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Bioptic basics for beginners Part 1

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According to the RNIB 2017 report[1] an estimate of prevalence for those living in the UK with sight loss is 2.07 million people. This is predicted to rise by around 30 per cent by 2030 and reach around four million by 2050[2] . For the purposes of that report, the threshold of significant sight loss was defined as, '*A recorded acuity of 6/12 or worse that has a significant impact on their lives*'.

It is well documented that the primary cause of permanent sight loss in the UK is age-related macular degeneration (AMD), followed by glaucoma and diabetic retinopathy (DR)[3] . From the figures published in the RNIB report[1], it is possible to estimate that in 2017 around half a million people were suffering significant vision loss due to AMD and DR. Both AMD and DR can result in central vision loss, which can make it difficult to recognise faces[4], perform reading tasks, use a computer, and discern central detail when watching television, the theatre and concerts, etc[5].

All registered dispensing opticians, not just those with specialist low vision qualifications, are ideally placed to recommend and dispense all sorts of optical aids to this ever-increasing group of individuals. Optical aids could be as simple as a hand magnifier to be used as an adjunct to current spectacles, or more complex telescopic devices.

Figure 1. Zeiss Galilean lens-mounted bioptic telescope

The purpose of this article is to provide an overview of the optical properties, availability and fitting process of bioptic telescopic devices to aid central vision magnification. The optics of bioptic telescopes involving the use of technology is outside the scope of this article.

WHAT ARE BIOPTIC TELESCOPES?

Bioptic telescopes (BTs) are small Galilean (**Figure 1**) or Keplerian (**Figure 2**) telescopes fitted to spectacles in order to provide additional magnification for the central field. Unlike normal telescope spectacle-mounted devices, they are mounted away from the visual axis and require users to make a head or eye movement in order to access the telescope. The telescope may be mounted in front of, on or behind the main 'carrier' spectacle lens, which may be bifocal or single vision.

'Normal' vision is achieved through the carrier lens with additional magnification achieved by either adjusting head posture or position of gaze. The act of moving from the non-magnified image to the magnified image through the telescopic device is referred to as 'translation'.

The use of a BT is analogous to using a rear-view mirror when driving. It is not used for constant viewing, but is used 'on demand' for short periods when further visual information is required.

Figure 2. Ocutech monocular Keplerian lens-mounted bioptic telescope

This article has been approved for 1 CET point by the GOC. It is open to all FBDO members, and associate member optometrists. The multiple-choice questions (MCQs) for this month's CET are available **online only**, to comply with the GOC's Good Practice Guidance for this type of CET. Insert your answers to the six MCQs online at www.abdo.org.uk. After member login, go into the secure membership portal and CET Online will be found on the L menu. **Questions will be presented in random order**. Please ensure that your email address and GOC number are up-to-date. The pass mark is 60 per cent. The answers will appear in the April 2020 issue of Dispensing Optics. The closing date is 12 March 2020.

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3a. Ocutech binocular Galilean telescopes mounted in front of the lens

3b. Ocutech monocular Keplerian bridge-mounted through the lens telescope

Figure 3. Binocular and monocular telescopes

BTs may be fitted monocularly or binocularly (**Figure 3**), and may be permanently fixed or capable of being removed from the spectacles (**Figure 4**). Additional lens caps may be supplied for some models.

Figure 4. Ocutech Galilean removable telescope with additional reading caps

Those that pass through the lens are either mounted on the lens or the bridge of the spectacles. The two most commonly available BTs are based on designs that are fitted in front of, or through, the spectacle lens. Those with an interest in the other variants available are directed to the reading list at the end of this article.

BASIC OPTICAL PRINCIPLES OF BIOPTIC TELESCOPES

Telescopes provide magnification by increasing the visual angle subtended at the eye in order to create a larger retinal image to aid central acuity. **Figure 5** shows an object o, when viewed through a telescope the object would appear to be nearer and is labelled now as h. It is evident from inspection of the diagram that the angle α' subtended by h, forms a larger angle than the angle α, subtended by o. Hence the increase in visual angle produces a larger retinal image h'.

It is helpful to understand the optical and image formation principles of the type of telescopes used in creating bioptics, as this ultimately forms part of the successful selection and fitting process.

It is perhaps easiest to understand the differences between Galilean and Keplerian telescopes by considering a simple construction of each telescope in the afocal setting. In this setting, telescopes are used for distance viewing purposes, and objects at infinity are imaged clearly by emmetropes or corrected ametropes.

