Emmetropia – The perfect imperfection

Emmetropia is the basis of our understanding of the ocular optical system. When we are referring to an emmetropic eye, we are thinking of an eye with a perfect optical system. The definition of emmetropia in the most acknowledged dictionaries (Merriam Webster dictionary, British dictionary, Dictionary.com) is the following “The normal refractive condition of the eye in which with accommodation relaxed parallel rays of light are all brought accurately to a focus upon the retina.”

To understand the real meaning of “normal refractive condition,” a couple of questions need to be answered;

• Does the “normal refractive condition” mean that “parallel rays of light are all brought accurately to a focus upon the retina” as the dictionaries mention?
• What is the relevance of the following terms; “perfect vision,” “eagle vision,” “super vision,” “40/20,” “aberration-free system” with emmetropia?
• Finally, what should be the target refraction for emmetropia?

Let’s have a deeper view of our optical system. The optical system of humans consists of static and dynamic components. Targeting emmetropia in itself is a multifactorial task.

Static Components

Miosis

Miosis increases the depth of focus and reasonable image quality can be achieved. For each subject, the higher the accommodative response, the greater will be the miotic effect, with the relationship being fairly linear [Fig. 1]. However, miosis does not necessarily accompany accommodation and its magnitude is not related to the ciliary muscle contraction [Fig. 2]. Further, small pupil diameters such as artificial diaphragms increase the depth of focus – they reduce the impact of defocus by selecting paraxial rays only [Fig. 3].

Bifocal elements

Bifocal elements rely on the principle that if only a portion of incident light intensity is in sharp focus, sharp edges are formed, the image is perceived as clear and image contrast is reduced [Fig. 4].

Aberrations

Aberrations (in particular spherical aberration) may contribute to the increased depth of focus at the expense of image quality. In a 2 µm spherical aberration system in a 6 mm pupil, the 5/10 letter remains legible for a range of more than 4 D [Fig. 5]. Correcting higher-order aberrations increases peak visual or optical performance, but results in a more rapid loss of performance away from the in-focus condition (Cheng, Bradley, & Thibos 2004; Guo, Atchison, & Birt 2008). In Nature 2001, Susana Marcos stated that “Imperfect optics is the protection against chromatic aberrations.” When the previous quotations are considered, a conflicting concept is observed in an ophthalmic correction – when to perform correction of higher-order aberrations to improve in-focus vision versus, when to deliberately increase the aberrations so that the rate of deterioration of the quality of vision away from best focus is reduced? [Fig. 6]. The question may be answered by adaptive optics. Adaptive optics systems can offer personalized correction with the latest developments such as incorporating a Hartmanshock sensor in phoropters [Fig. 7].

Dynamic Components (Optical and Ocular)

Optical dynamic components

Optical dynamic components are mostly related to the stability and accuracy of the accommodative response. Regarding the stability of accommodation, the following characteristics should be considered; rapid changes (fluctuations) in response, smaller amplitude (highest stability) at infinity, and considerable variation among subjects, in both the magnitude and in their changes with target vergence. Spherical aberration (c40) moves to negative values with accommodation (but there is a significant inter-subject variation), whereas coma-like aberrations (c3-1) (c31) on an average change to positive values. These are probably attributed to changes in lens shape and lens position during accommodation (Drexler et al., 1997; Roorda & Glasser, 2004) [Fig. 8].

Regarding the accuracy of accommodative response, there is over-accommodation (lead) for distant targets, under-accommodation (lag) for near targets, and response equals stimulus vergence at about -1.75D [Fig. 9]. Observed changes in aberrations induced by accommodation are about an order of magnitude smaller than those observed in aberration dynamics, which means that the best focus is not the paraxial focus [Fig. 10]. Micro-fluctuations in accommodation have reported frequencies of 2–3 Hz whereas observed changes in ocular aberrations can be up to 70 Hz.

Ocular dynamic components

Ocular dynamic components are a nontrivial combination of ocular movements (saccades), a metabolic process not related to visual function, artifacts introduced by blood flow, or other noise from involuntary eye movements.

