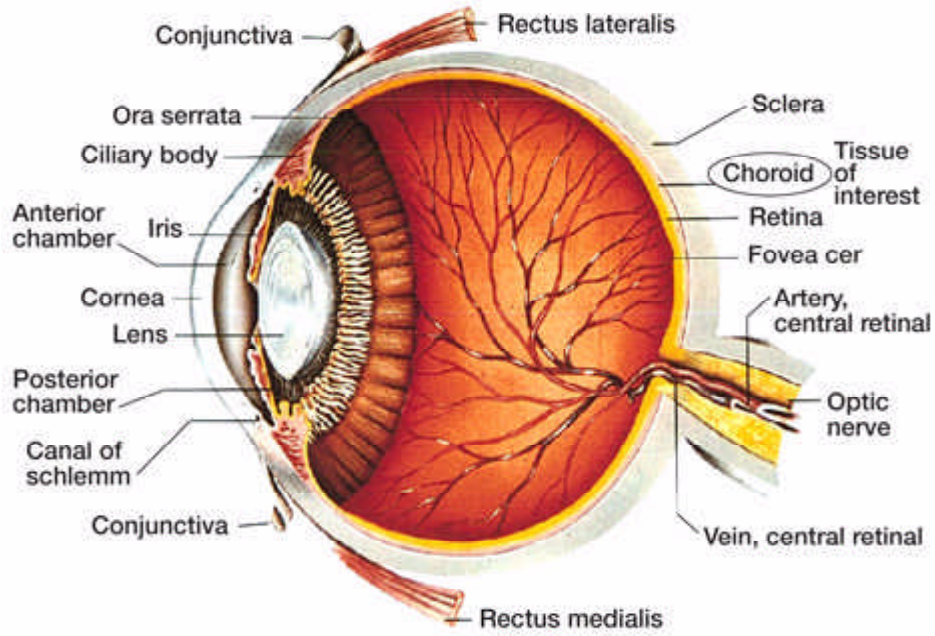
Ocular Blood Flow Measured Noninvasively in Zero Gravity



Blood flow is measured in the dense meshwork of capillaries in the back of the retina in a tissue layer called the choroid (see circled region).

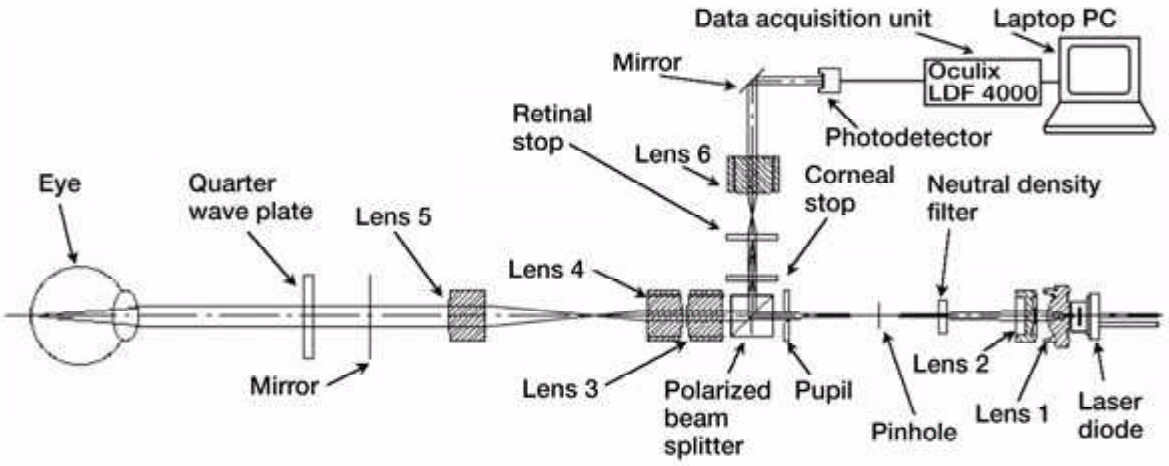
Long description of figure 1 Cross-section illustration of eye, showing rectus medialis, conjunctiva, canal of schlemm, posterior chamber, lens, cornea, anterior chamber, iris, ciliary body, ora serrata, conjunctiva, rectus lateralis, sclera, choroid (tissue of interest), retina, fovea cer, central retinal artery, optic nerve, and central retinal vein.

