaluate performance rather than VA alone.
García-Lázaro et al. (2015) [185]	40–46 years	Double-masked crossover, 1 month	28	1. MFCL (Air Optix Aqua Multifocal, Alcon) 2. MFCL (PureVision Multifocal, Bausch + Lomb0 3. MFCL (Acuvue Oasys for Presbyopia, Johnson & Johnson Vision Care) * 4. MFCL (Biofinity multifocal, CooperVision)	Binocular distance VA, binocular distance contrast sensitivity under mesopic conditions both with no glare and under 2 levels of induced glare. Also compared to single vision, monofocal lenses (Air Optix Aqua, Alcon)	Air Optix Aqua and PureVision Multifocal provided better visual performance than Biofinity multifocal and Acuvue Oasys for Presbyopia for distance vision with low addition and under dim conditions. All provide worse performance than monofocal CLs.
Back et al. (1989) [161]	Presbyopes	Wear one lens for at least 3 months.	200	1. MV hydrogel 2. Concentric CN bifocal hydrogel 3. CN/CD concentric bifocal hydrogel	Success after 3 month's wear and intention to continue.	MV most successful system (67 %); disrupted stereopsis was not a significant reason for failure. Lower success with concentric systems attributed to greater visual compromise.
Sha et al. (2016) [188]	Mild presbyopia mean 49 years; moderate/severe presbyopia mean 58 years	A single-blinded crossover trial 1 h per lens (overnight washout)	42	1. MFCL (Acuvue Oasys for Presbyopia, Johnson & Johnson Vision) * 2. MFCL (Air Optix® Aqua Multifocal, Alcon) 3. Single vision (Air Optix® Aqua, Alcon)	VA - high and low contrast, contrast sensitivity, stereopsis, and subjective visual performance (vision clarity, ghosting, overall vision satisfaction, and comfort)	Further development of MFCL lenses is required before significant advantages over single vision lenses are observed in presbyopes.
Diec et al. (2018) [196]	Presbyopes	Retrospective, masked crossover	55	1. MFCL (Acuvue Oasys for Presbyopia, Johnson & Johnson Vision) * 2. MFCL (Air Optix® Aqua Multifocal, Alcon)	Investigate whether initial MFCL CL performance predicts short-term dispensing performance. Subjective questionnaires on fitting and on days 2, 4 and ≥ 5 days after fitting; vision clarity, lack of ghosting at distance, intermediate and near at day/night time points. Vision stability, vision while driving, overall vision satisfaction, willingness to purchase, comfort, VA.	Initial performance at fitting did not predict short-term performance of MFCL. Subjective measures peaked at fitting and declined while VA remained constant. Subjective rating tools may aid ECPs to gauge success of MFCL.
Tilia et al. (2016) [176]	Age 45–70 years	Prospective, crossover, randomised, single-masked, short-term	41	1. Novel Extended Depth of Focus lenses (EDOF) 2. MFCL (Acuvue Oasys for Presbyopia, Johnson & Johnson Vision) *	Objective high-contrast VA, logMAR at 6 m, 70 cm, 50 cm, and 40 cm; low-contrast VA, contrast sensitivity at 6 m; stereopsis at 40 cm. HCVA measured as "comfortable acuity" rather than conventional resolution acuity. Subjective performance ratings for clarity of vision and ghosting at distance, intermediate and near,	EDOF lenses provide better intermediate and near vision performance in presbyopic participants without compromising distance vision

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Table 6 (*continued*)

Authors	Age	Design	n	Lenses evaluated	Methods	Findings
					overall vision satisfaction, ocular comfort, and lens purchase.	
Guillon et al. (2002) [180]	Presbyopes with low (+0.75D to +1.25D); medium (+1.50D to +1.75D); and high presbyopia (+2.00 to +2.50D).	Randomised, double-masked, non-dispensing crossover study	45	1. Soft bifocal (Acuvue Bifocal, Vistakon) * 2. MFCL (Focus Progressives, Alcon) *	Visual performance LogMAR VA under range of luminances, distances and contrasts	VA with multi-zone bifocal superior overall with progressive MFCL design. Having only one addition is detrimental to performance with progressive MFCL lenses, particularly for low presbyopes.
Novillo-Díaz et al. (2018) [182]	Mean age 49 years (range 40–62)	Multicentre single-blinded randomised controlled trial, three months follow-up for three groups	150 single vision soft CL wearers	1. CN 2. CD 3. Aspheric-CN MFCL	Understand if lapsing from MFCL soft CLs is independent from the design to determine causes for discontinuation and psychosocial factors involved. Cases of discontinuation, anxiety and quality of life were measured at one week and one month.	Discontinuation of MFCL wear depends on the design. Most common cause for discontinuation is poor distance vision (1/3). Psychosocial factors do not impact discontinuation rates.
Martínez-Alberquilla et al. (2021) [178]	Presbyopes	Crossover, single masked, randomised, 15 days wear	30	1. EDOF design 2. MFCL (Biofinity MFCL, CooperVision)	Evaluate visual function, ocular surface integrity (NIKBUT), NIKBUT-avg, TMH, bulbar and limbal redness, and conjunctival and corneal staining) and dry eye symptoms (OSDI questionnaire); Defocus curves, depth-of-focus range, contrast sensitivity under photopic and mesopic conditions (with and without glare) and subjective perception of halos and glare were evaluated.	Both CL for presbyopia offer good visual quality, preserve the ocular surface integrity and provide the patient with similar symptomatology levels after 15 days of lens wear.
Papas et al. (2009) [107]	Presbyopes	Four clinical sites, wore each of four MFCLs for 4 days DW	88	1. Bifocal (Acuvue Bifocal, Vistakon) * 2. MFCL (Focus Progressives, Alcon) * 3. MFCL (Proclear Multifocal, CooperVision) 4. MFCL (SofLens Multifocal, Bausch + Lomb)	Understand if evaluation MFCL performance conducted at dispensing are representative of behaviour after a moderate adaptation period	Early assessment is relatively unrepresentative of performance later on; VA based measures remain unchanged over the medium term, so are insensitive indicators of performance compared with subjective alternatives.
Fedtke et al. (2017) [184]	55.1 ± 6.9 years		17	1. Four CN MFCL designs 2. CD MFCL 3. Bifocal contact lens 4. Single vision control	Impact of primary and secondary spherical aberration terms on visual performance. High- and low-contrast distance VA, contrast sensitivity, high-contrast VA at near, and range of clear vision. Subjective vision variables including clarity of vision at distance and near, ghosting, and overall vision satisfaction.	The amount and direction of aberrations with different MFCLs can affect vision performance at different distances. Information can help inform designing new or optimise existing MFCLs for improved vision performance at specific distances.
Sha et al. (2018) [177]	Presbyopes	1 week, double-masked, prospective, crossover, randomised study	57	1. MFCL (1 DAY ACUVUE MOIST Multifocal, Johnson & Johnson Vision) 2. EDOF prototype	High- and low-contrast VA at distance, intermediate and near, and stereopsis at near. Subjective performance for vision clarity and lack of ghosting at distance, intermediate and near, vision stability, haloes at night-time, overall vision satisfaction, and ocular comfort.	MFCL was not significantly different from EDOF for high- or low-contrast VA at any distance, or for stereopsis. Subjectively, EDOF was significantly better than the MFCL for vision clarity at intermediate and near, overall lack of ghosting, vision stability, and overall vision satisfaction.
Madrid-Costa et al. (2012) [190]	Astigmatic presbyopes	Crossover study design 1 month DW	20	1. Toric MFCL (Proclear Multifocal toric, CooperVision)	High-contrast distance VA, near high-contrast VA, distance contrast sensitivity	MFCL toric CL good option to compensate both presbyopia and

(continued on next page)

Table 6 (*continued*)

Authors	Age	Design	n	Lenses evaluated	Methods	Findings
				2. Single vision distance toric (Proclear toric, CooperVision) with reading spectacles	under photopic and mesopic conditions without and with glare, near contrast sensitivity, defocus curve, and stereopsis.	astigmatism, providing optimal distance and near visual quality without compromising stereopsis
Sha et al. (2018) [183]	Presbyopes	1 week, prospective, randomised, double-blind, crossover clinical trial.	72	1. MFCL (1 DAY ACUVUE MOIST Multifocal, Johnson & Johnson Vision) 2. MFCL (BioTrue ONEday for Presbyopia, Bausch + Lomb) 3. MFCL (Dailies AquaComfort Plus Multifocal, Alcon)	High and low contrast VA at 6 m and 40 cm, stereopsis at 40 cm. Subjective performance ratings for clarity, ghosting, driving vision, vision stability, ease of focusing, overall vision satisfaction, and ocular comfort. Willingness to purchase.	BioTrue OneDay for Presbyopia had better distance performance compared with near, whereas 1 Day Acuvue Moist Multifocal performed conversely. AquaComfort Plus Multifocal performed reasonably overall.
Łabuz et al. (2017) [181]	Presbyopes	Prospective randomised, comparative study	16	1. MFCL (Proclear Multifocal, Distance/ Near CooperVision) 2. MFCL (Acuvue Oasys for Presbyopia, Johnson & Johnson Vision) * 3. MFCL (Air Optix Aqua Multifocal, Alcon)	Effect on MFCLs on disability glare with ocular straylight using commercial straylight meter with natural and dilated pupils.	A difference in measured straylight was found between the MFCL lenses; the variability and straylight-pupil size dependency should be taken into account to avoid elevated straylight in MFCL wearers.
Fisher et al. (2000) [197]	Presbyopes (low, medium, and high spectacle adds)	Crossover, randomised study, daily-wear 7 to 12 days	42	1. MFCL (Focus Progressives, Alcon) * 2. Bifocal (Acuvue Bifocal, Vistakon) *	Snellen VA at distance and near, Bailey-Lovie acuities under high and/or low ambient illumination conditions at near, intermediate, and far viewing distances, stereoacuity, a timed visuomotor task (needle threading), apparent glare/ flare, and near work range of subjectively clear binocular vision. Handling, comfort, distance and near ghosting, subjective visual quality, acceptability for common tasks and preference.	Focus Progressives better distance VA with high and low illumination, and higher ratings for visual quality (overall and at distance), comfort, and handling. Focus Progressives preferred 5:1 over Acuvue Bifocal. No differences for near VA, perceived quality of near vision, near point binocular range, stereoacuity, or acceptability of vision for common near work tasks. Both lenses were a viable alternative to spectacles.
Rueff et al. (2021) [192]	Symptomatic CL wearers 30–40 years old	Randomised, participant-masked, crossover clinical trial, 2 weeks	48	1. Single vision (Ultra, Bausch + Lomb) 2. MFCL (Ultra for Presbyopia, Bausch + Lomb)	Contact lens discomfort was assessed using the CLDEQ-8; accommodation.	Younger participants had more favourable wearing experiences with the single vision lens. Older subjects had similar wearing experiences with both lens types. Symptomatic CL wearers approaching 40 years may benefit from wearing MFCL sooner than typically practised.
Vasudevan et al. (2014) [175]	40–45 years, habitual CL wearers	Non-dispensing study	10	1. MFCL (Acuvue Oasys for Presbyopia, Johnson & Johnson Vision) * 2. MFCL (Air Optix Aqua Multifocal, Alcon) 3. MFCL (Biofinity multifocal, CooperVision)	Low and high contrast distance and near VA, contrast sensitivity, range of clear vision and through-focus curve, measurement of open field accommodative response at different defocus levels and optical aberrations at different viewing distances	Accommodative response not significantly different between three MFCLs at each accommodative stimulus level. Accommodative lag increased for higher stimulus levels for all 3 types of CLs. Ocular aberrations were not significantly different at each of the different viewing distances and optical aberrations did not significantly differ between different viewing distances for any of these lenses. No significant difference in high and low contrast distance VA, near VA or contrast sensitivity function.

