Calibration of Adjustable Focus Telescopes for Near Vision

Tadaaki Tanabe [1], Hiroshi Uozato [2]

[1] Welfare Center for the Blind, Nippon Lighthouse

[2] Graduate School of Medical Science, Kitasato University

Low vision aids used for the near point may be either simple plus lenses or telescopes focused for near. Krefman[1] reported that a near vision telescope had a longer corresponding working distance than a simple plus lens of the same equivalent viewing power (EVP). Bailey suggested that there are three different methods by which a telescope can be focused for near vision: 1) Adding positive power to the objective lens. 2) Adding positive power to the eyepiece lens. 3) Increasing the tube length[2]. Method 2) is not a useful method compared to the other two because the resultant power of the system results in less than the power of the addition, which makes the telescope a minifier.

Increasing the tube length of an adjustable focus telescopes can provide focus for many different working distances, however, it is difficult to determine the EVP. If the EVP were known, a telescope could be manipulated just like a simple plus lens, and clinicians could select effective aids for the near task by comparing the working distances. Reich developed a method to select the telescope with a suitable working distance and the EVP using a nomogram[3].

From the point of view of convenience for clinicians, telescopes labeled with the EVP and the working distances would be more useful than a nomogram to select low vision aids. Since present labeling on the body of a telescope by manufacturers is in units of angular magnification[4] only for distance vision, it cannot easily be compared to the magnification of a simple plus lens. This is the reason we have decided to display the calibration of the EVP and corresponding working distance on the body of the tube.

MATERIAL AND METHODS

Common telescopes are made by some manufacturers such as Carton, Kenmax, Zeiss and so on. Some telescopes made by Kenmax already display calibrations only in working distances on the tubes by which users can easily focus (Fig.1). However, the values of magnification corresponding to changes in working distance are not easily known. Thus we included calibrations of the EVP and the working distance on the telescopes.

Fig. 1

Two equations are proposed in order to make the calibration on the tube. One is for the working distance; the other is for the length of calibration or the change of the tube length. The equation of the working distance(*a*) is described as follows where *Fe* is the EVP, *De* is the equivalent power of the objective lens, and *m* is the labeled magnification. The working distance is defined as the distance between the objective lens and the object in this article.

$$a = \frac{m}{F_e} + \frac{1}{D_e} \qquad (1)$$

The equation of the length of calibration (⊿t) according to the changes of the EVP is described as follows.

$$\triangle t = \frac{F_e}{m {D_e}^2} \qquad (2)$$

Derivation of the equations (1)(2) are described by Reich[3].

Therefore, when the power of the objective lens and the labeled magnification are constant, the working distance and the length of calibration can be calculated relative to the EVP. Hereby, how to determine the power of the objective lens is the problem. Even if Reich and Bailey proposed some convenient methods without disassembling the telescope, they contain an error caused by accommodation or an empirical measurement. Thus we decided to separate the object lens from the barrel and measured the anterior and posterior vertex focal power using a lensometer and we measured the thickness of the lens with calipers. Fortunately, the objective lenses of PK-4 and PK-6 made by Kenmax Ltd. were easily disassembled, so we used those two telescopes for the examples to make our calibrations. The equation to get the equivalent power of the objective lens with those factors is derived as follows: where Dn=anterior vertex focal power, Dv=posterior vertex focal power, d=thickness of the lens, D_1=anterior surface power, D_2=posterior surface power, n=refractive index of the material, and De=equivalent power.

$$D_n = \frac{D_1 + D_2 - \frac{d}{n} D_1 D_2}{1 - \frac{d}{n} D_2} \Rightarrow D_2 = \frac{n(D_1 - D_n)}{d(D_1 - D_n) - n} \qquad (3)$$

$$D_v = \frac{D_1 + D_2 - \frac{d}{n} D_1 D_2}{1 - \frac{d}{n} D_1} \qquad (4)$$

Substituting (3) into (4),

$$D_1^2 d^2 D_V - D_1 \left(d^2 D_v D_n + 2ndD_v \right) - n^2 D_n + ndD_v D_n + n^2 D_v = 0 \qquad (5)$$

This expression has the form of a quadratic equation , the solution of which is given by:

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Thus the solution for the quadratic equation (5) are:

$$D_1 = \frac{d^2 D_v D_n + 2ndD_v \pm \sqrt{d^2 D_v D_n \left(d^2 D_v D_n + 4n^2 \right)}}{2d^2 D_v} \qquad (6)$$

Once the anterior surface power(D_1) and the posterior surface power(D_2) are calculated with the substitution of the anterior vertex focal power(*Dn*), the posterior vertex focal power(*Dv*) and the thickness(d), the equivalent power(*De*) of the objective lens is given by:

$$D_e = D_1 + D_2 - \frac{d}{n} D_1 D_2 \qquad (7)$$

RESULTS

Since the anterior vertex focal power(*Dn*), the posterior vertex focal power(*Dv*) and the thickness(d) of the objective lens of PK-4 and PK-6 were measured, the equivalent power(*De*) can be calculated using the equation (6)(3)(7). The values are indicated in Table 1.