In spaceflight or a reduced-gravity environment, bodily fluids shift to the upper extremities of the body. The pressure inside the eye, or intraocular pressure, changes significantly. A significant number of astronauts report changes in visual acuity during orbital flight. To date this remains of unknown etiology. Could choroidal engorgement be the primary mechanism and a change in the curvature or shape of the cornea or lens be the secondary mechanism for this change in visual acuity? Perfused blood flow in the dense meshwork of capillaries of the choroidal tissue (see the preceding illustration) provides necessary nutrients to the outer layers of the retina (photoreceptors) to keep it healthy and maintain good vision. Unlike the vascular system, the choroid has no baroreceptors to autoregulate fluid shifts, so it can remain engorged, pushing the macula forward and causing a hyperopic (farsighted) shift of the eye. Experiments by researchers at the NASA Glenn Research Center could help answer this question and facilitate planning for long-duration missions.

We are investigating the effects of zero gravity on the choroidal blood flow of volunteer subjects. This pilot project plans to determine if choroidal blood flow is autoregulated in a

reduced-gravity environment. It will help ascertain in future experiments if there is a relationship between changing intraocular pressure and a systemic blood pressure with the choroidal flow. These experiments are being conducted onboard a wide-body aircraft (KC-135) during parabolic flight trajectories (which produce environments varying from low to high gravity). A low-power (~100 μW) continuous-wave (CW) solid-state laser operating at a wavelength of ~780 nm is being used to measure frequency shift in a head-mounted miniature laser Doppler flowmeter. The Doppler shift results from red blood cells flowing through the choroids. This yields parametric measurements of blood volume, speed, and flow. Each measurement takes approximately 15 s to complete.

In these experiments, the incident laser light shifts in frequency after it interacts with the red blood cells flowing in the choroidal tissue. This frequency shift is proportional to the speed of the moving red blood cells: $\Delta f = 1/2\pi(K_s - K_i)V_{RBC}$, where K_s and K_i are the wave vectors of the scattered and incident light, respectively, with magnitude $2\pi n/\lambda$, where n is the refractive index of the medium, λ is the wavelength of light in vacuum, and V_{RBC} is the velocity of the red blood cells. The experimental scheme uses heterodyne detection, in which the light scattered from red blood cells is mixed with light reflected from the nonmoving tissue at an avalanche photodiode (APD) photodetector. After the electronic processing of these signals, a power spectrum is obtained and parameters such as blood volume, speed, and red blood cell flux are calculated.



Optical system.

Long description of figure 2 Illustration of optical system, showing the light path from the eye to a quarter wave plate to a mirror to lenses 5, 4, and 3, to a polarized beam splitter to a corneal stop to a retinal stop to lens 6 to a mirror to a photodetector to t he Oculix LDF 4000 data acquisiton unit to a laptop PC and from the polarized beam splitter to the pupil to a pinhole to lenses 2 and 1 and to a laser diode.

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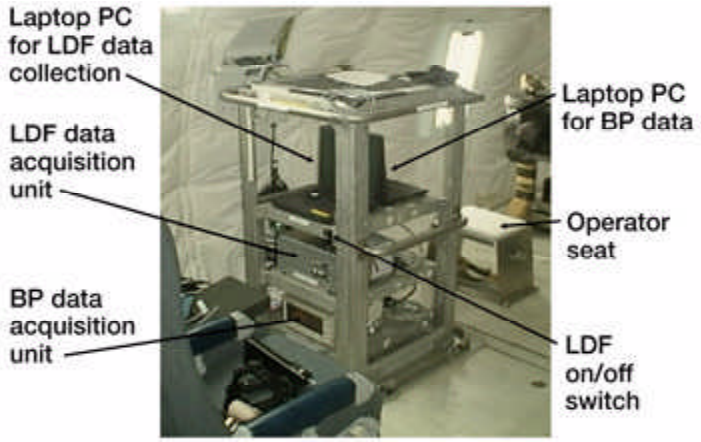
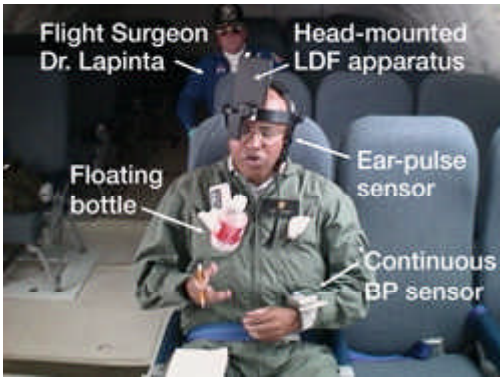
The optical system (see the preceding schematic diagram) for the illumination and detection of ocular tissue consists of 18 parts. First the source, a laser diode controlled by an electronic driver, is imaged and magnified by two lenses (lenses 1 and 2) on a pinhole (for pseudoconfocal arrangement on the detection path). A neutral-density filter located