Table 6 (*continued*)

Authors	Age	Design	n	Lenses evaluated	Methods	Findings
García-Lázaro et al. (2014) [189]	Mean age 54 years (range 48–62)	Randomised crossover, 1 month wear	38	1. Artificial pupil SiHy CL in non-dominant eye 2. MFCL (Biofinity multifocal, CooperVision)	Binocular distance and near VA, defocus curve, binocular distance, near contrast sensitivity, near stereoacuity	VA intermediate and near, contrast sensitivity distance and near, mean stereoacuity better with MFCL than with artificial pupil CL; the MFCL design is more appropriate than CLs based on depth-of-field under real-life conditions.
Fogt et al. (2022) [61]	Mean age 54 years	Randomised crossover, 2 weeks wear prior to assessment in driving simulator	19	1. MFCL (DAILIES TOTAL1 Multifocal, Alcon) 2. PAL	Sign identification, distances and driving performance metrics	No difference in sign identification distance between PAL and MFCL for most distances; only signs 70 m from roadside showed difference in favour of PALs. Distances were greater than those required to safely stop a vehicle. No differences in driving performance metrics between PALs and MFCLs.
Talens-Estarelles et al. (2022) [78]	Mean age 54.8 years (range 45–58)	Prospective, controlled, double-blind study	32	1. MFCL CD, aspheric, SiHy CL (5 designs with varying central optic zone diameter determined from pupil size measured under photopic light conditions for 60–100 % pupil diameter)	Impact different COZDs, obtained from pupil size, on visual performance with CD MFCLs. Visual performance evaluated through distance, intermediate and near VA using VA Defocus Curve and Contrast Sensitivity Function.	Differences for distance and intermediate VA with best for 80 % and 90 % COZDs vs 60 %. 90 % and 100 % COZD better contrast sensitivity vs 60 % and 70 % designs.
Piñero et al. (2015) [191]	Range 43–58 years	Pilot prospective, randomised study with 1-week wash-out period.	8	1. Hybrid MFCL (Duette multifocal, SynergEyes) 2. MFCL soft (Air Optix Aqua multifocal, Alcon) 3. MFCL soft (Biofinity multifocal, CooperVision)	VA, photopic contrast sensitivity and ocular aberrometry.	No differences in distance and near VA with 3 MFCLs or for monocular and binocular defocus curves. For contrast sensitivity, better monocular with hybrid and Air Optix MFCL monocularly although not binocularly. Trefoil aberration higher with soft MFCLs compared to the hybrid lens.
Bakaraju et al. (2018) [126]	Age range 42–63 years	Prospective, participant-masked, crossover, randomised, 1-week dispensing clinical-trial	43	1. MFCL (Air Optix Multifocal, Alcon) 2. MFCL (ACUVUE OASYS for presbyopia, Johnson & Johnson Vision) * 3. Extended-depth-of-focus prototype CLs	Visual performance of CLs designed to alter higher-order spherical aberrations to extend-depth-of-focus compared to 2 MFCLs. High-contrast VA at range distances, low contrast VA and contrast-sensitivity distance, stereopsis at 40 cm. Subjective questionnaire comprising clarity-of-vision and lack-of-ghosting at various distances during day/night-viewing conditions and overall-vision-satisfaction.	EDOF better than MFCLs for high contrast VA averaged across distances yet worse than Alcon MF for low contrast VA and for contrast sensitivity in medium and high add-groups; although none clinically significant. EDOF better than MFCLs for mean stereoacuity and for clarity-of-vision across most distances. EDOF better than MFCLs for overall vision satisfaction.
Sivardeen et al. (2016) [42]	Mean age 54 years	Double-masked randomised crossover trial, 4 weeks' daily wear	35	1. MFCL (Air Optix Aqua multifocal, Alcon) 2. MFCL (PureVision 2 for Presbyopia, Bausch + Lomb) 3. MFCL (Acuvue 4. OASYS for Presbyopia, Johnson & Johnson Vision) * 5. MFCL (Biofinity multifocal, CooperVision)	Performance 4 MFCLs and compared to MV. High- and low-contrast VA photopic and mesopic, reading speed, defocus curves, stereopsis, halometry, aberrometry, Near Visual Activity Questionnaire rating, and subjective quality of vision scoring. Impact on ocular physiology.	High-contrast photopic VA, reading speed and aberrometry not different between MFCLs. Defocus curve profiles, stereopsis, halometry, Near Activity Visual Questionnaire, quality of vision differed between lens types. Biofinity multifocal typically outperformed other lenses. Although ocular aberration variation between individuals largely masks differences in optics between current MFCLs,

Table 6 (*continued*)

Authors	Age	Design	n	Lenses evaluated	Methods	Findings
						certain designs outperform MV, even in early presbyopes.
Tilia et al. (2017) [179]	Range 45–70 years	Prospective, crossover, randomised, single-masked (participant), short term clinical trial	52	1. MFCL (Air Optix Multifocal, Alcon) 2. Prototype EDOF; manipulation multiple higher-order spherical aberration terms	Visual performance of prototype EDOF compared to a CN MFCL. Objective high and low contrast VA log MAR, contrast sensitivity, stereopsis; subjective clarity-of-vision and ghosting at distance, intermediate and near, overall vision satisfaction and ocular comfort and lens purchase.	EDOF better than for some VA measures, stereopsis, clarity-of-vision at intermediate and near, lack-of-ghosting, overall vision satisfaction and ocular comfort. More chose to only-purchase EDOF. There were no differences for objective measure at 6 m or clarity-of-vision at distance.

CD = centre distance; CLs = contact lenses; CN = centre near; CSF = contrast sensitivity function; DW = daily wear; EDOF = extended depth of focus; LDI = light distortion index; logMAR = logarithm of the minimum angle of resolution; MFCL = multifocal contact lens; MV = monovision; NIKBUT = non-invasive Keratograph break-up time; PALs = progressive addition spectacle lenses; QoV = quality of vision; SiHy = silicone hydrogel; TMH = tear meniscus height; VA = visual acuity.

with 60 % and 70 % coverage.

When comparing a contact lens with an artificial pupil (aimed to enhance depth-of-field) in the non-dominant eye with a widely used multifocal contact lens, one study noted that a range of vision, contrast sensitivity and stereoacuity measures to replicate real-life conditions were shown to be better with the multifocal lens design [189].

One area for development is with toric multifocal contact lenses. There have been a few frequent replacement (monthly) contact lenses introduced in recent years, although there are no daily disposable options available to date. One study reported the performance of a toric multifocal contact lens compared to that with the equivalent single vision toric for distance and reading spectacles [190]; the results showed good objective and subjective vision performance with the lenses. Another study assessed the performance of a hybrid multifocal contact lens compared to two soft multifocal designs by looking at visual acuity, photopic contrast sensitivity and ocular aberrometry [191]. There were no differences in vision performance between the three contact lenses tested in presbyopes, nor for monocular and binocular defocus curves. Trefoil aberration was found to be higher with soft multifocal contact lenses compared to the hybrid lens.

While comfort is a key criterion for successful contact lens wear, and it is understood that this may be poorer in presbyopes due to a compromised tear film and ocular surface; it is less often reported in comparative studies on contact lens options for presbyopes. This is perhaps not surprising bearing in mind a study on new contact lens wearer retention found that while comfort is a key reason for lapsing in spherical lens wearers, visual problems are the most common among new wearers of multifocal contact lenses [101]. Comparisons in comfort have been described in three studies, each with two multifocal contact lenses [86,109,177], with little difference between lenses, although one did show a decline in comfort ratings over time.

More recently, researchers looked at contact lens discomfort with symptomatic pre- and early presbyopes using the contact lens dry eye questionnaire (CLDEQ-8) with single vision and multifocal soft contact lenses [192]. This study found that while the younger participants (less than 35 years old) preferred the vision experience with single vision lenses, older participants, approaching 40 years, that were symptomatic, benefitted from wearing a multifocal contact lens.

Reviewing the comparative studies on contact lens options for presbyopes highlight that these have been mostly on monovision compared to some early soft multifocal designs some years ago. More recent studies tend to compare a wider range of newer soft multifocal contact lenses aimed to enhance vision performance, and also simplify the fitting process to make this easier and more successful on first fit for eye care professionals and their patients [46,47].

There are some differences in performance between the latest

contemporary multifocal contact lens designs, although overall they are minor. The main conclusions from these studies are that some multifocal contact lens designs provide better vision performance overall than monovision, provide good visual acuity for most tasks and have better functional vision than spectacle lenses. Furthermore, some time is required for patients to properly adapt to the lenses and assessing overall subjective vision performance will give a good indication of likely success.

2.8. Aftercare

2.8.1. Frequency of aftercare examination

As with any contact lens user, a presbyopic contact lens patient is typically seen at regular clinical examinations termed 'aftercare visits'. The rationale for such assessments includes: the preservation of ocular health, maintenance of vision, optimising comfort, and to ensure a satisfactory lens fit [198]. Indeed, a significant proportion of asymptomatic soft contact wearers have been reported to have some form of clinical complication at routine aftercare examinations [199].

Recommended aftercare frequency is every two years for soft daily disposable lenses and annually for soft reusable and rigid daily wear lenses [198]; however, intervals between visits may be shortened where the ECP anticipates changes to occur more often or otherwise identifies a need for increased monitoring [52]. Based on the progressive loss of accommodation (and thus reducing near vision quality), annual check-ups are recommended for patients where their presbyopia is advancing [52,198].

2.8.2. Aftercare routine

Following a comprehensive review of the literature, an aftercare routine was proposed as part of the BCLA CLEAR report on evidence-based contact lens practice [52], a summary of which is provided in Table 7.

Whilst the literature frequently highlights the importance of tear film changes in the presbyopic eye, a comparison of younger (40–51 years old) and older (52–71 years old) presbyopes showed that following 6 months of soft contact lens wear neither age nor gender influenced dry eye symptoms as much as contact lens wear itself [200].

2.8.3. Managing complications

The aetiology of contact lens complications can be infective, inflammatory, metabolic, mechanical, toxic/allergic, tear/dry eye, and may present issues related to contact lens discomfort [201]. Serious contact lens-related pathological complications are rare; more commonly ECPs will encounter discomfort-related issues which can be broadly categorised as being either contact lens or environment-related.

Table 7
Aftercare routine based upon Wolffsohn et al. (2021) [52].

	Aftercare recommendations
Update	Dates of last eye exam and aftercare
	Reason for visit
	Comfortable and average wearing times
	Changes to health/medication, education, work/hobbies, driving, environment
	Ensure patient has back up spectacles
	Compliance issues
Current	Period lenses worn today, lens age
	Check care system and lens
	Observe care regimen, case cleanliness
	Vision with contact lens and over-refraction
	Check lens fitting and lens wettability/deposition
	Observe hand washing and drying
	Observe lens removal
	Anterior eye health assessment, including tear film, lid eversion, corneal staining, corneal topography if required
	Additional history and symptoms where required
	Manage complications, upgrade lens and/or care system where required
	Observe lens application where appropriate
Reiterate	Reason for visit, how issues have been addressed
	Repeat lens application/removal teach
	Reiterate points relating to compliance
	Indicate next aftercare and eye examination dates

Contact lens-related factors may include issues with the lens material, design, fitting, or lens care. Environmental factors may refer to the ocular environment (for example, tear characteristics), the external environment (for example, humidity), modifiable patient factors (for example, compliance) or inherent patient factors (for example, age) [202].

2.8.4. Discomfort and dropouts

Discomfort with contact lenses was estimated at 50 % of wearers in a 2013 report [203], whereas a 2016 survey found that 31 % and 39 % of contact lens wearers in the United Kingdom and United States, respectively, have 'contact lens-related dry eye' sometimes or more frequently [204]. Overall, it seems that the prevalence of contact lens discomfort has not greatly altered since the 1990s [205] although recent data on this area is scant. Contact lens discomfort can present as increased lens awareness, visual disturbances, reduced comfortable wearing time, and may eventually lead to either temporary or permanent suspension of lens wear [203]. Nevertheless, the majority of contact lens dropouts can be successfully refitted at least for part-time wear [206–208].

The main reasons for contact lens discontinuation amongst presbyopes tend to be discomfort, dryness, or poor visual performance related [53,209], although issues such as maintenance costs and lens handling may also play a role [53].

Encouragingly, a study of lapsed contact lens wearers reported that 76 % of presbyopes could be successfully refitted (completing at least one month of wear). Overall, factors such as higher levels of astigmatism or being more presbyopic were associated with lower chances of refit success [207].

2.8.5. Visual performance

By design, most multifocal lenses will split the light entering the eye promoting light scatter, haloes, and ultimately a potential reduction in contrast sensitivity. Such changes may be difficult to distinguish using conventional high contrast visual acuity charts, thus separate contrast sensitivity measurements may be considered when evaluating presbyopic lens performance [32]. Furthermore, *subjective* loss of contrast has been suggested as a key predictor of contact lens success in presbyopia [50].

Several studies have confirmed a relationship between contact lens comfort and vision or subjective visual satisfaction. This relationship is reported for single vision, toric, and multifocal lenses [210–212], emphasising the need to optimise visual experience. It has also been

suggested that subjective visual quality may be a better indicator of contact lens performance than visual acuity. Thus, the use of subjective visual satisfaction scales in presbyopic contact lens wearers has been suggested [51,187]. Recent work has shown that 'silent reading speed' is improved in a presbyopic group with multifocal contact lenses (compared to single vision contact lenses) due to faster average fixation duration and a lower number of fixations [213].

2.8.6. Complications and compliance

In general, the likelihood of significant contact lens complications such as corneal infiltrative events [214–216] and microbial keratitis [217] reduce with age and so are less likely to occur in a presbyopic group; in part, this may be due to better compliance with contact lens care in older wearers [218].

