Full title: HAND-HELD PHOTOREFRACTOR – READING REFRACTION FROM THE DISTANCE BETWEEN THE EYE AND THE LIGHT SOURCE

Short Title: Hand-held Photorefractor

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Abstract

Purpose. Conventional photorefractors applying either camera or video have fixed distance between the viewing line and the light source and read the refraction from the size of the crescent. Since the relationship between the crescent size and the refraction is not linear and the resolution at higher refractive error is poor, a hand-held photorefractor was introduced which employed fixed crescent:pupil ratio as endpoint and read the refraction from the varying distance between the eye and the light source. The relationship between the distance and the refraction is linear.

Methods. For ‘axial’ myopia and hyperopia, a simple formula holds that $d_o = \text{Ratio} \bullet \text{Pu} \bullet l_o \bullet R$ where d_o is the distance between the eye and the light source; Ratio is the non-crescent:pupil ratio; Pu is the pupil diameter; l_o is the test distance and R is the refraction relative to the vergence of the test distance. A design of hand-held photorefractor, similar in shape with direct ophthalmoscope and retinoscope, was proposed that by sliding the

light source up and down and looked through a fixed viewing hole for a fixed crescent:pupil ratio, the refraction could be read from a linear scale with good resolution. Oblique astigmatism could be read simply by aligning the instrument with the oblique crescent, no need to rely upon complicated calculation.

Results. With random combination of spherical and cylindrical lenses in front of a model eye I read the refraction blindly with a prototype of this hand-held photorefractor. The result was satisfactorily accurate.

Conclusions. A practical hand-held photorefractor was designed, with which the refraction could be read on a linear scale with good resolution, and the axis of oblique astigmatism could be determined by simply aligning the instrument with the tilted crescent.

Introduction

Pediatric refraction, despite technology advancement, is still a crucial clinical challenge. Autorefractor is accurate, but it is only applicable to children older than 2 year-old. Refracting children under 2 year-old depends mainly upon retinoscopy. Putting neutralizing lens or the retinoscopic rack near the children's eye is a major practical barrier of this technique. Photorefraction can refract at a distance from the children[1-3]. It is nevertheless not accurate enough. How to increase its accuracy and convenience is an ongoing hot topic nowadays.

Photorefractor is mostly operated by paramedical personnel to screen amblyogenic factors before referring to ophthalmologists/ optometrists for further evaluation. Retinoscopy remains the most accurate measure which most ophthalmologists/optometrists rely on.

Conventional eccentric photorefractors applying either camera or video have fixed distance between the viewing line and the light source and read the refraction from the size of the crescent[1,2,4-7]. The relationship between the crescent size and the refraction is not linear and the resolution at higher refractive error is poor. I introduced a hand-held photorefractor employing fixed crescent:pupil ratio as endpoint and reading the refraction from the varying distance between the eye and the light source. The relationship between the distance and the refraction is linear.

In this study, a novel refractor was designed employing the optical principle of photorefractor, with its appearance simulating that of direct ophthalmoscope and its operation mimicking that of retinoscope. Since it is operated on a clinical basis, at a distance from the children and without the need of neutralizing lens, I think it will help opthalmologists/opthometrists to refract young children more facilely

Materials and Methods

For ‘axial’ myopia and hyperopia, a simple mathematical formula holds:

$$d_o = \text{Ratio} \bullet Pu \bullet l_o \bullet R$$

I derive it with the notations illustrated as following (Fig.1,2,5,6),

d_o : distance between the eye and the light source. d_o stands for ‘distance at object space’. ($d_o \geqq 0$)

d_i : distance between the images of the eye and the light source at the conjugate plane. d_i stands for ‘distance at image space’. ($d_i \geqq 0$)

l_o : distance between examiner and examinee. l_o stands for ‘length at object space’. ($l_o > 0$)

l_i : distance between the conjugate plane and principle plane of the eye. l_i stands for ‘length at image space’. ($l_i > 0$)

Pu : pupillary diameter. ($Pu > 0$)

P : power of the refractive components of the eye. ($P > 0$)

R : refraction ‘relative to the vergence at test distance’. For example: The vergence is -2D at 50 cm test distance. Then R = -1 for -3D myopia ((-3) - (-2) = -1) and R = +2 for emmetropia (0 - (-2) =

2).etc..

x : the distance between retina and conjugate plane. ($x > 0$ for $P < 0$ and $x < 0$ for $P > 0$)

a+b : the retinal area representing the whole pupil the examiner sees.

a : represents non-crescent part of the pupil. ($a > 0$)

b : represents the crescent part of the pupil. ($b \geqq 0$)

b+c : the image (blurred) of the light source on the retina.