Afocal Galilean telescopes in their simplest form consist of two lenses separated by the sum of their second focal lengths (**Figure 6**). The objective lens is a positive power and the eyepiece lens is a negative power. The object at infinity forms a virtual, inverted image at the second focal length of the objective lens. The eyepiece lens is placed such that the virtual image formed by the objective lens falls at the first focal length of the eyepiece lens and now acts as the 'object' for the eyepiece lens. The eyepiece lens then forms an enlarged, upright image of the object at infinity. In this setting the magnification of the telescope M_t = -Fe/Fo.

Afocal astronomical telescopes (**Figure 7**) are used as a basis for the design of a Keplerian telescope. Astronomical telescopes consist of two positive lenses separated by the sum of their focal lengths. The object at infinity forms a real, inverted image at the first focal length of the positive objective lens. The eyepiece lens is placed such that the real image formed by the objective lens falls at the first focal length of the eyepiece lens and now acts as the 'object' for the eyepiece lens. The eyepiece lens then forms an enlarged, inverted and laterally reversed image. In this setting, the magnification of the telescope M_t =-Fe/Fo.

For an astronomical telescope to be used to improve central acuity, the device must be fitted with additional elements. Obviously, the final image must be upright and laterally reversed in order to provide useful vision. The additional elements used to re-orientate the image may consist of a series of additional lenses, prisms or mirrors or a combination of these elements. Astronomical telescopes modified in this way are referred to as Keplerian telescopes.

The fact that both designs of afocal telescopes must be separated by the sum of the objective and eyepiece focal length provides a significant limiting factor in the magnification that is achievable, and the telescope tube length that it is viable to physically mount on the spectacle lens.

For this reason, Galilean afocal design BTs readily available in the UK are limited to a maximum power of 2.2x, although higher powers are available from US suppliers. In this instance, the tube length of the telescope is the same as the optical path length of the telescope. This type of design produces a small compact design unit, with a relatively narrow field of view, and low contrast images. It is important to appreciate that Galilean lenses have limited field of view due to the exit pupil of the telescope lying within the telescope. All of these factors are significant when choosing the type of BT that may be most suited to the user's needs.