2.9. Future of contact lens correction of presbyopia

Several novel technologies for 'accommodating' or 'focusable' contact lenses for presbyopia correction have been proposed; such enhancements offer the intriguing proposition of providing a form of presbyopia correction which mimics the youthful (pre-presbyopic) situation. When designing accommodating contact lenses, a number of key challenges need to be addressed. When a patient wears spectacles with bifocal lenses, the eyes can rotate independently of the lens; therefore, the visual axis of the eye aligns with the distance or near focal zones of the lens. However, with contact lenses, the relative motion during eye movements cannot be achieved as the contact lenses are placed directly on the ocular surface [95]. Accordingly, with accommodative contact lenses, it is important to track the position of the eye of the wearer, monitor the viewing distance, and also actively control the focal length of the optical elements [219,220] In general, accommodating contact lenses should change focus between near and distance depending on the viewing direction of the wearer and provide an additional +2.00D for near vision [220].

2.9.1. Mechanically accommodating contact lenses

A few methods have been proposed wherein the eye position is utilised to mechanically control the contact lens optics. In one method, contact lenses are moulded and/or altered by the pressure from the eyelids resulting in change in the dioptric power. In this design, contact lenses have a modified anterior surface, and this surface provides a contact point on the lens for the eyelids to re-shape the contact lens either by squeezing or lifting it anteriorly from the eye when attempting to focus at intermediate or near [221].

In other designs, fluid-filled adjustable contact lenses are described. One such contact lens design incorporates a lens chamber that is positioned to align with the pupil of the wearer. In addition, a reservoir is connected to the lens chamber and an actuator located within the lens transfers the fluid between the chamber and the reservoir. The movement of the eye is determined using a sensor, and a control signal is transmitted which in turn activates the actuator. The resultant fluid movement alters the optical power of the lens to shift focus from distance to intermediate or near [222]. In a further approach, a meniscus-shaped lens module is composed of structures that decrease the pressure to move the surfaces of the lens module and increase the distance between the anterior and posterior surfaces of the contact lens, thereby increasing in optical power to enable intermediate or near vision [223].

2.9.2. Electronic accommodating contact lenses

An innovative approach to the development of an accommodating contact lens is to incorporate microelectronics into a contact lens. A capacitive sensor is used to monitor the gaze direction of the cornea based on capacitance variations [224]. Information from both eyes can be coordinated and transmitted to an external device to enable better processing and control [225].

For any 'smart' contact lens design like this to perform its functions

optimally, the optical components should include a power source [226,227] and an antenna [228]. Several methods have been proposed to control optical elements in an accommodating contact lens to create a change in optical power. These designs are currently in the state of patent filings. Clinical trials will be required to determine the safety and performance of these designs in the correction of presbyopia. Some of these approaches have been proposed using electroactive elements (also called accommodation actuators); these alter the shape of the contact lens, resulting in a change in refractive power in response to a signal [229,230].

In addition to the electroactive element, an accommodative contact lens would also include a gaze detection system, an actuator or a controller (such as a chip or an integrated circuit), a battery and an external power source [230–232] The electroactive elements may be present within the optic zone of the contact lens or may be incorporated within the bulk of the contact lens material [229].

In a few other designs, similar to mechanically accommodating contact lenses, fluid in a reservoir present within the contact lens may be transferred from the peripheral region to the lens centre with the help of an electromechanical pump, resulting in altering the lens shape and thereby the refractive power [222].

Liquid crystals are well known for their applications in liquid crystal displays such as computer monitors, cell phone displays and televisions. This technology has also been utilised in contact lens designs. The essential construct of a liquid crystal contact lens is a liquid crystal component embedded between two layers of electrodes [220,233–235].

The principle behind this technology is based on the unique orientation properties of the naturally occurring rods in liquid crystals. These rods can be reoriented by applying a relatively small voltage; when the electric potential is withdrawn, the rods will reorient back to their primary original alignment [236]. The reorientation of these rods results in the alteration of the refractive index of the material, which consequently leads to a change in the optical power of the contact lens [219,220]. Furthermore, this can be configured with the aid of a controller to function as a pinhole, leading to an increased depth of focus.

In summary, several innovative technologies have been developed which can help in the management of presbyopia using accommodating contact lenses. Whilst some of these ideas are ambitious, the principles and technologies behind them are unique and will underpin development of these novel contact lens designs. There is likely to be a significant amount of interest in these approaches amongst researchers and the contact lens industry, which may in turn result in novel developments in presbyopia management in the next few years.

3. Spectacles for presbyopia correction

3.1. History

The history of spectacles dates back hundreds of years, and for a long time, spectacle use was confined to the correction of presbyopia. The first attempts of using smooth curved glass surfaces for magnification purposes had Arabic origins from Arab scholar and astronomer Ḥasan Ibn al-Haytham (Latinised as Alhazen). Roger Bacon in the 1260s [237] records the first mention of using curved surfaces in Latin. In the 14th and 15th centuries, the refinement of the production of glass, especially in the Veneto region of Italy, meant that lenses began to be made not solely for presbyopia correction, but hyperopia and myopia also. An increased demand for spectacles was driven by the invention of the printing press and more widespread access to books and printed material [238]. Lenses were initially mounted in frames balanced on the nose, or supported with the hand before the face. Later, sides were added to grip the temples, forming the basic frame design we still use today.

The onset of presbyopia occurs at the age of 40–50 years, and as life expectancy has dramatically increased in the last two hundred years, along with literacy rates and occupations with near visual demands, correction of presbyopia has become more and more necessary for daily living. In his review, Charman [95] notes that despite many changes in nutrition, age of onset of puberty and increased life expectancy, the subjective amplitude of accommodation as a function of age is largely unchanged as seen from studies from Donders in 1864 [239] through to more recent work by Kragha in 1986 [240].

Correction with single vision lenses was the typical means to correct presbyopia, but for those with ametropia, this necessitates changing spectacles frequently depending on the visual task. This issue of the need to change spectacles for distance and near tasks precipitated Benjamin Franklin to create arguably the first bifocal lens circa 1760, through cutting in half single vision lenses for his distance and near prescriptions, and placing the top and bottom sections into a frame for distance and near viewing respectively. Letocha summarises original letters and material from Franklin to friends and associates and surmises he was likely hyperopic as well as presbyopic [241]. While other bifocal lens designs creating fused lens materials and utilising smaller and differently shaped segments (for example, Round segment, D-segment, B-Segment, C-Segment) have advanced bifocal design, fundamentally, the optical performance of the Franklin split still constitutes a practical lens design.

There have been many other types of multifocal corrections, with clip-on plus-powered additions, and auxiliary plus lenses hinged to the side of frames to be swung around when near correction was needed. Trifocal lens design, inserting an intermediate segment approximately 7 mm in height between the distance and near segments of a lens, were invented by John Isaac Hawkins and patented in 1827 [242]. Trifocals have enjoyed some popularity as an alternative to bifocals, though more in the United States of America (USA) than in Europe.

The issue of image jump from bifocal/multifocal lenses having a sudden change from one refractive power to another has been the subject of much study, with many attempts at producing a progressive power surface. A UK patent (GB190715735A), granted in 1908 to Owen Aves of Yorkshire [243] was an early description of progressive lens, describing an invention to *"provide lenses each of which is made of a piece of glass of other suitable material and which shall have a previously determined constantly and continuously altering, increasing or decreasing refractive power along certain directions of the plan of the said lens, the surfaces of the said lens however being free from lines, creases, projections and the like conspicuous and objectionable defects."*

It was not until 1959 that Essel (Société des Lunetteries) launched the first commercially successful varifocal design, the Varilux lens, developed by Bernard Maitenaz. Essel and Silor (Société Industrielle de Lunetterie et d'Optique Rationnelle) merged in 1972 to become Essilor, and launched the Varilux 2 design, creating asymmetric right and left lenses to follow the reduction in near pupillary distance as a result of convergence of the visual axes when viewing a near object (see Fig. 9). This essentially formed the basis of modern-day varifocal design, consisting of a large distance zone, narrow intermediate corridor, and near zone.

Zeiss launched their Gradal progressive lens in 1970, and other manufacturers brought progressive lenses to market, all attempting to improve optics with successive generations of lens designs, for example, AO Pro (American Optical), Progressiv (Rodenstock) and Varilux Expert (Essilor).

In the last 20 years, developments in computer numerically controlled design of free-form surfaces in the production of progressive addition lenses have enabled refinement of design and manufacture of varifocals, which are vastly superior to the relatively simplistic earlier designs [244]. Optimising progressive design for each individual prescription serves to minimise unwanted astigmatic off-axis aberrations, and yield a perceivable visual benefit to the wearer. However, to maximise these benefits, it is necessary to take into account the precise nature of how the spectacle frame and mounted progressive lenses fit the individual wearer. Assessment of back vertex distance, face form angle and pantoscopic tilt measurements, are often required, in addition to conventional monocular pupillary distances and fitting heights, to
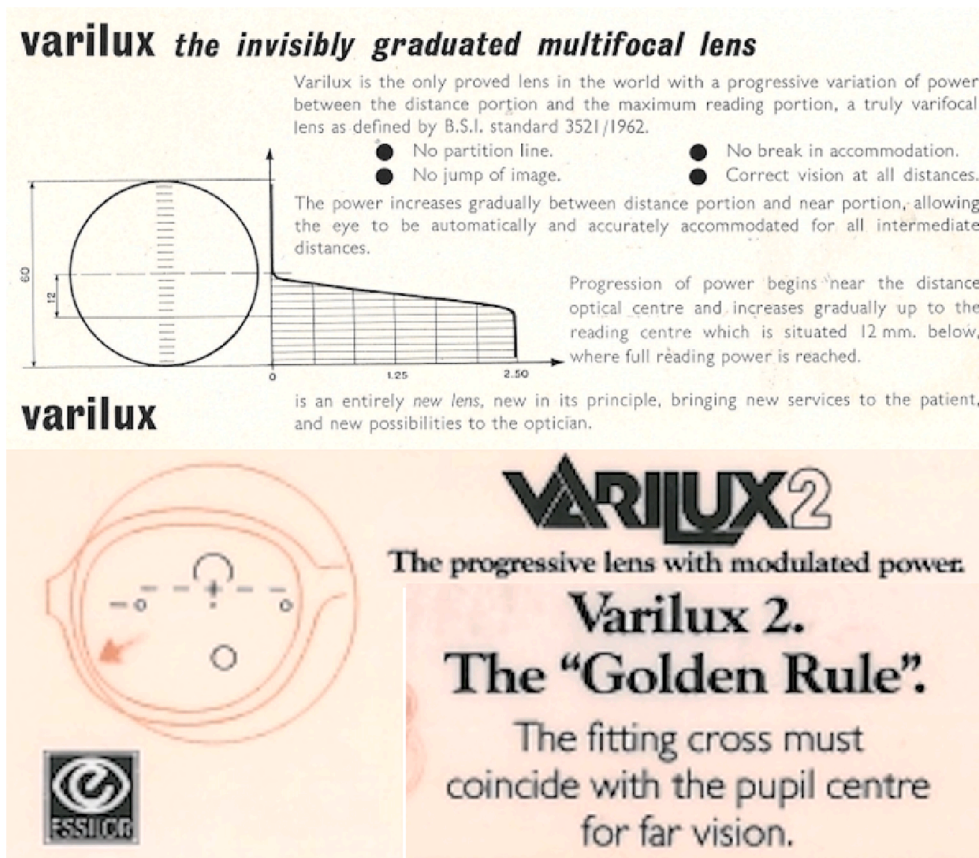
Fig. 9. Original guides for ECPs regarding design and fitting instructions for the Varilux, and Varilux2 lenses. Courtesy of the British Optical Association Museum, College of Optometrists, London.

achieve optimal results when fitting such lenses.

3.2. Current market information

Very limited information is available in the public domain about market details for spectacle lenses for presbyopia. Some online projection data suggests that the overall market for spectacle lenses will be US$ 62.4 billion in 2028 [245] whereas the market for progressive lenses will be US$ 38.6 billion by 2027 [246]. Using data from two different market research companies may be prone to error but this analysis suggests that in financial terms at least, progressive lenses account for about 60 % of the world spectacle lens market. Similarly, there is little information about how precisely presbyopes use a spectacle correction. One analysis of over 500 presbyopes in London reported that many used a combination of spectacle corrections (typically a mix of near spectacles and progressive lenses) and 55 % wore no correction for most of the day. Overall, though, a detailed review of the nature of spectacle presbyopic correction is lacking in the literature.

3.3. Clinical examination

Today, presbyopes have a large selection of vision correction options from which to choose. Patients can be provided with single vision near glasses, bifocals, trifocals or progressive spectacles [247]. Interestingly, much of the process for prescribing spectacles for presbyopia is informed by anecdotal knowledge and textbook learning, and there is only a small evidence base from clinical research.

3.3.1. Understanding patient needs and how this informs product choice

Correction of presbyopia strongly depends not only on the needs and regular tasks of the patient, but also careful consideration of related ophthalmic issues (such as their refractive error and accommodative status). In modern optometric practice, the majority of presbyopic patients who require a distance prescription choose progressive power lenses; segmented lenses (bifocals or trifocals) or separate single vision spectacles are no longer commonly used [247].