$\text{Ratio} = \dfrac{a}{a + b}$: proportion of non-crescent part of the pupil.

From Newton’s geometric optics, variables at image side, l_i, d_i and x, were represented by variables at object side (Fig. 1,2,5,6):

Fig 1,2 about here

$$\frac{1}{l_o} + \frac{1}{l_i} = P \quad \rightarrow \quad l_i = \frac{l_o}{P \bullet l_o - 1} \qquad \text{eq.(1)}$$

$$\frac{d_o}{l_o} = \frac{d_i}{l_i} \quad \rightarrow \quad d_i = \frac{l_i \bullet d_o}{l_o} = \frac{d_o}{P \bullet l_o - 1} \qquad \text{eq.(2)}$$

$$\left(\frac{1}{l_o} - R\right) + \frac{1}{l_i + x} = P$$

$$\rightarrow \quad x = \frac{l_o}{l_o \bullet P + l_o \bullet R - 1} - \frac{l_o}{P \bullet l_o - 1} \qquad \text{eq.(3)}$$

For myopic eye, i.e. relatively more myopic than the vergence of the test distance, $R<0$ ($x>0$), from Fig.1

$$\begin{cases} \dfrac{a}{d_i} = \dfrac{l_i + x}{l_i} \\ \\ \dfrac{a+b}{Pu} = \dfrac{x}{l_i} \end{cases} \rightarrow \text{Ratio} = \frac{a}{a+b} = \frac{d_i \bullet (l_i + x)}{Pu \bullet x}$$

Applying eq. (1), (2) and (3)

$$\mathrm{Ratio} = \frac{a}{a + b} = \frac{do}{- Pu \bullet l_o \bullet R}$$

$$\rightarrow \quad d_o = - \mathrm{Ratio} \bullet Pu \bullet l_o \bullet R \qquad \text{eq.(4)}$$

For hyperopic eye, i.e. relatively more hyperopic than the vergence of the test distance, R>0 (x<0), from Fig.2

$$\begin{cases} \dfrac{a}{d_i} = \dfrac{l_i + x}{l_i} \\[2ex] \dfrac{a + b}{Pu} = \dfrac{- x}{l_i} \end{cases}$$

Similar to the derivation of eq.(4) we get

$$d_o = \mathrm{Ratio} \bullet Pu \bullet l_o \bullet R \qquad \text{eq.(5)}$$

Eq.(4) and (5) show that, for axial myopia and hyperopia

R is directly proportional to d_o

R is inversely proportional to Ratio

R is inversely proportional to	Pupil diameter
R is inversely proportional to	Test distance
R is irrelevant to	Refractive components of the eye

For example:

If pupil is dilated to have 8mm diameter, test distance is 50cm and ¼ crescent:pupil is used as endpoint of reading,

$Pu = 8 \text{ mm} = 0.008 \text{ m}$

$l_o = 50 \text{ cm} = 0.5 \text{ m}$

Ratio = ¾ = 0.75 (¾ non-crescent and ¼ crescent)

then $d_o = 0.75 \bullet 0.008 \bullet 0.5 \bullet R = 0.003 R$

i.e. Every 3 mm of d_o corresponds to 1D of refraction. And with 4.8 cm range of d_o it measures -18D (R=-16) to 14D (R=16)

Alternatively, if disappearance of crescent is used as endpoint of reading,

$Pu = 8 \text{ mm} = 0.008 \text{ m}$

$l_o = 50 \text{ cm} = 0.5 \text{ m}$

Ratio = 1 (all non-crescent and no crescent)

(limiting condition whereby crescent disappears)

then $d_o = 1 \bullet 0.008 \bullet 0.5 \bullet R = 0.004\,R$

i.e. Every 4 mm of d_o corresponds to 1D of refraction. And with 4.8 cm range of d_o it measures -14D (R=-12) to 10D (R=12)

Practically, Ratio = ¾ (¾ non-crescent and ¼ crescent) may be easier to detect than Ratio = 1 (no crescent, disappearance of crescent) as the endpoint of reading, despite that the latter has better resolution than the former, i.e. 4mm for 1D vs. 3mm for 1D.