between the lenses and the pinhole attenuates the power. Two other lenses (lenses 3 and 4) image the pinhole on an intermediate image plane. A pupil determines the beam size, and a polarized beam splitter redirects the light collected from the eye on the detection path. Both the pupil and the polarized beam splitter are located between the pinhole and lens 3. Lens 5 collimates the beam, and the eye lens refocuses it on the probed tissue. This lens is placed on a translational stage to allow image adjustment at the retina for myopic or hyperopic (near-sighted or far-sighted) eyes. A mirror deflects the path for 90° redirection in the eye axis, and a quarter waveplate modifies the polarization state of the beam. The power at the exit pupil of the laser Doppler flowmeter instrument or the power falling on the subject's cornea is 100 μW. The light is then reflected back along the same path to the beam splitter, where it is redirected along the detection path. Light reflected from the cornea is focused on the corneal stop, where it is prevented from continuing along the detection path. Likewise, light reflected from the retina is focused on the retinal stop. The remaining light of interest from the probed tissue is then collimated by lens 6 and redirected by a mirror onto the photodetector. The data are then sent to the data acquisition unit (Oculix LDF 4000), where the information is analyzed and sent to a laptop PC for display and storage. During the experiment, the arterial blood pressure (BP) is monitored continuously from heart beat to heart beat (Colin model 7000).



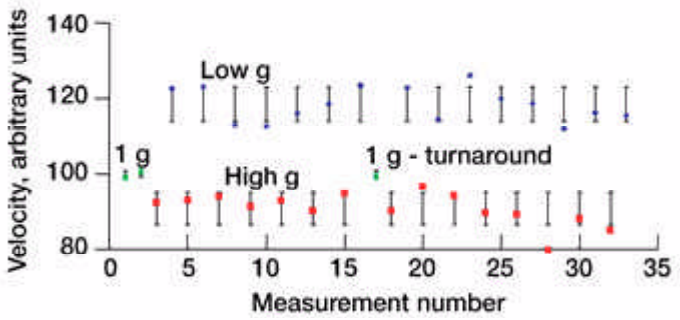
Instrument rack for ocular blood flow experiments onboard the KC-135 aircraft.



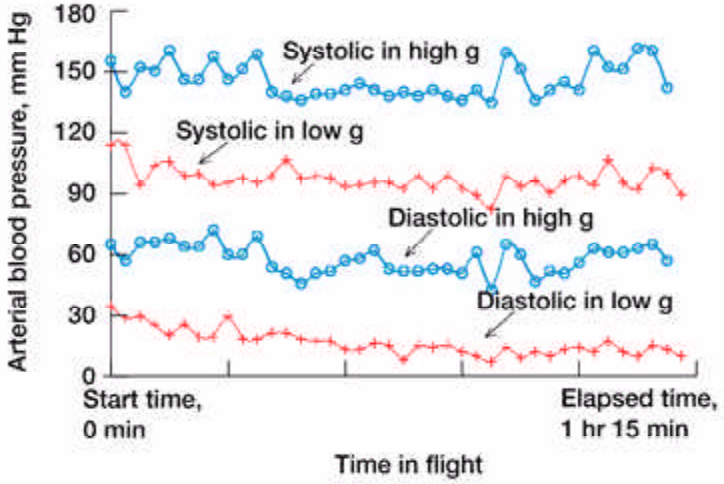
Head-mounted LDF instrument on a volunteer subject monitors ocular blood flow in 0g onboard the KC-135 aircraft.

These two photographs show the instrument rack onboard the KC-135 and the head-

mounted LDV on a volunteer subject (Dr. Rafat Ansari). Preliminary data on ocular blood velocity and arterial BP are presented in the following graphs. Both the velocity of the red blood cells flowing in the choroid and the arterial BP changed as gravity levels were varied during the parabolic flight of the KC-135. The red blood cell velocity increased consistently in reduced gravity and decreased in high gravity. The BP (both systolic and dystolic) decreased in low gravity and increased in high gravity. More experiments are being done at the time of this writing to understand this phenomenon.



Blood velocity data with ± standard deviation error bars from two consecutive parabolic flight sets.



Arterial blood pressure data measured in parabolic flight.

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