Some patients without the need for a distance correction may be more satisfied with a pair of reading spectacles than progressive lenses, whereas others will wish to avoid the inconvenience of switching between spectacles and will prefer progressives [248]. Understanding patient needs is necessary for successful prescribing. The primary requirement of some patients is only for a suitable correction when reading books or newspapers, whereas others are more concerned about vision for intermediate distances of between 40 cm and 1 m, such as for computer work.

Given the above, it is key that an ECP records a comprehensive case history and undertakes a task demand analysis to offer the best dispensing recommendation [248]. However, clinical/physiological optics considerations must also be considered. For example, an early presbyopic patient who asks for improved vision when working on a computer but who has a reasonable residual amplitude of accommodation is likely to be satisfied with single vision spectacles prescribed with computer distance in mind as their remaining accommodation will allow for good vision at a typical close working distance (40 cm). Such a 'single vision' option of course provides a full field of view over a specific range of distances.

However, with reducing amplitude of accommodation with age, the functional distance range offered by a single vision correction diminishes compared to progressive lenses and it is likely that this latter option will be an increasingly superior solution with advancing presbyopia [247]. For those in this situation who spend a significant proportion of time in a classic office environment, specific 'occupational'

progressive lenses may be preferred. Others will need multiple bespoke correction types - best suited with occupational lenses at work, progressives for general daily use and single vision near spectacles for specific hobbies or interests [248].

There is a minority of patients with binocular vision issues or anisometropia who may require more complex dispensing considerations. People with insufficient accommodative convergence will need to be fitted with progressives or bifocals with an amended lens inset. People with high anisometropia may have problems in downgaze with progressive lenses due to lens-induced prismatic differences at the near point giving rise to diplopia and/or asthenopia. While such issues can be addressed by some special progressive lenses to some extent, bifocals with compensating prisms or using single-vision glasses may be indicated and offer broader options for prismatic correction. Thus, bifocals or trifocals can still act as a good 'problem solver' in some clinical cases. Additionally, single vision spectacles may be the simplest option. Single vision spectacles may also be the preferred option in older patients that are at higher risk of falls [249,250].

In general prescribing, the optimum presbyopia correction requires very careful, multi-factorial consideration for most patients and is best performed by addressing the individual needs and optical aspects of each patient [248].

3.3.2. Preliminary examination and clinical measurements

3.3.2.1. Ocular health and patient history. Conducting a careful patient history and task analysis is critical ahead of a clinical examination and spectacle dispensing for presbyopes. This discussion should include what correction types have been used previously, and assessing which options were successful and which may have failed. Task analysis should include information about the distances at which optimum vision is especially critical, which could include discussions about reading books, e-books or newspapers, driving, use of digital devices and a large range of distance-orientated tasks. Obtaining occupational and lifestyle information is vital; how does the patient split their time between indoor and outside pursuits [248].

3.3.2.2. Refraction. To prescribe the most appropriate spectacle lenses, a full and detailed monocular and binocular subjective refraction is necessary. This should include the evaluation of accommodative amplitude, binocular vision and distance and near visual acuity [248]. Near addition must be determined. Even though addition power is generally similar for each eye, some patients do have different accommodative amplitudes which may lead to non-matching addition powers.

There is limited formal evidence of the literature and ECPs are generally reliant on clinical experience to determine addition power. One school of thought is to not to give the full theoretical addition power for the distance needed but to reduce the theoretical addition power by around half of the accommodative amplitude of the patient. For example, if the patient wants to read at 40 cm (a vergence requirement of 2.50D) with an accommodative amplitude of 1.00D, the recommended addition power would be 2.00D (2.50 − (1.00/2) [248]. Various methods of determining addition power tend to arrive at similar outcomes [251].

3.3.2.3. Lens dispensing measurements. Depending on the type of presbyopia correction used, different measurements are needed. In single-vision near glasses, pupil distance for near tasks and vertical height are sufficient [247]. In bifocal lenses, pupil distance and vertical height position of the segment need to be measured. Generally, an inset of 2.5 mm is taken into account in segmented glasses as bifocals; however, if the patients convergence is significantly different, suitable adjustments may be needed [247].

For standard progressive lenses, monocular pupil distance, vertical height and vertex distance (in high ametropia) are sufficient. The

pantoscopic tilt (ideally tilt should be 7-12°) and wrap angle should be within the normal range; ideally 7-12° for the former, and 5-10° for the latter [252]. The near pupil distance should be determined separately for each eye, as this can be different between eyes and different to the standardised inset of the manufacturers [253].

For personalised progressive lenses, manufacturers require the measurement of many more variables including (in addition to pantoscopic tilt and wrap) vertex distance, working distance and design bias (for example, balanced) [248,252]. Such an approach can be adopted in patients who have unusual refractive errors or facial features but again, there is limited evidence to guide ECPs at this stage. Theoretically, the evaluation of these parameters is generally only required in a small number of patients. Manufacturers advertise better vision with personalised lenses versus standardised ones, although there is little independent scientific proof of this.

3.4. Single vision and multifocal spectacles

Presbyopia can be corrected with either single vision (that is, monofocal), multifocal or progressive addition spectacle lenses. 'Multifocal' lenses are those which provide the wearer with two (bifocal), three (trifocal) or even four (quadrifocal) visibly divided areas of different focal powers [254] whereas progressive addition lenses are those offering varying focal powers without a visible division between areas of different power.

3.4.1. Single vision spectacles

Single vision spectacles could be considered the most versatile spectacle option for the management of presbyopia. In theory, all lens materials, lens forms, tints, filters and surface treatments are possible including freeform surfaced designs, with availability only limited by the required prescription power. A UK-representative, presbyopic patient sample showed in relation to single vision spectacle wear, that near correction was the most utilised form of refractive correction by presbyopes, but single vision distance spectacles were worn for a greater proportion of time [255].

As a monofocal, wearable device having no alternative power areas in the lens, if a suitable and correctly fitted frame is selected, a large viewing field is enabled. However, single vision spectacles impose compromise on the user compared to no correction requirement. For the presbyope, clear vision through a single vision lens will only be achieved at a limited focal-distance, be it far, intermediate or near, though this is accommodation-availability dependent [95,256].

Depending on the specifics of the near visual task, some younger presbyopes will be able to accommodate efficiently through their distance spectacles [95]. The need to remove distance spectacles and any associated nuisance can be therefore reduced. For presbyopes who require more than one correcting power for their visual needs, the limitations of single vision spectacles may outweigh the benefits. A multifocal or progressive lens may therefore be considered, although quality of vision scores have been found to be similar for presbyopes wearing single vision distance, bifocal or progressive lens corrections [255].

3.4.1.1. Near correction. A near correction is traditionally considered for tasks performed at approximately 40 cm [32]. The focal-distance limitations of a single vision near correction should be discussed to support the decision-making process for the presbyope, as the correction will need to be removed and replaced as they change visual tasks. Distance-viewing through a near correction creates pseudo-myopia [257] and this may be difficult for the inexperienced wearer to comprehend. Communication errors have been shown to contribute to spectacle non-tolerance, including patient expectations to see in the distance with a near correction [258]. The effect can be emphasised when the near correction is in place during the examination process to

support consideration by the patient of which spectacle correction method may be suitable for them.

Presbyopes who currently wear a single vision distance spectacle correction and are considering an additional single vision correction for near, will need to determine whether changing between two pairs of spectacles, dependent on task, will be appropriate for their personal needs. Subjectively-assessed quality of vision has been shown to decrease the greater the proportion of time spent wearing a single vision near correction, and this may be in part owing to frustration of physically changing correction methods [255].

3.4.1.2. Ready-made reading spectacles. For the emmetropic presbyope and those looking to use reading spectacles over contact lenses, off-the-shelf single vision reading spectacles may be an inexpensive and convenient choice. Additionally, they may be an accessible solution for presbyopes in countries where access to prescribed spectacles is limited [259]. These 'ready-made' reading spectacles provide the same spherical dioptric power in both lenses, which can be aligned to the prescribed reading addition of an individual. As ready-made spectacles can be self-selected by the user, they may choose a lower power than their prescribed addition to support their intermediate vision. Any required cylindrical prescription component will not be present which, even at low levels of uncorrected astigmatic error, may reduce near vision acuity and increase visual discomfort; however, a causative link is yet to be established between uncorrected astigmatism and asthenopia [260].

The quality of ready-made reading spectacles may be of concern. It has been shown from a random sample purchased in the UK that a large percentage (42 %) do not conform to international optical standards, mainly owing to induced horizontal and/or vertical prism, particularly in the +3.50 power [261].

In view of the above considerations, the purchase and use of ready-made reading spectacles should be discouraged even for emmetropes – in favour of a full eyecare examination by a qualified ECP. This will facilitate provision of an accurate and personalised prescription – taking all relevant physiological and environmental factors into account, setting appropriate expectations of visual performance and addressing any expressed concerns – and careful dispensing of appropriately designed spectacles. The purchase of ready-made spectacles should only be entertained in emergency situations, or as noted above, in countries where access to prescribed spectacles is limited.

3.4.1.3. Distance correction spectacles. Distance as a principal task is a common requirement for presbyopes [255]. Myopes who can focus on near tasks unaided may choose to only utilise a single vision distance correction, which provides the advantage of being spectacle free for near tasks. However, any cylindrical prescription requirement will be uncorrected for near. Daily computer users aged 36–57 years who habitually wore single vision distance spectacles and had not been prescribed an addition, reported increasing ocular strain with increasing durations of computer work, suggesting an additional near/occupational correction may be appropriate [262]. Older, outdoor-active multifocal spectacle wearers have a reduced risk of falls with the provision of a single vision distance correction to be worn outside the home, though the risk of falls is increased for older presbyopes who undertook low-levels of outdoor activity [58].

3.4.1.4. Occupational correction. A modification of the near addition may be determined to support clear viewing at a required distance within the intermediate to near focal range. Individuals under the age of 52 are generally considered to have enough accommodative reserve to be able to focus on intermediate distance tasks through either their distance correction, or unaided in the case of the emmetrope [95,263]. An intermediate addition may be prescribed in the eye examination or a modification of the prescribed near correction may occur when a detailed visual task analysis takes place during the spectacle dispensing process.

3.4.1.5. Near over-specs. Presbyopes wearing a distance-only contact lens correction may opt to have their full reading addition worn as a pair of single vision over spectacles [95]. This correction method may also be a consideration for those fitted with distance-only intraocular lenses post cataract surgery. A modified, intermediate addition as required for specific visual tasks could be calculated, bearing in mind those fitted with intraocular lenses will have no remaining accommodation to consider. Theoretically, if required, multifocal and monovision contact lens wearers can be supported in near vision tasks by additionally wearing near correction spectacles, particularly where small font size, low light levels and poor contrast are an issue, or the full addition is not provided by the contact lens correction [95]. Research in this area is required to understand subjective acceptance of a spectacle over-correction and appropriate prescribing.

3.4.1.6. Distance over-spectacles. Though not commonly encountered owing to the general predilection for good distance vision, some individuals may choose to wear a near-only contact lens correction to support their vocational needs. Theoretically, they may then be prescribed an over-distance spectacle correction, which may include any required cylindrical correction if this is not present in the contact lenses, to enable clear distance viewing for tasks where this is essential, such as driving. This option could also be considered for monovision contact lens wearers to provide the near-oriented eye with an over distance correction for distance specific tasks.

3.4.2. Bifocal spectacles

Bifocal spectacle lenses allow the presbyope to view two separate focal distances whilst wearing the same pair of spectacles. Most commonly selected are lens powers to correct viewing at far and near distances, although occupational combinations can be provided such as intermediate and near. The addition portion of the lens in the form of the lens segment, is traditionally located in an inferior and nasal position to support downward gaze and the associated convergence when viewing at near. Fig. 10 provides an indication of the range of bifocal segment types possible, though availability is prescription, material and manufacturer dependent.
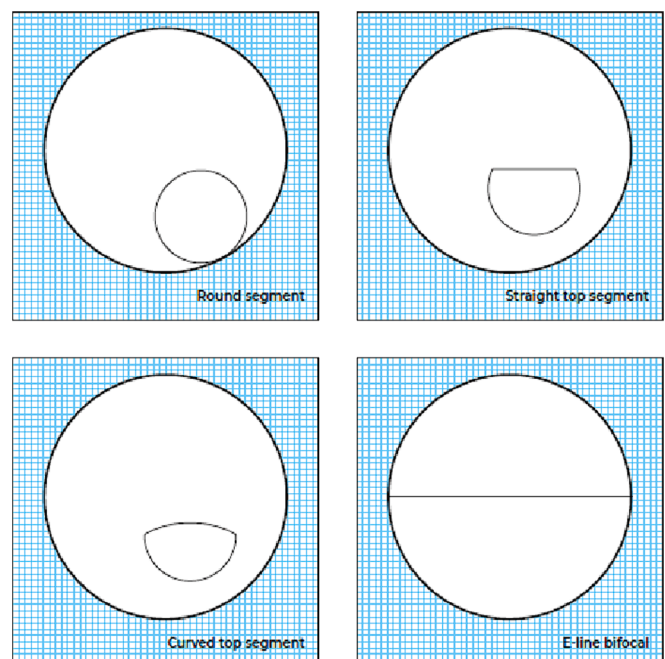

Fig. 10. Bifocal segment types.