From the fact that R is directly proportional to d_o, a hand-held photorefractor (Fig. 3) similar in shape to direct ophthalmoscope and retinoscope was designed. By sliding the light source and prism up and down, the distance between examiner’s eye and the light source varied within a range of 5cm. With a fixed crescent:pupil ratio as the endpoint, the refraction could be read on a linear scale up to 10^{+}D on either myopia or hyperopia side. The resolution was also practically adequate, i.e. 3-4mm for 1 diopter.

Fig. 3 about here

Oblique astigmatism gives tilted crescent. Conventional photorefractors measure the refraction along two or three fixed meridians and calculate the power and axis of oblique astigmatism through complicated formulas[8,9]. This results in even more inaccuracy upon a basis of pre-existed inaccuracy of the technique of photorefraction[10]. Hand-held photorefractor reads oblique astigmatism by simply aligning the instrument with the oblique crescent and gets the power at two major axes.

Results

A prototype of this hand-held photorefractor was made and tested on model eye. The model eye was set at emmetropia and in front of it I blindly put two lenses which were selected from a pool of -6D to +6D spherical and -6D to +6D cylindrical lenses. Since the resultant spherical power and the power and axis of cylinder could not be straightforwardly figured out. I read the refraction with hand-held photorefractor first and later on calculated the resultant refraction with computer to see the goodness of fit. The result was satisfactorily accurate.

Discussion

Despite an ophthalmoscope is not a retinoscope[11], it is optically a photorefractor. Ophthalmoscope makers tried to make light path and viewing line coaxial for small pupil examination. But most ophthalmoscopes actually have small distance in between, which mimics the optics of photorefractor (Fig. 6). This is obvious if we observe model eye at a distance with ophthalmoscope and continuously change the refraction of the model eye from minus to plus. We will see the whole spectrum of the photorefraction, including the dark zone.

Fig. 4 about here

Calculation of dark zone:

The limiting condition of photorefraction, i.e. at the margin of dark zone, is when Ratio = 1 or b = 0 (Fig. 5,6), then

$$d_o \quad = \quad Pu \bullet l_o \bullet R$$

or $$R = \frac{d_o}{Pu \bullet l_o} \qquad \text{eq.(6)}$$

Fig.5,6 about here

The dark zone is from $\left(\frac{-1}{d_o} - R\right) D$ to $\left(\frac{-1}{d_o} + R\right) D$

with a range of 2 • R (at limiting condition),

which is directly proportional to d_o,

inversely proportional to Pu,

inversely proportional to l_o.

For example:

If $d_o = 1$ mm = 0.001 m,

Pu = 8 mm = 0.008 m and

$l_o = 50$ cm = 0.5 m,

then $$R = \frac{0.001}{0.008 \bullet 0.5} = 0.25\ D$$

The dark zone is from -2.25 D (-1 / 0.5 - 0.25) to -1.75 D (-1 / 0.5 + 0.25).

Crescent size vs. refraction, with d_o fixed, in conventional photorefraction:

Conventional photorefractors employ fixed d_o and read refraction from crescent size or the crescent:pupil ratio.

$$\text{From eq.(5)} \quad \text{Ratio} \bullet \text{R} \quad = \quad \frac{d_o}{\text{Pu} \bullet l_o}$$

The relationship between Ratio and R is hyperbolic, and the curve of crescent:pupil ratio (1-Ratio) vs. refraction, which is often depicted in conventional photorefraction, is non-linear (Fig. 7). This curve has good resolution at lower refractive error but poor resolution at the plateau of higher refractive error[8].