In summary, the eye is a dynamic system that scans the subject continuously in 3D and shows complex behavior [Fig. 11]. The dynamics of ocular aberrations are random and so far unpredictable. These dynamics introduce noise when estimating a wavefront and an average of several measurements should always be considered to minimize these effects. There are many other sources of dynamic ocular aberrations like tear film instability error [Fig. 12], none of them are completely well understood. The emmetropic eye should have a great balance of these static and dynamic components to give the best possible vision to the person in different situations. Some aberrations are required for our optical system to maintain the depth of focus, stereopsis, and 3D processing. We call them “commensal aberrations.” If we get rid of them completely, the individual will not be happy with such an optical system.

How Perfect should Refraction be?

To answer the question of how perfect should the refraction be in an emmetropic eye, the term of emmetropia should be understood by analyzing the real meaning of the word and as Antisthenes stated (~445-365 BC) “The principle of wisdom lies in the study of words.” In Dictionary.com, the Neo-Latin equivalent to emmetr- “(stem of Greek émmetros in measure, equivalent to em- em2+ métron (on measure + -os adj. suffix) + -opia -opia Related forms Expand emmetrope, noun.” As Plato quoted in Theaetetus “Antrópos metron” which means “Man is the measure (of all things).” Cleobulus, according to Diogenes laertios stated “Metron Ariston” meaning
“Moderation is the best.” The temple of Apollo at Delphi is also inscribed with the phrase “Miden agan” meaning “Nothing in excess.” The description of “metron” has been described as an imperfection since ancient times by the Greek philosophers.

Imperfection can also be observed in perfect architectural buildings. The world’s first renowned monument “The Parthenon” was built in a way that somebody entering the...
Acropolis space will have the perfect analogical view of all the dimensions. The lines of the columns were shown straight and parallel, the aetoma was a perfect parallelogram, and the three lines were engraved over the head of the columns. From the constructional point of view, many imperfections were used to have this perfect view. The columns were oval and have less space between them from the central to the peripheral part of any side. The aetoma was not parallel and the engraving lines over the columns were slightly shifted so that the last in the row could be adjusted on the external column head [Fig. 13].

And also in the art; the survival of the rural population is now focused on what the Japanese theorist Gianagki Soetsou believes: We must emphasize the importance of the archaic technology and embrace “the Art of Imperfection,” where the manufacturing defects could be “the state of the art,” as the art of the famous artist’s Raku, Soratsou, and Korin.
With regards to the question, what should be the target refraction of an emmetropic eye, the answer should be firstly related to the patient’s needs. If we can understand the needs of any human being in his specific life environment and profession then probably we may customize his refraction targeting “his emmetropia” which will be by considering static and dynamic systems at work, of course as much as possible with the existing technology. In these corrections, we will be targeting both lower and higher-order aberration corrections to suit the person’s needs. Because we are not far from the day when alternatively we can work on the different emmetropic models that are closer to the patient’s needs. Speaking about needs means that we should spend more time to understand the patient, his requirements, and his optical system to achieve his/her emmetropia. We also need to educate them when they have the wrong expectations.

Wavefront, adaptive optics and ray-tracing technologies are very helpful to know our optical system. Customized optical solutions are available to a certain degree, either with a premium intraocular lens (IOL) or advanced refractive surgery. Fortunately, the human brain is very adaptive and what we realize in our everyday practice is that patients do accept a loss of a certain degree of a perfect image in favor of a better functional vision for their lifestyle.

The definition of emmetropia should be rewritten based on the ancient knowledge of the world which also reflects the state of the art.

“Emmetropia is the refractive state in a healthy eye in which, any individual achieves the perfect visual function.”

It should always be in our minds what Solon the Athenian stated in one of the seven Sages of Greece “I grow old always learning many things” and Socrates, paraphrased from Plato’s Apology “I know one thing, that I know nothing.”

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Cite this article as: Pallikaris I. Emmetropia – The perfect imperfection. Indian J Ophthalmol 2020;68:2656-9.