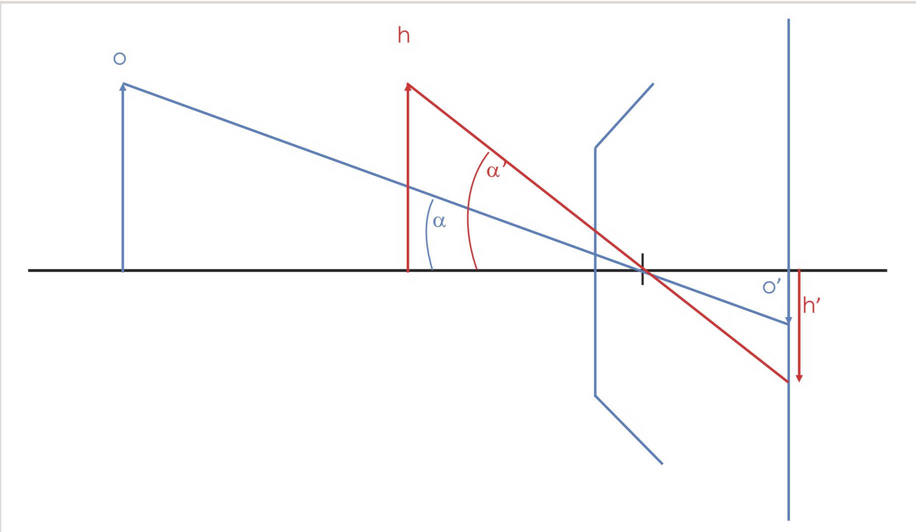

Figure 5. Visual angle

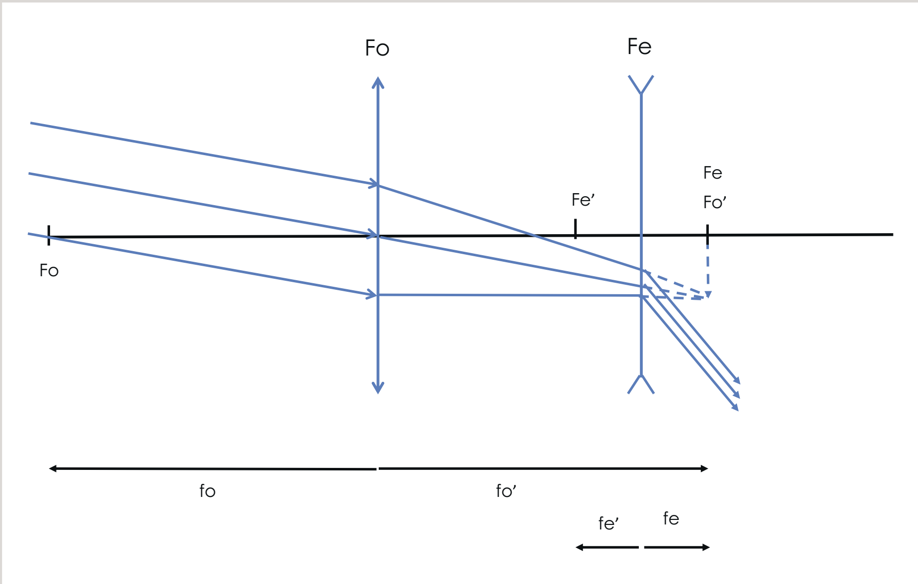

Figure 6. Afocal Galilean telescope

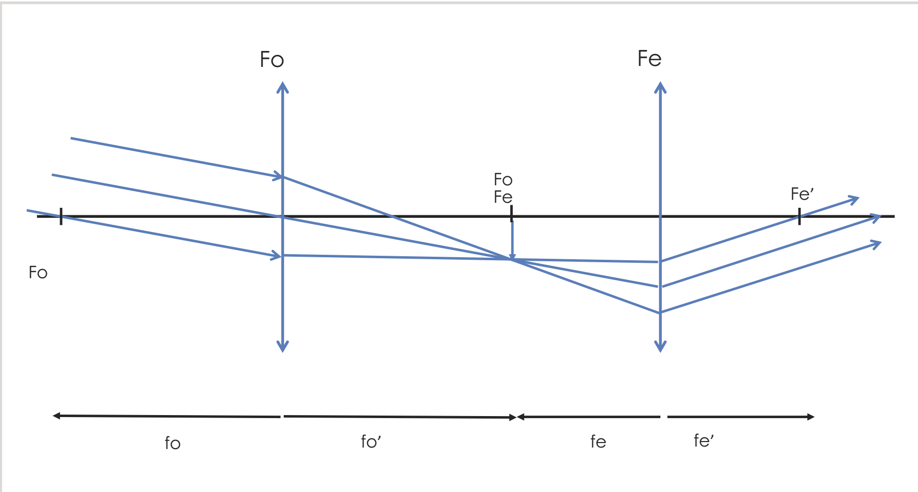

Figure 7. Afocal astronomical telescope

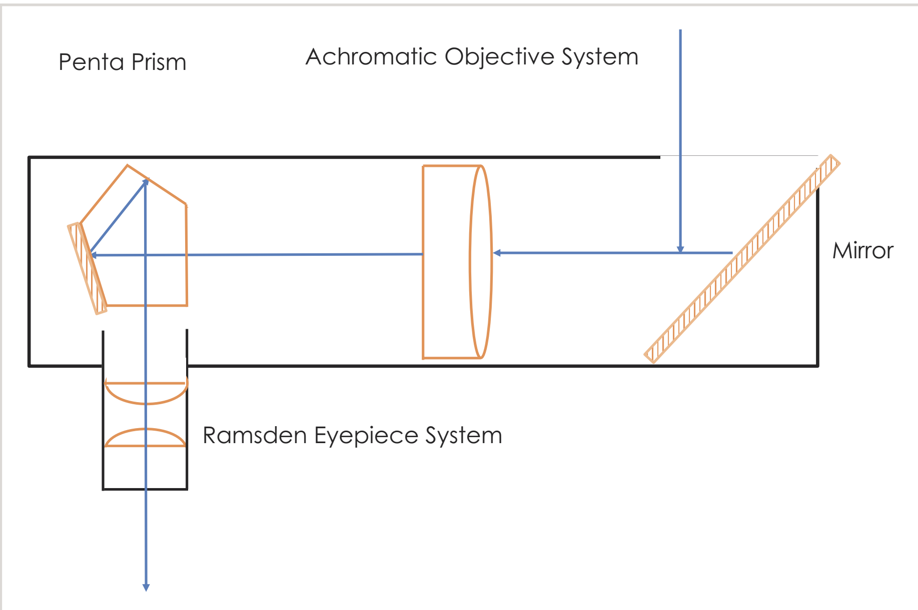

Figure 8. Schematic representation of monocular Keplerian through-the-lens telescope

For users who require more magnification, brighter higher contrast images, and/or a wider field of view then it may be necessary to provide a Keplerian BT. The use of additional reflecting surfaces in the form of plane mirrors and a semi-mirrored prism allows the optical path of the telescope to be lengthened whilst maintaining a wearable tube length. Field lenses may be included within the telescope to widen the field of view by displacing the real exit pupil of the telescope closer to the entrance pupil of the eye. Longitudinal transverse chromatic aberration, spherical aberration and coma may all be reduced or eliminated by the uses of specialist eyepiece lenses, such as Ramsden eyepieces.