Fig. 7 about here

Eq.(6) and Fig. 7 show that smaller $d_{o,}$ larger pupil and longer test distance lessen the dark zone, increase the resolution at lower refractive error and decrease the resolution at higher refractive error. On the contrary, larger $d_{o,}$ smaller pupil and shorter test distance increase the dark zone, yet may increase the resolution at higher refractive error[8].

One difference between spot and linear edged (such as photoflash) light source is that when the pupillary light reflex is small (non-crescent Ratio > ¾), the latter is really crescent-shaped, but the former makes dome-shaped.reflex. When the reflex is large (non-crescent Ratio < ¼), either light source makes dome-shaped reflex[12].

In conclusion, in this study I formulated the optics of photorefraction with spot light source; found the linear relationship between d_o and refraction and suggested this relationship, along 5 cm range of d_o, is suitable for hand-held photorefraction, and must be superior to the non-linear relationship between crescent size vs. refraction, which was used in most conventional photorefractors.. With its hand-heldness, the oblique astigmatism could be simply measured by aligning the instrument with the tilted crescent.

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Legends

Fig. 1 Refraction sketch for R<0, i.e. relatively more myopic than the vergence of the test distance ($-1 / d_o$).

Legends

Fig. 2 Refraction sketch for R>0, i.e. relatively more hyperopic than the vergence of the test distance ($-1 / d_o$).

Legends

Fig. 3 Design of hand-held photorefractor. The examiner’s eye and light source are of equal distance to the examinee’s eye. This is achieved by sliding the prism (or mirror) and light source together to keep constant distance between light source and the examinee. To adjust d_o by sliding the prism up and down is a maneuver similar to retinoscopy where we slide the lens or light source up and down to change the vergence.

Legends

Fig. 4 Direct ophthalmoscope is itself a photorefractor. The light path and the visual line are not completely coaxial. The optics mimics that of photorefractor.

Legends

Fig. 5 Limiting condition for R<0, i.e. a condition at the border of dark zone.

Legends

Fig. 6 Limiting condition for R>0, i.e. a condition at the border of dark zone.

Legends

Fig. 7 The relationship between Ratio (non-crescetn:pupil) and R is hyperbolic, and the relationship between crescent:pupil (1-Ratio) and refraction is non-linear. This curve is often depicted in conventional photorefraction.

Figures

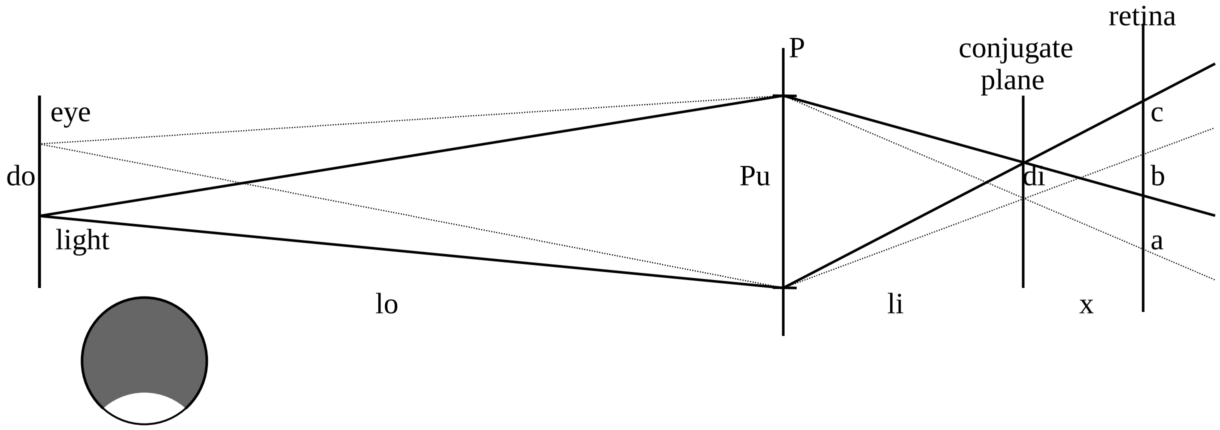


Fig. 1 Refraction sketch for R<0, i.e. relatively more myopic than the vergence of the test distance ($-1 / d_o$).

