The Shape of the Eye:

Why the Eye is Round

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ABSTRACT

The most striking characteristic about the eye is that it is a round, spherical structure. This chapter explores the optical, mechanical, structural, phylogenic, and ontogenic reasons why eyes are round. This exploration is used as a starting point to describe how the different features of the eye are related to each other and how the roundness is maintained by the inflow and outflow of fluid in the eye.

INTRODUCTION

If you look up into the night sky at the constellation of the Big Dipper and have 20/30 or better visual acuity and adequate night vision, you will see that the next-to-the-last-star in the handle of the dipper is actually two stars that are quite close together. One star is brighter than the other. The brighter star is called *Mizar*, and the fainter *Alcor.* It is easy to fall into the trap described by the ancient Arabic proverb that, “He sees Alcor, but not the full moon.” The lesson here is that the most outstanding fact about eyes is not something arcane, but the obvious fact that eyes are round; that is, eyes are spheres. Therefore, this first chapter will focus on the fact that eyes are round. Why should eyes be round? What does it tell us about how eyes are constructed and how they work? Not only is this shape similar in different animals but the variation in size of the vertebrate eye, from tree shrew to whale, is much smaller in proportion than the variation in size of these creatures. I will also describe how different features of the eye (shown in Figure 1) are related to each other and how the roundness is maintained and controlled by the formation, flow, and removal of fluid in the eye.

WHY ARE THINGS ROUND?

When I first thought about the roundness of eyes, I realized I didn’t know why anything was round. So, I made a list of other round objects to help organize my thought process. My list consisted of the sun, the earth, the moon, oranges, frog urinary bladders, basketballs, and rocks. As you can see, the list consists of both organic, animate and inorganic, inanimate objects.

Inanimate Objects

Before we start with the inanimate objects on the list, we first need to understand the concept of *equilibrium*. Consider your textbook, unopened, on a desk. Even though it is static, there are at least two forces at work, making it that way. It is actually in dynamic equilibrium, subject at every instant, to opposing forces which balance it. Gravity is pulling the book down toward the center of the earth. The desk is pushing it up, preventing it from moving. All objects that appear static are actually in this balancing act of opposing forces. If one of the forces were stronger, it would change the object rapidly, until an opposing force balanced it, and then the object would again be at a new equilibrium. Objects change so rapidly when out of equilibrium that we are not likely to catch sight of them during that time.