3.4.2.1. Bifocal lens designs. Bifocal spectacle lens availability is limited compared to single vision and progressive lenses. However, there are a number of manufacturers who offer this lens format in a range of plastics and glass materials across a variety of lens refractive indices. Photochromatic bifocal lenses are available, and a variety of tints and filters including polarised are possible, as well as lens surface coatings. Lenticular bifocal lenses are available for high prescription powers. Table 8 provides an indication of the segment diameters available across glass and plastics materials.

Bifocal lenses can be manufactured in a full range of plastics and glass materials using freeform technology, which enables the creation of multifocal lenses with a blended surface region between the different distinct lens power areas to create non-visible segments [257]. A range of manufacturer-dependent round segment sizes are available but, owing to the bespoke nature of freeform technology, choices of segment size as small as 15 mm (Fig. 10) and high adds are possible.

3.4.2.2. Hybrid bifocal lens designs. Freeform technology has enabled hybrid multifocal-progressive lens designs where a progressive blend replaces the bifocal segment top. Monocular horizontal and vertical pupil centration measurements are required. The progressive blend removes the issue of image jump (see section 3.4.2.3) as a dispensing consideration. Freeform bifocal lens designs are also available that combine a distinct, separate focal-power segment on the main lens with a low addition progressive surface worked on the rear, making it possible to split the power of a high addition onto both the front and rear lens surfaces.

An occupational freeform, bifocal-progressive hybrid design, originally conceived for pilots, is available where either an up-curve or e-line segment is situated at the top of the lens, with a progressive design worked on the lower rear surface of the main lens. This can be inversed with the segment in the lower portion and the progressive in the upper portion and additionally, a trifocal segment could be considered.

Monocular fitting heights at the pupil centre is required and the desired separation of the progressive and bifocal/trifocal segment needs to be stated as well as the chosen addition for both areas. A spectacle frame with enough depth to enable both the progressive and bifocal sections to be placed with ample central distance viewing needs to be selected. Patient crest height and the vertical position of the frame bridge should be carefully considered during frame selection, to ensure there is enough lens area for superior viewing.

3.4.2.3. Bifocal fitting and dispensing considerations. The prescription for a patient, in combination with their visual needs, must be considered to enable an appropriate bifocal segment type, diameter and fitting position to be selected. Bifocals lenses should be fitted so that the segment top aligns with the lower edge of the iris [257] or the top of the lower eyelid for small round segments, and 2 mm below the top of the lower lid for straight-top segments [264,265] as shown in Fig. 11. Depending on iris diameter and palpebral aperture, the lower edge of the iris may not be visible and the lower lid reference may be required for use. The segment top position may be fitted at an alternative height for occupational purposes, owing to non-standard patient posture or to match the previous segment top position used by the patient, where this has proved comfortable [264].

Image jump, a phenomenon associated with the lens segment, needs to be considered when dispensing bifocal spectacles. Subjectively, image jump is experienced as the sudden movement (jump) of an object into the near field of view. An area of scotoma is created at the dividing line though this may not be evident to the wearer. Image jump occurs owing to the sudden introduction of base-down prism as the line of sight of the wearer crosses into the segment area. The amount of jump a segment will cause is calculated in prism dioptres using Prentice's rule, $P = cF$, where c is the distance to the optical centre of the segment from the dividing line (cm) and F is the dioptric power of the segment.

From Fig. 11 it can be seen that a round segment will have a greater distance from the dividing line to the optical centre of the segment than a straight-top segment of the same dioptric power, and therefore will induce more base-down prism. A no-jump bifocal does not induce any base-down prism, as the optical centre of the segment is on the dividing line. This can be found with E-line and cemented/bonded bifocals. Alternatively, a no-jump bifocal can be created by surfacing an equal and opposite amount of base-up prism onto the segment to counteract the base-down prism.

Bifocals, along with progressive powered lenses, have been shown to be a falls risk factor for older patients [266]. In part, this is thought to be owing to the blurred and magnified image seen through the lens segment when looking down, for example when approaching steps, making judgement of the position of objects difficult [250]. Image jump in bifocals may also play a part for this group and it has been suggested that for active, older bifocal and progressive wearers, provision of a single vision pair of distance spectacles to use outside of the house may reduce the risk of falls [58]. Advising the bifocal wearer to tuck their chin in when looking down, such as when negotiating steps, so they view through the distance portion of their lens is suggested [250].

Consideration is required for presbyopes presenting with anisometropia in the vertical meridian when dispensing multifocal or progressive lens solutions, owing to the different amount of prism induced by each lens as they lower their gaze to see at near. General subjective tolerance for differential prism is suggested at 1^Δ [257] to 2^Δ [264]. The near visual point (NVP) is assumed to be approximately 10 mm below the distance optical centre [257] and for a multifocal lens this is expected to be within the segment.

The prismatic effect for each lens can be calculated using Prentice's Rule, $P = cF$, where c is the distance travelled by the eye (cm) from the distance optical centre to the NVP, and F is the dioptric power of the main lens in the vertical meridian. The difference between the results of each lens then provides the differential prismatic effect that will be experienced by the wearer and this should be noted along with which eye will experience more base-down prism, to ensure any solution is appropriately applied. Only the differential prismatic effect of the distance portion of the lens needs to be calculated, assuming the bifocal segments are of the same diameter and power and therefore, are exerting an equal amount of prismatic effect which effectively cancel each other out.

Several solutions are available to manage differential prism at near in bifocal spectacles, if it is considered outside of subjective tolerance:

● Prism-controlled bifocals
● Bifocals with unequal round segment sizes
● Bi-prism/Slab-off bifocals
● Franklin Spilt/Bonded bifocals
● Fresnel stick on prism

3.4.3. Trifocal and quadrifocal spectacles

Trifocal spectacle lenses provide three distinct areas of different focal power, traditionally far, intermediate and near. Compared to bifocal spectacle lens availability, fewer manufacturers provide access to trifocal lenses, but CR39, Polycarbonate, Trivex and Glass 1.5 index
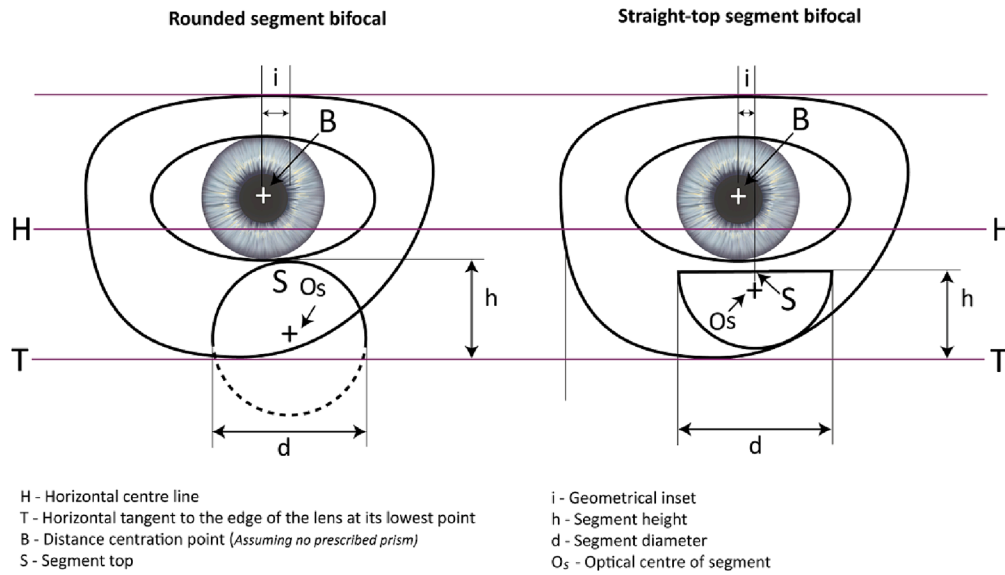
Table 8
Segment availability for standard manufacture bifocal lenses.

Lens material	Segment availability (diameter in mm)
Plastics	Round: R15 (golf and watchmaker) R22 (high plus), R24, R25, R28, R38, R40 Straight top: D25, D28, D35, D45 E-line Curved-top: C25, C26, C28
Glass	Round: R30 (solid) Straight-top: D28, D35 Curved-top: C25, C28

Rounded segment bifocal   **Straight-top segment bifocal**

H - Horizontal centre line
T - Horizontal tangent to the edge of the lens at its lowest point
B - Distance centration point (*Assuming no prescribed prism*)
S - Segment top

i - Geometrical inset
h - Segment height
d - Segment diameter
O_s - Optical centre of segment

Fig. 11. Bifocal fitting and measurements.

materials are available, including photochromatic and polarised options. A range of segment shapes and positioning is available (Fig. 12). Table 9 provides an indication of trifocal segment availability.

Straight-top trifocal lenses are specified by the depth of the intermediate segment followed by the width of the reading segment, both in millimetres. For example, a straight-top trifocal with an intermediate segment depth of 7 mm and a reading segment width of 28 mm, would be ordered as a 728. Concentric trifocals have a round reading segment within a round intermediate portion. The reading and intermediate segment diameters in millimetres are usually provided, but the depth in millimetres of the intermediate area to the top of the reading portion may also be specified by the manufacturer. Trifocal spectacles usually have an intermediate portion/reading [near] portion (IP/RP) ratio stated. This is the percentage power of the intermediate addition in

Table 9
Segment availability for standard manufacture trifocal lenses.

Trifocal	Segment availability (diameter in mm)
Plastics	Round concentric: 12/36, 22/36, 28/42 Straight top: 728, 835, 1435 E-line Double D
Glass	Straight top: 728

relation to the reading addition power. A trifocal with an IP/RP ratio of 50 % and a reading addition power of +2.00D would have an intermediate addition power of +1.00D.

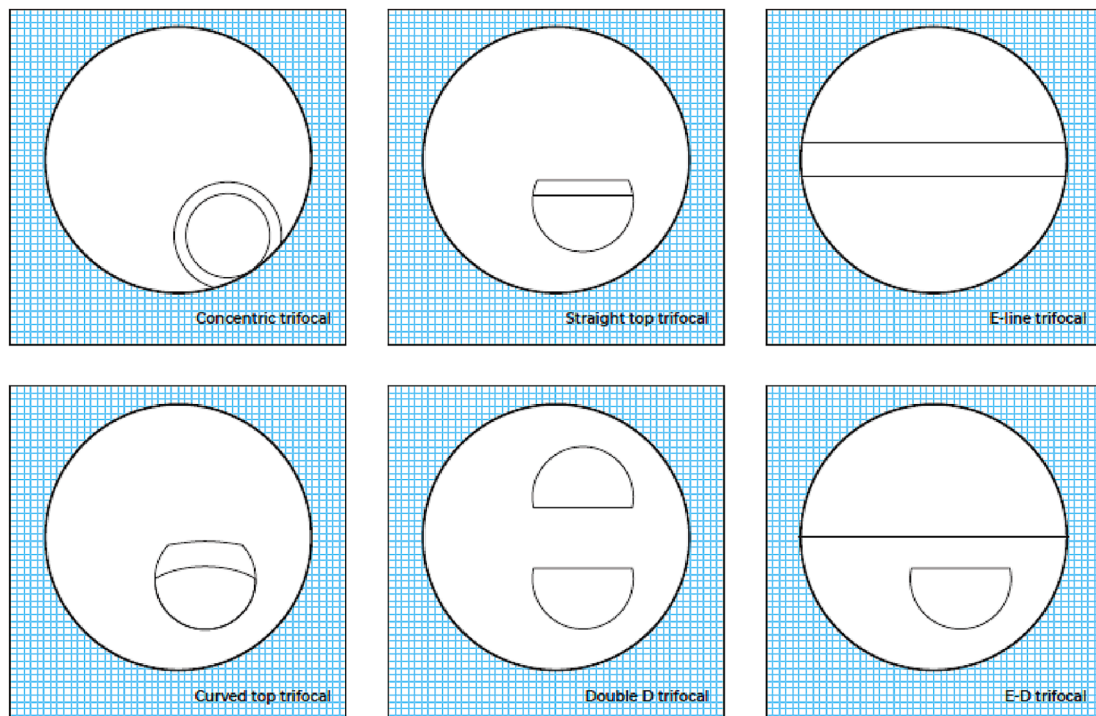Trifocals can be manipulated for occupational purposes both in lens

Fig. 12. Trifocal segment types.

power selection and segment placements. The Double-D trifocal is an occupational-specific design, with an upside down straight-top segment in the superior area of the lens and a regular straight-top segment in the inferior portion of the lens (Fig. 12). This may be considered for occupations or hobbies that require focus at near additionally in a superior gaze. Either the near power can be specified in both segments or an intermediate power in the upper segment. A similar up and down design is available using freeform technology to create invisible round segments (Fig. 12). Here the separation of the two segments can be specified in millimetres, along with individual powers for the main lens and the two segments. There is a lack of research available to understand the usability of trifocal spectacles from a subjective perspective, or regarding issues that may present, other than those anticipated with all multifocal spectacles which have been discussed in section 3.2.