Figures

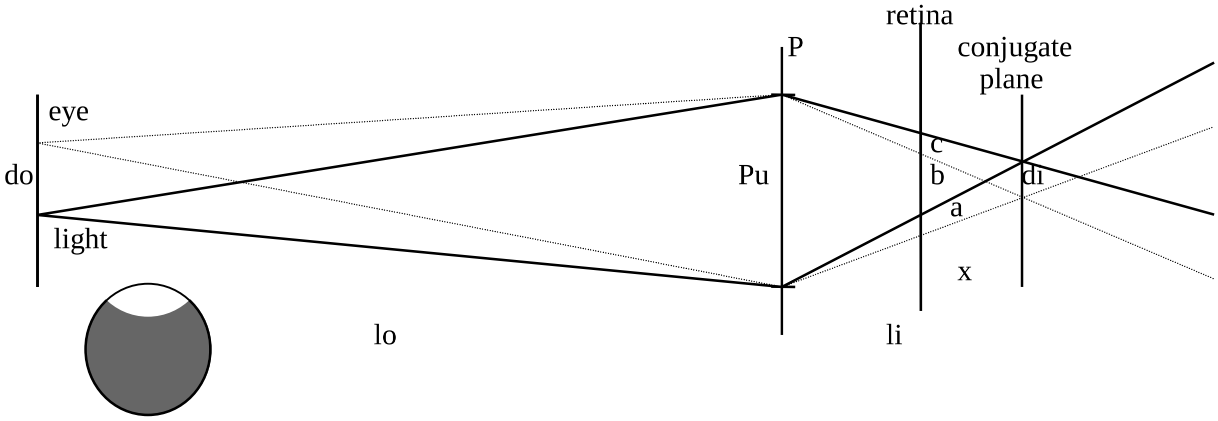
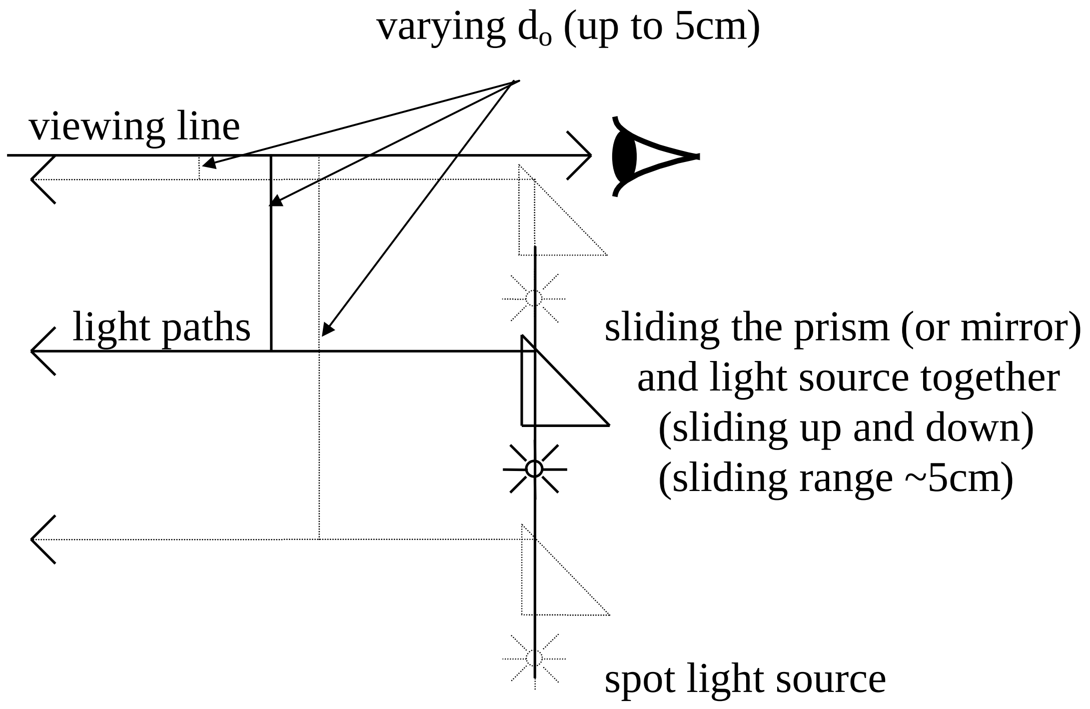


Fig. 2 Refraction sketch for R>0, i.e. relatively more hyperopic than the vergence of the test distance (-1 / d_o).