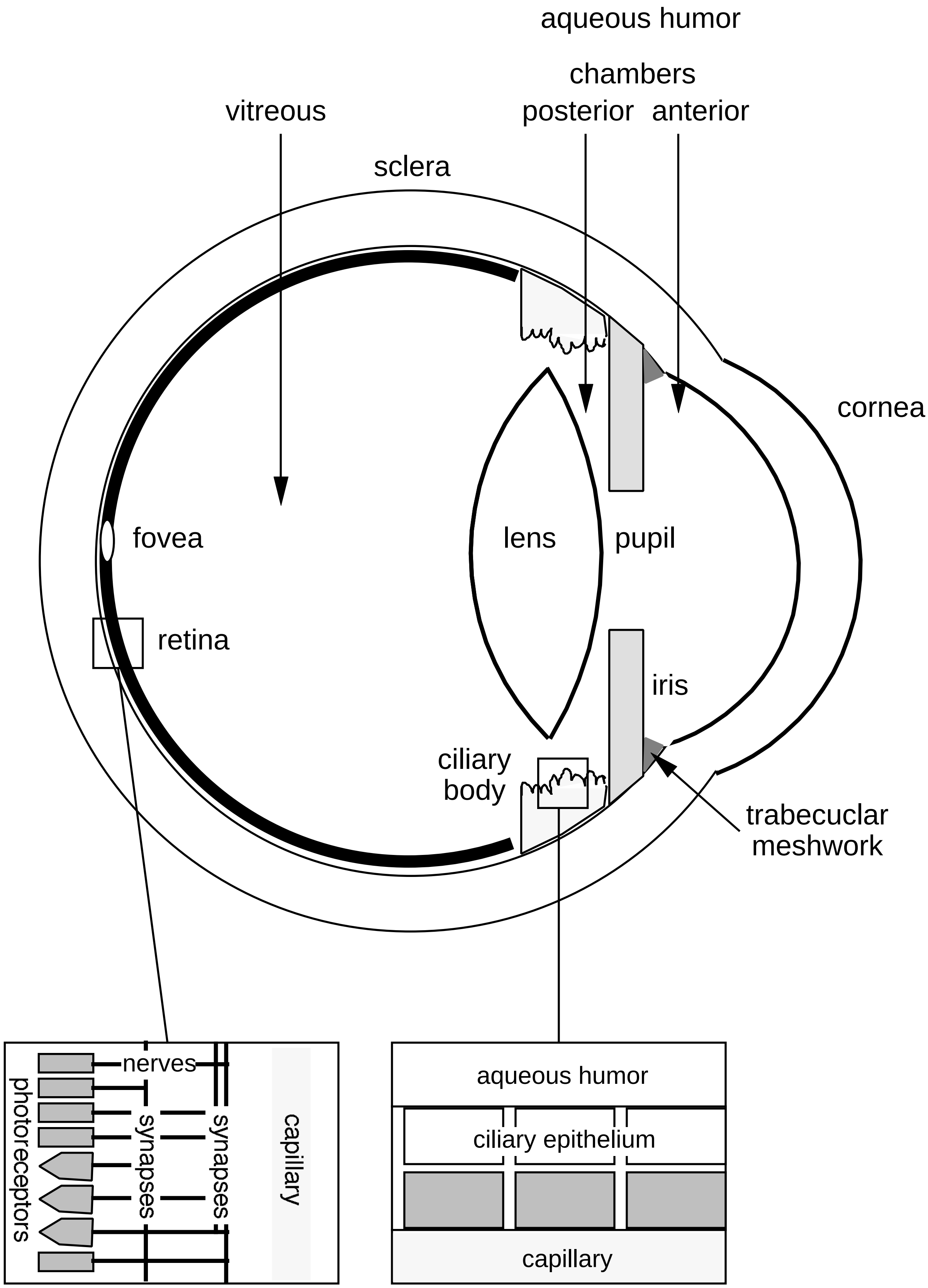
What forces are balancing in these inanimate objects? How do those forces determine the shapes of these objects? In the sun, gravity pulls the gases of the sun together, pushing all its material toward its center. The inward pull of gravity raises the temperature which raises the pressure of the gas in the sun until the outward pressure of the gas balances the inward pull of gravity. Both the inward pull of gravity and the outward push of gas pressure are *isotropic*. That is, they are equally effective in all directions. That is why the sun is round. If one of these forces were not isotropic, then the sun would not be round. Sometimes there are other pressures. If a star is rapidly rotating, or has a strong magnetic field, then the gas pressure is weaker along that axis. The gas collapses along that axis, and the star becomes a flattened disk. The weaker pressure along the axis balances the weaker gravitational force of the thin mass in the thickness of the disk, whereas the stronger pressure along the radius of the disk balances the larger gravitational force of the larger amount of mass in the radial direction. Thus, round objects exist when forces are *isotropic* and non-round objects when forces are not isotropic.

In the earth, the gravitational force pushing inward is balanced by the outward push of the strength of the rocks, a result of the push of electrons against each other in adjacent atoms. Both these forces are isotropic, and so the earth is round. In a basketball, the air pressure pushing outward is balanced by the tension on the fabric pushing inward. Again, both these forces are isotropic and so the basketball is round.

Animate Objects

In inanimate objects, a round configuration results from a balance of *isotropic* forces, that is, forces experienced equally in all directions. But what determines the shapes of living things? The Zoologist and classical scholar, D'Arcy Thompson attempted to answer this puzzling phenomena in his book, "On Growth and Form" published in 1917. Although you may not be familiar with his publication, there is a good chance that you have seen reproductions of his drawings. His exquisite illustrations of forms of radiolaria or how the shapes of animals change from one species to another have been prolifically copied. The seminal point of Thompson's book was that genes do not set the blueprint of the shape of an organism, but they set the rules of how the organism interacts with its environment. It is then this dynamic interaction between the organism and its environment that produces the structure.

For example, the *final* shape of the long bones in the arms and legs is dependent on forces between osseous cells and the forces of their environment. Since bone is alive, material is constantly being added and removed from biochemical reactions by cells within the bone. When a bone is bent, fluid flows inside the bone. The negative and positive ions in this fluid flow at different rates generating an electrical voltage. This voltage affects the cells in the bone so that their enzymes add more calcium on the electrically negative side of the bend, and remove more calcium on the electrically positive side of the bend. As a result, the bone is resculpted into a straighter shape. Bone is very strong at resisting compressive forces pushing inward on both ends. It is weak at resisting tensile forces pulling outward from both ends. The resculpting adds material where the bone is in compression and more material is needed. It removes material where the bone is in tension and excess material is wasted. Thus, the genes, through their complex programming of cells and their enzymes, have set the rule: add material where it is needed and remove material where it is not needed. The genes have set the rule of how the bone interacts with the environment. That rule and its interaction with the environment then generates the straight shape of the bone.



aqueous humor
chambers
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nerves
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