Although very limited global availability, quadrifocal spectacle lenses are an occupational design that provides four distinct areas of lens power by utilising the Double-D trifocal design with an inferior double (trifocal style) segment as opposed to a single straight-top segment (Fig. 13 and Fig. 14).

3.4.4. Progressive addition spectacle lenses

Progressive addition spectacle lenses are designed to provide the wearer with clear vision from distance in the upper area of the lens, through intermediate distance viewing with near vision optimised in the lower area. Unlike the multifocal spectacles discussed in section 3.4, progressive addition lenses are manufactured with a seamless, progressive surface with no delineation between the gradual prescription power change across the lens.

Owing to the Minkwitz rule, progressive addition lens design produces increasing astigmatism perpendicular to the increasing lens power [267]. To minimise this oblique surface astigmatism which can create a narrow visual corridor for the wearer, manufacturers use blending in their lens designs to improve the horizontal visual performance of the lens in the intermediate and near zones. Modern computer numerical control (CNC) machining processes enable complex and individualised lens surfaces to be produced to improve progressive addition lens wearer experiences.

3.4.4.1. Designs. Recent developments in progressive addition lenses have continued to adapt to modern visual needs and lifestyles. Notable here are the changes which have been brought about since the introduction of the first smartphone in 2007. Close to two billion people are presbyopic [1] and there are now more mobile phone subscriptions than people on the planet [268]. Further to this, the historic situation of somewhat static near requirements when work was often conducted for moderate periods at approximately fixed distances (for example, time working on a document followed by time at a computer display) has been rapidly replaced by a more fluid situation of phones, tablets, laptops and desktop computers with ongoing changes in vision between them all.

Lens manufacturers created the newest generation of progressive addition lens designs to keep up with the increasing near/intermediate demand of multiple digital devices. They have been able to further minimise peripheral optical aberrations or 'swim effect' by creating dual-lens surface (front and back surface) modelling and calculations, allowing greater near-range design and manufacturing control, reducing prismatic effect, improving binocular depth of field and overall vision. Manufacturer claims and clinical experience suggests that these continuous innovations allowing higher wearer acceptance and success [269,270] but there appears to be no independent analysis of such
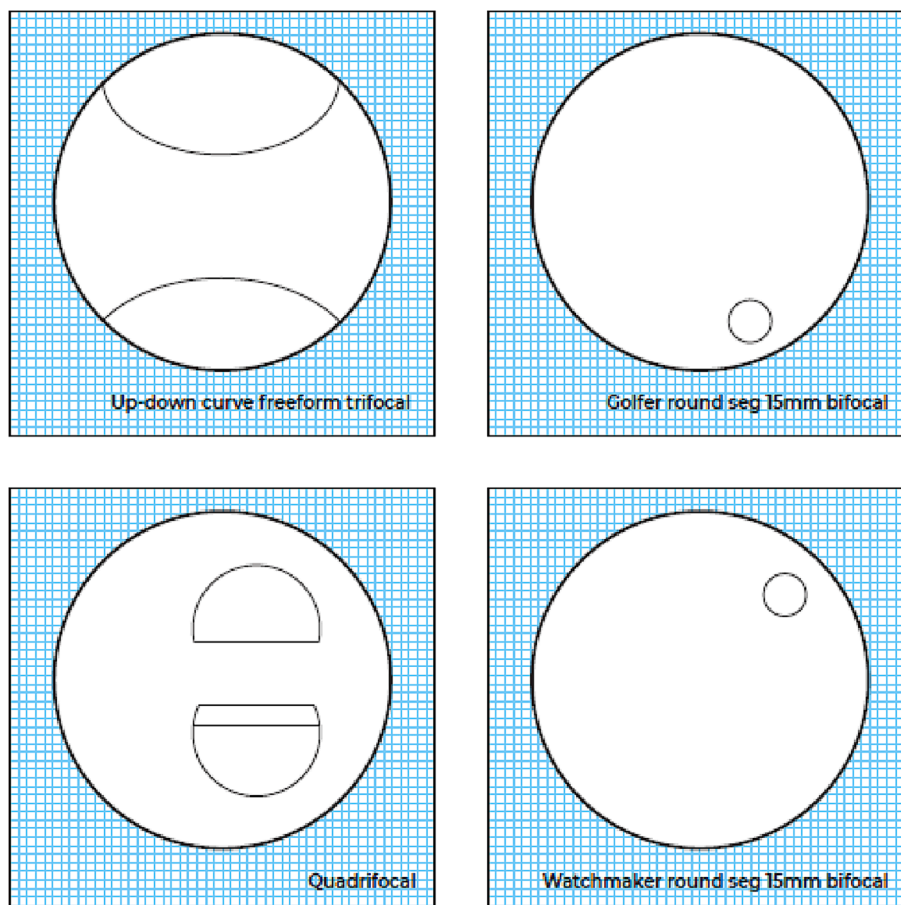

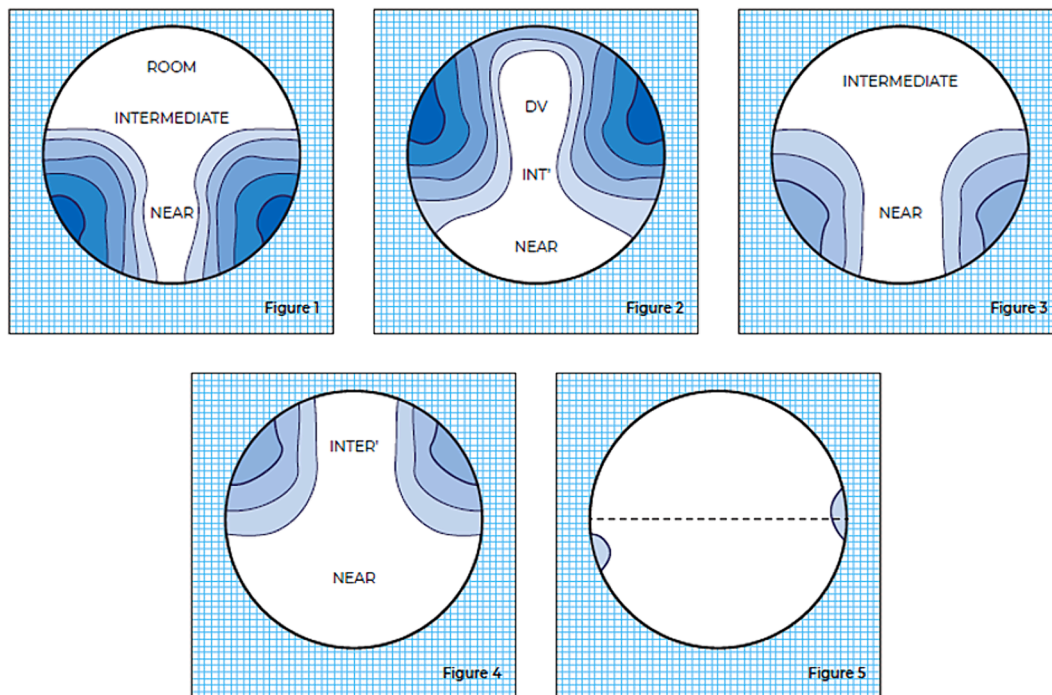**Fig. 13.** Occupational multifocal segment types.

Fig. 14. Examples of generic power variation lenses showing typical *iso*-astigmatism lines.

claims in the literature.

3.4.4.2. Materials, prescription range and lens design. Most lens manufacturers have an expansive range of materials and progressive addition lens designs to satisfy modern visual and lifestyle needs. Table 10 illustrates examples of current regular availability of progressive addition lens designs, materials and prescription range as supplied by many manufacturers around the world. Additionally, owing to free-form technology, some manufacturers offer bespoke prescription availability beyond the range shown in Table 10.

3.4.4.3. Specific dispensing considerations (adaptation and communication). With a plethora of available progressive addition lens designs, it is imperative that ECPs are familiar with the differences between the various designs and identify the most suitable for each patient. Interestingly, there is no evidence base to support a particular workflow to select a preferred progressive addition lens choice from patient refraction and other characteristics which points to a significant deficiency in the literature. One schema from long-term clinical experience is presented in Table 11 and it is recognised that this type of approach will differ between ECPs depending on their experience, training and education, product availability and other factors.

Table 10

Examples of modern progressive-addition lens (PAL) materials and regular prescription range.

Lens Material/ Refractive Index	*Power Range	*Addition Power Range	*Max Cylinder
Plastic 1.50	−10.00 to +6.00	0.75 to 4.00 D	Up to −6.00
Trivex 1.53	−10.00 to +6.00	0.75 to 4.00 D	Up to −6.00
Polycarbonate 1.59	−10.00 to +6.00	0.75 to 4.00 D	Up to −6.00
High Index 1.67	−12.00 to +9.00	0.75 to 4.00 D	Up to −6.00
High Index 1.74	−14.00 to +13.00	0.75 to 4.00 D	Up to −6.00

If a thorough visual task analysis has been undertaken, and a well-fitting frame chosen and accurate measurements taken, poor adaptation to progressive addition lenses appears to be rare. However, if patients do not feel comfortable, clinical experience suggests that this may be due to a number of factors: insufficient education of the patients, too high expectations by the patient, poor dispensing, including not fitting the frame for individualised lenses before measuring, or incorrect manufacture in the lab. It has been found that inappropriate near prescription refraction was a major cause of non-tolerance to multifocal spectacles [258]. Table 12 lists detailed steps on how to improve progressive addition lens adaptation and dispensing success for all patient types, again based on clinical experience in the absence of an evidence base in this area. As a general rule, it is also advisable to follow the specific instructions and recommendations of the lens manufacturers with regard to patient management.

3.4.5. Occupational/power variation/degressive lenses

3.4.5.1. Designs, materials and manufacture. An 'occupational' spectacle lens can be designed in many forms. It can be a specific product marketed as a lens to offer the presbyopic wearer particular visual task solutions, such as lenses designed specifically for use in an (open) office environment, degressive lenses or low addition anti-fatigue lenses. All forms of these lenses offer benefits for specific situations but ultimately there will be some form of compromise in either the viewing distance or the field of view [54]. Alternatively, an occupational lens may be dispensed in a more traditional lens form with specific placement of power and/or lens positioning. This could be as simple as single vision lenses dispensed for a specific working distance, an ideal solution if the patient requires a full field of vision and needs to position themselves in a particular (relatively) static manner with no requirement to regularly view other distances.

Bifocal and trifocal lenses can also be dispensed as 'occupational' lenses where, for example, intermediate power may be dispensed in the top portion of the lens with the addition power altered to correct a particular working distance. The position of the segment top can also be dispensed away from the traditional fitting position of the lower limbus either higher or lower, or even placed in the periphery of the lens for

Table 11

Recommended prescribed addition powers for progressive addition lens (PAL) wearers. SV = single vision, AF = anti-fatigue, IOL = intraocular lens. Recommended addition powers (in dioptres) in the table are over the final distance manifest refraction prescription. When specific computer PALs are not available, can use normal PAL designs with the prescription recommendations in the table.

Patient Age (years)	Addition Power Recommendation	Additional Computer or Near Glasses Addition Power
Late 30s – Early 40s	AF: +0.40D to +0.75D PAL: +1.00D to +1.25D	SV: addition +0.50D to distance Rx, depends on the visual needs and lifestyle of the patient AF: +0.40D to +1.00D
Early/Mid 40s – 50	PAL: +1.25D to +2.00D	SV: addition +0.75D to distance Rx, depends on the patient's visual needs, size/number of monitors, and lifestyle AF: +0.50D to +1.00D can work for patients with lower addition power needs Computer PAL: choose specific design based on availability for patient Using normal PAL step 1: addition +0.75D to the original final distance Rx, make resulting numbers the new top part of Rx (adjusted distance) Using normal PAL step 2: subtract +0.75D from the original addition power, the difference is the new addition power
50–60	PAL: +2.00D to +2.75D *depends on patient's visual needs & lifestyle*	Computer PAL: choose specific design based on availability for patient Using normal PAL step 1: addition +1.00D to +1.25 to the original final distance Rx, resulting numbers are the new top part of Rx (adjusted distance) Using normal PAL step 2: subtract same +1.00D to +1.25D from original addition power, the difference is the new addition power
60–70 *No cataract surgery yet*	PAL: +2.50D to +3.50D *depends on the visual needs of the patient and lifestyle* *take cataract and retinal health into consideration*	SV: addition +1.50D to +2.00D to distance Rx, depends on patient's visual needs, size/number of monitors, and lifestyle Computer PAL: choose specific design based on availability for patient Using normal PAL step 1: addition +1.25D to +1.75D to the original final distance Rx, resulting numbers are the new top part of Rx (adjusted distance) Using normal PAL step 2: subtract same +1.25D to +1.75D from original total addition power, the difference is the new addition power
Over 70	Before cataract surgery	Follow age 60–70 recommendation above
After cataract surgery		1. Communicate with cataract surgeon to learn and understand the IOL implant optics 2. Prescribe Rx to enhance or amend what IOL implant did not achieve for the patient 3. Take retinal health into consideration

Table 12

Recommendations to improve progressive addition lenses (PAL) adaptation and dispensing success. SV = single vision.