Figures



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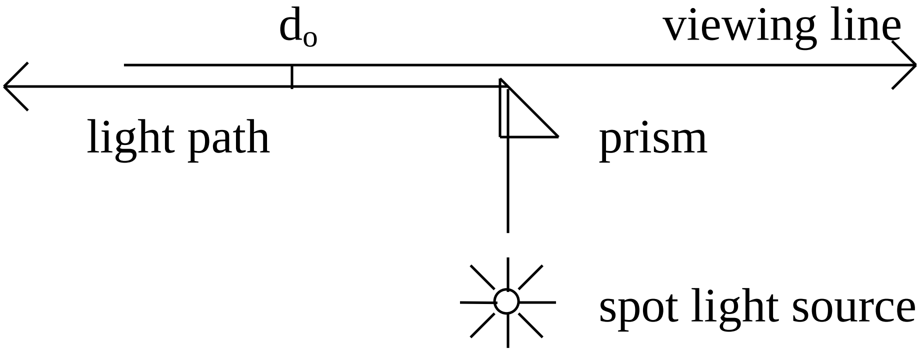
Figures



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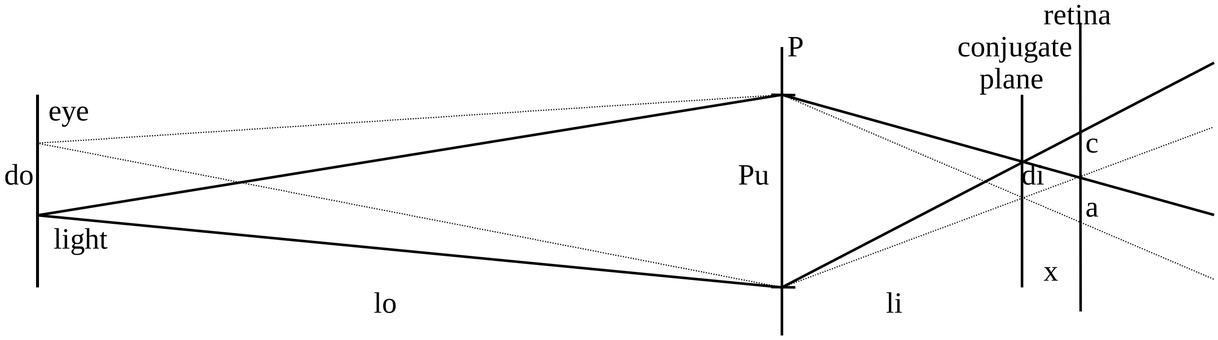