Figure 8 illustrates a Keplerian BT similar to one shown in **Figure 3b** that is commercially available[6]. Note the inclusion of a plane mirror and a roof pentaprism. The plane mirror mounted at an angle of 45 degrees is used to deviate the incident light through 90 degrees, thus laterally reversing the image that is incident upon the objective lens.

The simple single objective lens viewed in the basic astronomical design has been replaced with an achromatic doublet. The achromatic doublet is designed to produce refraction whilst eliminating chromatic aberration for two specific wavelengths of light.

A pentaprism is placed between the objective and eyepiece lenses in order to deviate the light through 90 degrees so it is now incident upon the eyepiece lens and ensure it correctly reversed but remains inverted.

The single eyepiece lens described in the basic astronomical model is replaced in this example with a Ramsden eyepiece. It is a combination of two plano-convex lenses, placed with their curved surfaces facing each other, separated by a distance (often two thirds of their common focal length) in order to minimise transverse longitudinal chromatic aberration and widen the field of view. Some designs of BT incorporate more sophisticated image inversion and lens systems but the basic optical principles of the Keplerian system remain the same.

FURTHER OPTICAL CONSIDERATIONS

In addition to aforementioned points, it is instructive to consider further limitations of telescopic systems in order to be able to pre-empt any user difficulties.

Ametropia

The telescopes described so far have all

OPTICAL PROPERTY	GALILEAN BT	KEPLERIAN BT
Magnification	1.7 – 6x	3 – 6x
Image property	Lower contrast	Higher contrast
Exit pupil	Virtual	Real
Field of View	Narrower than Keplerian	Wider than Galilean
Scotoma	Less scotoma than equivalent power Keplerian	More scotoma than equivalent power Galilean
Tube length	Shorter than Keplerian	Longer than Galilean

Table 1. Comparison of general optical principles of Galilean and Keplerian bioptic telescopes

assumed afocal use for emmetropes or corrected ametropes. The consideration of how the telescope is to be mounted is important when considering if ametropic correction needs to be incorporated within the telescope. Generally speaking, any refractive error that is uncorrected results in a blurred image. If a blurred image is then subjected to magnification it can produce lower than anticipated visual acuity results when viewing through the BT.

BTs may be mounted on front surface or back surface of the spectacle lens or through the lens itself. If the BT is mounted on or behind the spectacle lens, no consideration needs to be given to the user's ametropia as this is already fully corrected by their prescription. Telescopes that are mounted behind the spectacle lens are available in other countries but the author has not seen one on the UK market.

However, if the BT is mounted through the lens it is necessary to consider how the ametropia will be corrected. Ametropia can be corrected by either changing the power of either the objective or eyepiece lenses, by glazing supplementary corrective lenses behind the eyepiece or by altering the distance between the objective and eyepiece lenses of the telescope.

If the BT has an adjustable focus, moving the lenses closer together results in divergent light leaving the system, suitable for correcting some degrees of myopia, whilst increasing the separation of the lenses results in convergent light leaving the system, suitable for correcting some degrees of hypermetropia.

Obviously, neither of these adjustments will correct astigmatism and anecdotally it seems that anything less than 2.00DC of astigmatism does not seem to need correction. It is the author's recommendation that visual acuity with and without astigmatic correction is recorded at the BT trial stage, in order to ascertain the effect, or not, of correcting astigmatism.

Use at different distances

It is also worth remembering that BTs with adjustable focus mechanisms may be used to focus at shorter working distances, by increasing distance between the eyepiece and objective lenses, to provide near focus and magnification. This is particularly true of Keplerian designs as they have greater power components than their Galilean counterparts.

BTs without such adjustable mechanisms can be converted for near use with the addition of objective lens caps. The lens cap acts to allow an object to be placed at a near distance, at the first focal length of the cap, and then the emergent vergence from the system is again afocal. In such situations, the magnification of the telescope device overall becomes:

$M_{total}=M_{Bioptic} \times F_{lens\ cap}/4$

Applying lens caps reduces the free working distance of the telescope when compared to adjusting the distance between lenses.

Field of view and scotoma

The field of view gained using telescopes is significantly smaller than many other low vision devices; it is controlled by the shape and diameter of the objective lens. Circular objectives produced circular fields of view, whilst rectangular objectives can be used to make a laterally wider field of view. For the user of the device, the field of view is further limited by the position of the exit pupil of the BT in relation to the entrance pupil of the eye and the size of the user's pupil in relation to the exit pupil of the instrument.