PAL Patient Type	Recommended steps to improve adaptation and dispensing success
1. Successful Previous PAL Wearer	Identify the need for daily lenses, sunglasses, and computer/occupational PALs during preliminary evaluation or clinical examination Choose the correct fitting frames to match the visual needs and lifestyle of the patient Educate the patient on the benefits of new generation of PAL designs Review insurance coverage (if applicable) and fees for final selections Adjust the final frame chosen before taking measurements to ensure correct fitting (nose, cheeks, behind ears), correct pantoscopic tilt and face form angle. Take accurate measurements based on chosen PAL design recommendations
2. First Time PAL Wearer	Identify the right patient based on reported history and symptoms, educate the benefits of PALs and if suitable, follow steps in section 1 above
3. Previous Non-Adapt PAL Wearer	Obtain previous PAL designs, understand previous experiences of the patient, and identify reasons behind previous non-adapt Educate patient on reasons behind recommended new PAL designs Formulate and educate plan of actions in case of non-adapt again with new PAL lenses Follow steps in section 1 above
4. All Wearers at Dispensing Visit	Ensure proper glasses fit (nose, cheek, behind ears), ideal pantoscopic tilt and face form angle Teach new and previous non-adapt wearers on how to use the chosen PAL design to see at distance, intermediate and near. Teach patient the difference between a PAL design vs SV design if a SV lens is used for computer use in addition Offer a trial period (one to few weeks) for those who are experiencing adapting issues at dispensing and follow up (phone, text, email) Work with lab on remake solutions in case of non-adapt and communicate clearly with patients on logistics (time, payment or refund if applicable) Document in patient's record the reasons for non-adapt to assist the future eyecare and eyewear success

Traditional progressive addition lens designs give the wearer the advantage of correcting far distant through to near vision in one pair of spectacles. The disadvantage of progressive addition lenses is the relatively narrow fields of clear vision and the aberrational surface astigmatism that can cause the wearer to report a 'swimming' (with head movement) or bended floor (eye movement) effect when viewing through the periphery of the lens. As the addition power increases, the amount of surface astigmatism will also increase [257].

Therefore, if a progressive addition lens is ordered with an intermediate prescription at the top and a resultant reduced addition power, the relative surface astigmatism is reduced due to the smaller difference between the top and the bottom. This is also giving the wearer a wider and longer progressive corridor for the increase in power.

One other problem of progressive addition lenses appears, when going down stairs, especially steep ones. The stair steps appear blurry, when viewed through the near part of the lenses.

Individualised lens designs manufactured utilising freeform technology offers vast options to progressive addition lens designs where both the corridor length and insets can be specified, as well as taking into account the 'as worn' position of the spectacles and incorporates the vertex distance, pantoscopic angle and face form angle of the dispensed frame. Application of these parameters to the manufacturing process will maximise certain areas of clear vision for the wearer, however, there are still compromises in the overall visual performance.

This section only considers the vast array of power variation lenses defined as a 'spectacle lens with a smooth variation of focal power over

occasional near vision use that is not in the direct line of gaze, such as a golf spot bifocal. Inverted versions, with near in the top and distance vision in the bottom part may be used for specific tasks or occupations, too.

part or all of its area, without discontinuity, designed to provide more than one focal power' [271] which encompasses most occupational progressive-power and degressive-power lens designs. These lenses can be ordered in a range of plastic materials of refractive indices from 1.498 to 1.740 and in glass materials of 1.523 to 1.800. A plethora of manufacturing techniques exist for these lenses from moulded semi-finished blanks with the power variation either on the front or the back, dual surface power variation options are also available along with the application of individualised freeform surface technology.

3.4.5.2. Occupational lenses. Traditionally designed for the office environment, these power variation lens options offer a vast array of solutions to not only the working environment but also encompassing hobbies and lifestyle of the wearer.

Traditional progressive addition lens designs can be modified to increase the intermediate and near portions of the lens but retain a small area for far vision (Fig. 14-1). Similarly, if the wearer describes the majority of their time is spent utilising intermediate and near vision but they have a need for clear vision across a room – maybe to communicate effectively with colleagues – designs with options for a small, specific portion at the top of the lens to incorporate this requirement may be advised (Fig. 14-2) and these correct for a distance of approximately 4 m. If this is not a necessity and the range of vision described is more intermediate, designs are available at 2 m or 1.2 m for those working at a closer range.

Other occupational designs incorporate an addition of +0.50D to the far vision correction of the lens and also subtract −0.50 D from the near correction in order to elongate the range of clear vision in a working environment where far vision is not as critical to the wearer as the resultant range.

The majority of these lenses are ordered the same as a traditional progressive addition lens by specifying the monocular pupillary distances and heights of the pupil centres in order to place the fitting cross reference point of the lens directly in front of the pupil centre. Minimum heights vary by manufacturer, and it is important to dispense a frame with sufficient depth to allow the full benefits of the lens design to be experienced. The distance between the cross and the lower edge of the frame has to be long enough, to accommodate the desired design. Shorter corridor occupational designs are also available although these will inevitably encounter more surface astigmatism and reduce the width as well as the length of the corridor.

3.4.5.3. Degressive lenses. A power 'degression' is the reduction in power from near to intermediate [272]. A progressive addition lens will have two reference points for focal power, usually for distant and near vision, whereas a degressive-power lens often has one primary reference point for near vision with a variation in power for other working distances, such as an intermediate distance. Some designs favour the intermediate area over the near and vice versa (Figs. 14-3 and 14-4) to give more product choice for the range of visual demands.

Compared to a traditional or occupational progressive addition lens design, the advantage of the degressive design is that the change in power is relatively low, which reduces surface astigmatism [257], giving a wider and longer corridor of clear vision. This optical construct reduces the need to adopt strict postural positions, and less head movement is required to find areas of clear vision.

Degressive lenses are ordered by the near power with a negative degression, for example, −0.60D or −1.30D. The required centration details give the reference point position either in front of the pupil centre or at a specified point in relation to the pupil centre, depending on the manufacturer and the occupation. A minimum height from the pupil centre to the top rim of at least 10 mm is usually required. A slightly longer requirement from the pupil centre to the lowest tangent at the top of the bottom rim of the frame is necessary to allow for maximum benefit of the design.

Whilst these minimum values may vary between manufacturers, this reference to the pupil position is more accurate than stating a minimum vertical eye size of the frame, commonly known as a 'B' measurement, as the as-worn vertical position of the frame must be taken into account when placed on the wearer.

3.4.5.4. Low addition power variation lenses (anti-fatigue). Whilst still technically a power variation lens, a popular form of occupational lens is a low addition power lens designed specifically to reduce visual stress or fatigue caused by long periods of accommodation when using digital devices such as tablets and smartphones. These are often dispensed for early or pre-presbyopes and have an addition power range of 0.30D to 1.25D, usually determined by the age of the wearer. Similar to degressive lenses, as the change in power across the lens is relatively low, the benefit of this design to the wearer is a wide field of view, with a minimal amount of surface astigmatism (Fig. 14-5).

Ideally these lenses are ordered to allow for edging with the specifying monocular pupillary distances pupil height, otherwise manufacturers tend to default vertical positioning to the horizontal centre line of the frame. To ensure the wearer receives the full benefit of the low powered addition in the lower portion of the lens, manufacturers state minimum fitting heights of between 14 and 20 mm and a minimum frame depth in the region of 22–28 mm.

3.5. Specific dispensing considerations

Successful dispensing involves selecting a frame, lens type and design suitable for a specific task or occupation, after the application of an appropriate visual task analysis to determine exacting needs of the wearer. This process is not only limited to the optimum refractive correction(s) positioned on the lens in an appropriate manner and maximising the field of view for their particular task. ECPs should also investigate the visual behaviour of the wearer, such as habitual gaze, head tilts and eye/head movements [272]. Other considerations which may impact on vision include physical factors such as the arrangement of the workstation and the environment such as luminance and potential glare sources (workplace ergonomics).

Effective communication is essential to fully understand these visual demands and practitioners should not assume they understand the needs of general occupations – for example, using a computer. Working from home may mean the more traditional office set up is not possible or needed and ergonomics will need further investigation [273]. Similarly, different types of technology, such as tablets, laptops and smartphones bring other visual requirements when the home environment is considered, such as seating position, lighting and glare, along with the duration, gaze direction and specific size of task [274].

Managing patient expectations effectively is also essential. It is often difficult for a patient to also understand why their new increased reading prescription no longer gives the range of useful vision previously experienced. Considering an emmetropic presbyope working in an office environment, a +1.00D addition will give an artificial far point of 100 cm; therefore, single vision reading spectacles would likely be acceptable for a traditional desk and computer arrangement as the working distances required are likely to fall within the 100 cm. When the addition power increases to +2.00D for example, the reduced artificial far point of 50 cm may mean the monitor now becomes blurred with single vision readers, as it now lies beyond the artificial far point and the range of clear vision reduces [257].

It is helpful if the range of vision in a prescribed solution could be demonstrated or simulated for a patient at the time of dispensing so they have experienced the advantages and limitations of recommended products. This will facilitate a more informed choice. Adaptation and satisfaction of a new lens type is often more successful if the wearer has identified a need to overcome a particular issue, such as not wanting to keep moving their head when working on multiple monitors.

For single vision occupational options, the advantage is the widest field of view possible and therefore no need to adapt a particular posture or line of gaze. Single vision lenses constitute the most comfortable option for adopting a reclined pose for a near vision task such as reading on a tablet, if that is the sole visual requirement. The choice of frames may include half readers, that allow for a variable position in front of the pupils. The disadvantages are if the wearer wishes to look further away from the near task, at a distance beyond the artificial far point where the vision will be blurred, and the spectacles will need to be removed and often replaced by a second pair, causing an inconvenience to the wearer. The choice of frames may therefore include half readers, that allow for a variable position in front of the pupils and are easy to look 'above' them.

For bifocal and trifocal occupational options, the advantages are the lack of surface astigmatism and the ability to have freedom in positioning of the segment for certain tasks where the near vision requirement may be in an upward gaze, for example. The disadvantages are potential issues with jumping images at the dividing line and the restriction of only two distinct working distance corrections, which may leave a gap between them.

The advantages of power variation lenses are the potential to offer that continuous range of working distances. Lower addition powers afford a relatively wider visual corridor, which allows the wearer to scan with their eyes over a wider lateral field and less head turning compared to standard progressive addition lens design, often resulting in a fast adaptation to this type of lens. The enhanced range of clear vision also benefits the wearer in terms of physical comfort, obviating the requirement to lean towards the task, or physically move either themselves or their workstation arrangements. Disadvantages of a power variation intermediate/near vision arrangement includes the loss of a useful field for distance vision, hence the inability to walk around and drive whilst wearing these lenses. For those wearers who work in an office environment, social contact with colleagues is also reported to be reduced [275], which could lead to feeling more isolated.

For occupational use, the relatively narrow intermediate portion of the standard progressive addition lens design may mean the wearer needs to turn their head laterally in the transverse plane in order to see clearly – for example, the full width of a monitor. Similarly with lengthy or onerous near vision tasks, the wearer may find they need to make remedial movements by raising their chin upwards in an unnatural position in order to read text in a comfortable manner [275].

One study measured the upward head elevation in degrees to be 17.4 ± 9.2 with progressive lens wearers compared to 12.6 ± 4.0 in computer vision lenses and 10.3 ± 6.1 in single vision wearers [276]. Such remedial movements, especially prolonged or constantly repeated over a working day, has potential to put strain on the neck [275,277] and back [278].

As well as the potential physical strain to the body, the eyes can suffer a range of visual symptoms and ocular complaints, known as computer vision syndrome, although this condition has been more accurately described in the recent literature as digital eye strain. The reported prevalence of digital eye strain of up to 90 % [274] could result in lost working time and an increased risk of potential errors. Computer vision syndrome or digital eyestrain can include dry eye, eyestrain, headaches, diplopia, ametropia and high demand of near work tasks give rise to related accommodation or vergence problems [279].

Previous work has reported that most adults suffering from computer vision syndrome/digital eye strain expressed a preference for a low addition power variation lens of +0.75D if they were working on laptops or a desktop arrangement and fell into the age bracket 20–40 years old [280], whereas others have found symptoms of computer vision syndrome reduced in occupational designed lenses when compared to traditional progressive addition lens designs, especially in emmetropes [281].