Table 1. Anterior and posterior vertex focal power, thickness, equivalent power

	Anterior vertex focal power (D)	Posterior vertex focal power (D)	Thickness (mm)	Equivalent power (D)
PK-4	21.25	22.25	3.5	21.21
PK-6	16.30	17.00	4.2	16.27

Using the equations (1)(2), the relation between the EVP, the working distance and the length of calibration was calculated. The example for PK-6 is shown in Table 2. The values of the shortest working distances were investigated by the following method. By gradually reducing the distance between the telescope and the object at the longest length of the tube, the shortest working distance can be measured when the virtual image can be clearly recognized with a relaxed emmetropic eye at the least accommodation.

Table 2. EVP, working distance and length of calibration for PK-6

EVP (D)	Working distance (cm)	Length of calibration (mm)
0	∞	0.0
2	306	1.3
4	156	2.5
6	106	3.8
8	81	5.0
10	66	6.3
12	56	7.6
14	49	8.8
16	44	10.1
18	39	11.3
20	36	12.6
22	33	13.9
24	31	15.1
26	29	16.4
28	28	17.6
30	26	18.9
32	25	20.1
34	24	21.4

The calibrations should be marked on the tubes according to the calculations. The marking for the shortest working distance of calibrations should be flush with the edge of the objective lens grip at the greatest extension of the tube (Fig.2).

Fig. 2

DISCUSSION

Adjustable focus telescopes for near vision could provide successive EVP. For example, the EVP of the PK-6 varied from 0D to 34D by lengthening the tube as denoted in Table 2.

Since apparent sizes of virtual images of lenses which have the same EVP should be equal, the virtual images of near vision telescopes and the simple plus lens magnifier of the Nikon 16D were taken as examples to ensure the validity of calibrations of the PK-4 and PK-6. Adjusting the calibrations of telescopes to 16D, and setting the objective lenses at the indicated corresponding working distances, the virtual images of the ruler through the telescopes and the magnifier were taken with a digital still camera. All resulting images were cascaded in Fig.3 and recognized as being the same size, which verified the closeness of the calibrations. Using the calibrations on the tubes, the working distances corresponding to the EVP of 16D were revealed as follows: 30 cm for the PK-4, and 44 cm for the PK-6. The working distance of the magnifier of the Nikon 16D was 6.2 cm which was derived from the reciprocal of the dioptric power of 16D. Knowing the variation of working distances in different low vision aids corresponding to the identical dioptric power, an appropriate low vision aid can be selected in accordance with the needed working distance for patients.

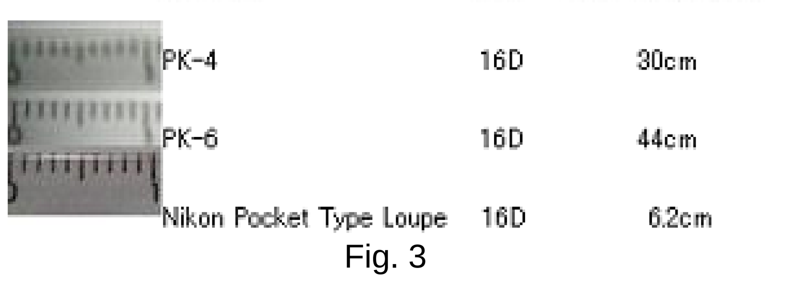

Fig. 3

To select a proper low vision aid for near vision, the equivalent viewing distance (EVD) should be calculated by using a reading chart[5]. The EVP is obtained by the reciprocal of the EVD. The calibration on the tubes of telescopes should be adjusted to the obtained EVP so as to check the corresponding working distances. By comparing the indicated working distances on the tubes, clinicians can easily determine which working distance is closest to the needed working distance for the task and choose the best telescope to use. Take an example of a low vision patient who wants to read newspaper from a distance of about 30 cm. If he/she can read 6M unit of a near vision reading chart at 20 cm working distance, EVD is calculated as 20/6=3.3(cm). Since EVP is given by the reciprocal of 0.033(m), EVP is 30D. In this case the PK-6 is a proper aid because it has 26 cm of working distance which is closest to 30 cm of any of the aids at an EVP of 30D.

CONCLUSION

Calibrations marked on the tube of the telescope for near vision is much more convenient for clinicians than using the nomogram described on the paper when they select low vision aids in the office referring to the needed EVP.

They can easily adjust the tube length according to the EVP and find the appropriate working distance immediately.

ACKNOWLEDGEMENT

The method to calibrate the EVP and the working distances on the tube of an adjustable focus telescope for near vision has a patent pending in Japan.

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