Anything outside the field of view lies in an area of scotoma that is caused by the mounting aperture of the objective lens obscuring the visual field. It is often the scomatic area that causes some challenge for users when trying to locate objects. Comparison of two BTs of 3x magnification have been shown to have, a field of view of 12 degrees and ring scotoma of 44 degrees for one Keplerian design compared to an eight degree field and 38.5 degree scotoma for one Galilean design[7].

Eye relief

It is important to be aware of the distance from the final lens of the eyepiece to the exit pupil of the telescope, known as the 'eye relief' distance. For maximum field of view, the exit pupil of the BT needs to coincide with the entrance pupil of the user's eye. In the simple reduced eye, the exit pupil is calculated to lie 3.01mm behind the single surface cornea and coaxially aligned with the visual axis.

Of course, in the real eye the entrance pupil position is not coaxial and is affected by parameters such as refractive error, angle of light incidence, iris thickness, etc. This often means that theoretical vertex distance fitting gives way to practical experimentation in order to achieve maximum field of view.

Image movement

Images that are enlarged by the use of angular magnification move at faster speeds than those viewed without magnification. The velocity of image motion relative to head motion is magnified by same amount as the magnification of the BT[8]. For example, a head movement that produces a three degree movement of an object in the central field would usually appear to remain stable as a result of the vestibulo-ocular reflex that keeps the image stable on the macula. The same head movement when wearing a 3x BT would appear to move 12 times as fast.

Such increases cannot be compensated for by the vestibulo-ocular system[8] and the mismatch often gives rise to feelings of motion sickness. It is also true that increasing image movement reduces contrast sensitivity and visual acuity[8].

OTHER FACTORS INFLUENCING SUCCESS

Having a good working knowledge of telescope optical properties is not the only consideration that influences a successful BT user experience. An interesting study by Demer *et al*[9] regarding predictors of success with telescopic spectacles, suggests that clinicians reviewing previous clinical records and using their own experience, were able to correctly

FACTORS LIKELY TO IMPROVE SUCCESS/ADAPTION	FACTORS UNRELATED TO SUCCESS/ADAPTATION
Ability to maintain a stable head position[8,9]	
Regular use on a common task[10]	Age[10]
Ease of use[5,13]	Nystagmus
Accepting of visual loss and of others, friendly, tolerant personality type[6]	Monocular or binocular use[10]
Training[11]	
Visual acuities of 6/18 – 6/75[8]	
Moderate contrast sensitivity loss of 1.20 or better measured using Pelli Robson chart[12]	
Eye with better VA is the dominant eye[9]	
Previous use of telescopic aids[13]	
Motivation to use telescope[13]	
Accepting of appearance[13]	
Stable ocular condition	
Lowest magnification resulting in desired visual acuity	
User's entrance pupil is same size or larger than the BT exit pupil size	

Table 2. Factors influencing success with bioptic telescopes

identify around 60 per cent of those who may be successful with telescopic spectacles, and predicted with a 100 per cent accuracy, users that are likely to be unsuccessful.

The outcome of their research appears to have been unable to identify sole predictive factors for success. This seems entirely appropriate given the complex nature of vision loss and human behaviour.

Author experience and research studies have found a number of other factors that may be related, or not, to success with telescopic spectacles (**see Table 2**). Anecdotal opinion gives rise to the idea that most practitioners feel that a gain of three lines of acuity is an acceptable result, coupled with the minimum magnification necessary at the required working distance, if it is sufficient to achieve the desired goal.

SUMMARY

The aim of this article was to provide an overview of bioptic magnification, refresh optical knowledge of the principles of telescopic magnification, and to consider additional factors that may influence users' successes with bioptic aids. Part two will use this theoretical foundation as a basis for understanding how to select and fit such aids including how to train users to gain the maximum benefit from bioptic telescopes.

ABI GRUTE has worked in optics for more than 30 years, mostly as a dispensing optician in independent practice. After more than five years as an ABDO College lecturer, she left to head the training and development department of a large independent optical group. In 2011, she went on to study optometry at City University. She has sat as an ABDO board member, General Optical Council Fitness to Practise Committee member, distance learning course author, CET review panel member and Worshipful Company of Spectacle Makers (WCSM) principal examiner. In 2018, she was awarded the WSCM Outstanding Service Medal in recognition of her service to the Education Committee. Abi continues to serve as an ABDO practical examiner and principal examiner for optics in the ABDO Low Vision Honours course.

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FURTHER READING

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