In a similar comparison between standard progressive addition and computer vision lenses (degressives) with intermediate ranges of 2–4 m, Jaschinski et al. found that half the participants preferred each option,

demonstrating that the recommendations of products to wearers needs to be individualised, combined with a thorough investigation of the actual tasks, needs, wants and effective communication of the possible solutions [276].

With the vast array of working environments and digital devices now in use, the presbyope will need to compromise comfortable, stable vision if they attempt to solve their visual requirements with one pair of spectacles. Some wearers will not want the inconvenience of changing spectacles for their working environment or hobbies, despite being shown the benefits, and are happy to compromise visual comfort / quality of vision for convenience.

3.6. Comparative performance of spectacle lens options

Despite the abundance of progressive addition lenses on the market, and the advances of freeform technology in the design of progressive addition lens surfaces, the nature of progressive addition lens designs is that there is a relatively narrow intermediate corridor with unwanted surface astigmatism, as the eye moves away from the umbilical line. The unwanted power variation in the periphery of progressive addition lenses have been shown to reduce visual acuity and contrast sensitivity [267], affect depth perception [266], and give rise to unwanted distortion and swim effects [282]. Several studies report that bifocal and progressive addition lens wear increases the risk of falls in elderly people, and it has been argued that older patients who are at high risk of falling and are established single vision lens wearers should not be switched to bifocals or progressive addition lenses [250].

To obtain optimum vision the progressive addition lens wearer has to direct gaze through the appropriate part of the lens, through a combination of eye, head and body movements. These postural adaptations also occur with bifocal lenses to some extent, though horizontal field of view will be greater in this simpler lens design. For single vision near lens wearers, there may also be the need to look over spectacles for viewing distant objects. Thus, progressive addition lenses, bifocals and single vision near spectacle correction are distinctly different in terms of their usage, and recommendation on type of correction will depend on multifactorial reasons including daily viewing habits, occupation, refractive error, near working distance, ergonomics and patient preference.

The widespread use of portable digital technology in the workplace and home life means increased near task demands across a variety of working distances [283,284]. It is therefore perhaps surprising that more research studies are not evident for comparing the performance of progressive addition, bifocal and single vision lens performance for these common and visually demanding near tasks. Wolffsohn and Davies [32], in their review of presbyopia correction strategies, note the paucity of published research studies on spectacle lens designs for ameliorating presbyopia. Those that exist tend to be wearer trials of progressive addition lenses conducted by industry and focused on subjective patient preference and acceptance. Nevertheless, there have been a number of studies investigating the impact of different modalities of spectacle correction for presbyopia on near tasks, specific vocations, and driving. These are summarised below, with the majority of literature focused on progressive addition lens performance.

3.6.1. Comparison of presbyopia spectacle corrections

In the 1980s and 1990s, a few studies compared progressive addition lenses with bifocal and single vision wear, as progressive addition lenses began to be the multifocal lens of choice for presbyopia correction [285–288]. A consistent finding was the overwhelming general preference for progressive addition lens wear, providing they were correctly fitted and participants had opportunity to adapt to wear. For example, in a large-scale study utilising ECPs across the USA to recruit 1713 presbyopes, 85 % preferred newly prescribed progressive addition lenses over existing presbyopic corrections [289]. Other work reported that when 265 existing bifocal wearers were given a new progressive

addition lens, and after a period of wear 92 % subjectively preferred this new product [290].

More recently, the performance of newer generations of progressive addition lenses have been compared with older designs [291,292]. One study compared performance of a free-form progressive addition lens with conventional progressive addition lenses (both Zeiss) on 95 presbyopic participants in a randomised double-masked crossover trial [282]. They tested visual function with standard clinical tests of visual acuity, bespoke tests of off-axis performance, and subjective patient preference. While little difference was found between lenses in conventional visual acuity measures for distance and near, off-axis low contrast near visual acuity and the horizontal extent of near viewing were significantly better with free-form progressive addition lenses after one week of wear. Subjectively, patients also preferred free-form progressive addition lenses, particularly for mid-range, transitional and distance viewing. A 2017 study compared free-form personalised lens performance (Rodenstock Impression Freesign3) with a conventional progressive addition lens in 51 presbyopic participants, and found 82 % preferred the personalised design, and reported more visual comfort and improved near vision [293].

3.6.2. Performance of progressive addition lenses for specific tasks

There have been a number of studies interested in the impact of multifocal correction on occupational tasks, such as aviator target detection [294], vehicle driving performance [295] and computer and near tasks [276]. Military and aviation fields have had particular interest in the potential impact on performance of progressive addition lens and bifocal wear while engaging in demanding tasks, but current recommendations are that progressive addition lens and other multifocal corrections are acceptable for adapted wearers. Such lenses were deemed to be advantageous for the transitional viewing required from distance to intermediate/near viewing of cockpit/vehicle instrumentation [296].

One study compared the performance of progressive addition lenses and single vision for different intermediate tasks for 30 presbyopic participants, 13 of which had not worn progressive addition lenses before [297]. Participants were fitted with single vision lenses for intermediate task distance (64 cm), and conventional 'industry-standard' progressive addition lenses. Those tasks which required the individual to move their gaze outside the intermediate corridor of vision in the progressive addition lens increased the task completion time significantly compared to a single vision lens. This was evaluated by directing participants to view data in a large spreadsheet and asking them to direct their gaze to different areas in the computer screen. However, for other conventional reading tasks, it was found that participants adapted to the relatively restricted intermediate view through progressive addition lenses, with no difference in task performance compared to intermediate single vision lenses.

One study investigated the impact of different presbyopic vision corrections on driving a vehicle [295]. They recruited 11 presbyopic drivers, naïve to multifocal contact lens or progressive addition lens spectacle use, who had only worn single vision reading spectacles previously. Participants were fitted with multifocal contact lenses, monovision contact lenses, progressive addition lens and single vision distance spectacles. After a brief adaptation period, participants completed a closed-circuit driving course with a range of visual corrections in a randomised order. The project recorded a range of parameters, including lane keeping, time to complete the course, recognition of traffic signs and dashboard viewing (using distance and near recognition tasks respectively). Participants were found to be significantly slower to complete the course with multifocal contact lenses. The spectacle progressive addition lens performed well, with no detrimental effect to lane keeping. For the near recognition task conducted while driving, participants took significantly longer with a single vision distance lens correction.

With the increasing use of navigation aids and additional in-car technology, ensuring that individuals are quick to visualise and interpret this information will be important. Thus, despite the negative associations with progressive addition lenses and peripheral blur, progressive addition lenses were deemed to be not detrimental to driving performance.

3.6.3. Approaches for assessing progressive addition lens performance

3.6.3.1. Eye and head movements.
Advances in eye tracking systems now mean that postural and eye movements can be examined in detail, and this has been applied to progressive addition lens spectacle wear to study the natural reading positions individuals adopt [298]. One project reported that the characteristics of user eye movements were distinctly different for those that preferred a 'hard' design of progressive addition lenses, with fewer fixations and less regressions, compared to those that preferred a 'soft' progressive addition lens [299].

Other work has examined the relationship between head and eye movements in presbyopic participants [300], evaluated gaze declination, posture and neck and shoulder musculoskeletal issues [301]. A separate study assessed the optimum position of visual display units by measuring the vertical areas of clear vision for a general-purpose progressive addition lens design in 22 presbyopes, and recommended that the top of visual display unit is placed 15 cm below eye level at a viewing distance of 75 cm [302].

Overall, these studies focusing on ergonomic aspects of presbyopic spectacle lens correction often evaluate and compare general-purpose and occupational progressive addition lenses but little work is available evaluating near single vision lenses.

3.6.3.2. Interviews and questionnaires.
The subjective experience of wearers and their perceptions and preference of lens designs remains a common method to evaluate spectacle lens performance for presbyopia. Studies tend to employ bespoke questions to determine this, asking participants to rate their perception of distance/near vision and extent of clear vision for different tasks.

3.6.3.3. Clinical visual assessment.
Many studies have incorporated clinical assessments of visual acuity and contrast sensitivity into lens performance studies, with some creating bespoke techniques and tasks for off axis viewing, and measurement of extent of clear near vision [282]. One such study conducted an in-depth investigation of binocular status of individuals and reported those with greater vergence facility and rate of phoria adaptation demonstrated better adaptation to progressive addition lenses [303]. Other researchers designed a series of images representing different types of common visual activities, to be used as a means to score the judgement of participants of the quality of their vision, yielding an overall metric termed the 'multifocal acceptance score' (MAS-2EV) [304]. This presents a promising means to evaluate visual performance but is yet to be applied in presbyopic populations for a range of spectacle lens types.

3.6.3.4. Optical ray tracing.
Some studies have taken the wearer 'out of the equation' and concentrated on investigating progressive addition lens performance with ray tracing techniques to map and compare optical power changes in different regions of the progressive addition lens. Manufacturers also present such results to ECPs in an effort to demonstrate improvements in next generations of lens design. These are often limited to simple prescriptions, with schematic examples having little to no distance power and a moderate addition. There is also little work investigating progressive addition lens performance with astigmatic prescriptions.

A recent study measured the refractive power profile of three different progressive addition lenses from Essilor, Hoya and Zeiss manufacturers for lenses with an astigmatic component of −2.00DC, both with- and against-the-rule [305]. A Moire-deflectometry-based

instrument was used to measure refractive power, which was mapped against spherical error, astigmatic errors and overall errors. Differences in performance were reported across manufacturers. There was a general trade-off in either higher quality of clear vision for distance or near zones. For all lens types, against-the-rule astigmatic lenses yielded significantly smaller clear near viewing areas.

3.6.4. Conclusions

Overall, despite challenges with off axis blur limiting peripheral clarity, progressive addition lenses remain a popular means of correcting presbyopia via spectacle wear. A recent systematic review and *meta*-analysis of non-tolerance to spectacle lenses found that the pooled prevalence of non-tolerance cases was 2.1 % (95 % CI 1.6–2.7 %) [258]. While this study was not confined to presbyopic spectacle correction, the main underlying reasons for lack of success with spectacle wear were errors in fitting and dispensing progressive addition lenses, or errors in near spectacle prescriptions. Precise fitting and dispensing of progressive addition lenses, and thorough discussion of adaptation with new wearers, is important to mitigate problems, but other spectacle alternatives, including single vision lenses continue to have a place for specific tasks, emmetropes, anisometropes or those at increased risk of falls.

3.7. Future of contact lens and spectacle correction of presbyopia

The likely future of presbyopic spectacle correction will continue to see enhancements around current progressive addition lens designs such as further efforts to reduce aberrational astigmatism and moves to satisfy the requirements of the range of digital devices used by patients in their homes and offices.

Further developments are also expected in the area of personalisation of spectacle correction for the wearers. This includes the bespoke tailoring of lens design to match daily activities and when taking account of the frame in which the lens will be glazed.

Continued advancements in technologies alternative to the traditional spectacle lens can be found. In an effort to replace the accommodative effect lost in presbyopia, technologies continue to be explored by a number of manufacturers to see how a seamless change in focal power can be presented to the spectacle wearer. This is a complex area and previous commercial attempts to launch a liquid crystal based spectacle lens to overcome some of the disadvantages of current approaches have failed [306]. That said, the Alvarez variable powered spectacle lens design, which adopts a tunable-lens principle to enable a change of lens power by the wearer, has been commercially available in self-adjusting spectacle lens products for a number of years, both for the correction of presbyopia and as a potential solution to support a greater level of refractive correction in low and middle income countries, where access to refractive error correction may be limited [307]. This lens technology is being utilised in virtual reality and augmented reality headset technology, in an effort to improve the overall visual experience of the wearer. Augmented reality is employed in 'smart spectacles' in several industries such as the military, to enable visualisations to be seen overlying real-world vision, and these areas of development continue to see overlaps in adopting technologies. Current limitations on the commercial viability of these technologies and their use in supporting the correction of presbyopia on a large scale are around the logistics of weight and size, as well as likely cost. However, companies continue to be interested in the market which can be evidenced with the patent granted to Apple in 2022 for 'tunable and foveated lens systems' for various ophthalmic applications including the correction of presbyopia [308].

4. Recommendations and future directions

A major finding from this review is the paucity of evidence underpinning many of the decisions which are made around the clinical management of presbyopia with spectacles and contact lenses. The

situation is particularly poor in the area of spectacle correction with very limited information comparing different lens options and the best clinical approaches, both of which could lead to better patient care and product performance. The situation with contact lenses is rather better, with a number of good quality publications supporting clinical practice but even there, more detailed research analyses would be welcome.

In terms of future products, 'accommodating' contact lenses have been described for some years now and do hold the promise of a revolution in presbyopia correction. Such devices may be mechanical or electronic in nature, with the latter option in particular potentially supported by advances in battery technology, micro-electronics and manufacturing improvements brought about in other fields. Improvements in spectacles are likely to be based around the continuing developments in manufacturing leading to enhancements in progressive addition lens designs and perhaps most intriguingly, towards greater levels of personalisation of spectacle corrections to account for individual ophthalmic, optical and activity needs.

Acknowledgement

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