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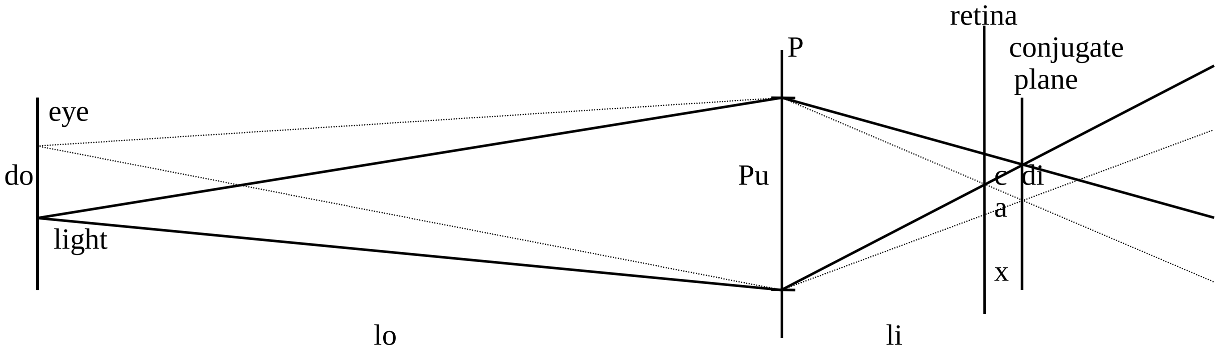
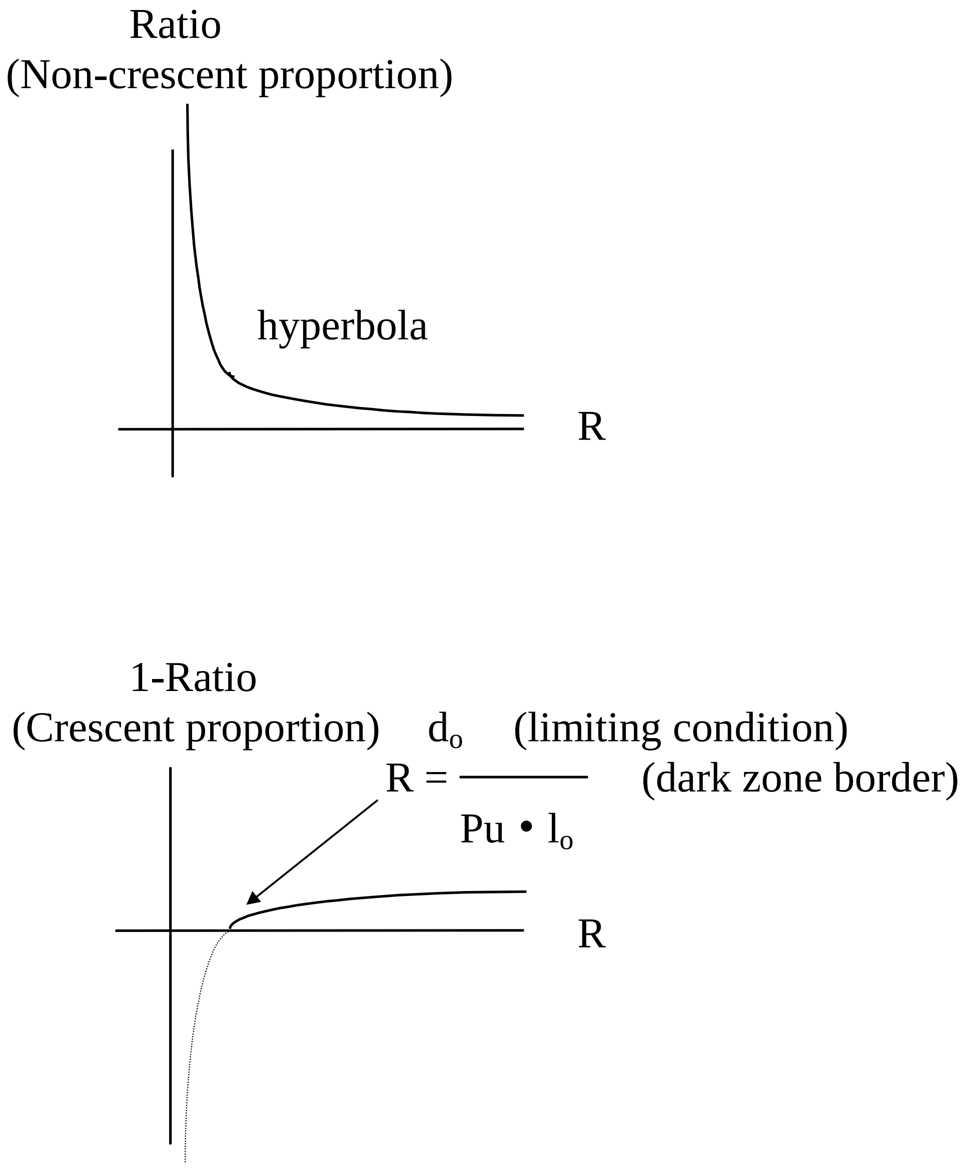


Fig. 6 Limiting condition for R>0, i.e. a condition at the border of dark zone.

Figures



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