Photorefractive Keratectomy and Laser-Assisted In Situ Keratomileusis on 6-Month Space Missions

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BACKGROUND: This article documents the stability of photorefractive keratectomy (PRK) and laser-assisted in situ keratomileusis (LASIK) in two astronauts during 6-mo missions to the International Space Station.

CASE REPORTS: Ocular examinations including visual acuity, cycloplegic refraction, slit lamp examination, corneal topography, central corneal thickness, optical biometry (axial length/keratometry), applanation tonometry, and dilated fundus examination were performed on each astronaut before and after their missions, and in-flight visual acuity testing was done on flight day 30, 90, and R-30 (30 d before return). They were also questioned regarding visual changes during flight.

DISCUSSION: We documented stable vision in both PRK and LASIK astronauts during liftoff, entry into microgravity, 6 mo on the International Space Station, descent, and landing. Our results suggest that both PRK and LASIK are stable and well tolerated during long-duration spaceflight.

KEYWORDS: PRK, LASIK, vision, spaceflight.

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This report documents the stability of photorefractive keratectomy (PRK) and laser-assisted in situ keratomileusis (LASIK) in two astronauts during 6-mo missions to the International Space Station (ISS). Launch, 6 mo of continuous spaceflight, extravehicular activities (EVAs), and re-entry create an extremely dynamic spectrum of ocular physiological and anatomical changes that may impact the cornea following refractive surgery. Although one previous report documented the stability of PRK in a spaceflight participant during a 12-d Soyuz ISS mission, there have been no reports on PRK stability during long-duration space flight (LDSF) and no reports of LASIK use during any length of spaceflight. This correspondence suggests that both PRK and LASIK are safe and effective procedures that provide stable vision during launch, 6 mo of continuous spaceflight, and descent, with no visual changes attributable to these procedures.

CASE REPORTS

Astronaut 1, a 44-yr-old white man, had bilateral PRK for myopia in 2009 without complications. His preoperative cycloplegic refractive errors were $-4.25 - 0.25 \times 90$ OD and $-4.50 - 0.25 \times 100$ OS. He had a VISX CustomVue procedure and a standard ablation profile with a 6.0×6.0-mm optical zone and an 8.0-mm ablation zone. He had no operative complications and his postoperative course was uneventful. His spaceflight took place several years following his PRK.

His pre-mission eye examination, performed ~3 mo prior to launch, documented uncorrected distance visual acuities of 20/20 OD and 20/20 OS using Acuity Pro software (AcuityPro, Inc., Elk City, OK, United States). Cycloplegic refraction, performed subjectively using 1% tropicamide, documented refractions of −0.25 sphere OD and −0.25 sphere OS with corrected visual acuities of 20/15 OD and 20/15 OS. Cyclopentolate was not used because of its impact on astronaut vision. The cornea was clear OU. Corneal topography, performed with the Zeiss Atlas corneal topographer (Carl Zeiss Meditec, Dublin, CA,

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United States), was consistent with post-PRK surgery in both eyes. Keratometry, performed with the Zeiss IOL Master (Carl Zeiss Meditec), was 39.66 D at 180 and 40.37 D at 90 OD, and 39.57 D at 174 and 40.18 D at 084 OS. Preflight axial length, performed with the Zeiss IOLMaster, was 25.29 mm OD and 25.48 mm OS. The intraocular pressure (IOP), as measured at 10:00 by Goldmann applanation tonometry, was 10 mmHg OD and 12 mmHg OS. The central corneal thickness, as measured with Zeiss Cirrus OCT (Carl Zeiss Meditec), was 468 μm OD and 496 μm OS. The remainder of the ocular examination, including dilated fundus examination and visual fields, was normal OU.

The Soyuz launch from the Baikonur Cosmodrome in Kazakhstan and docking to the ISS were uneventful, taking less than 2 d. This crewmember had no specific vision complaints in transit to the ISS. Once on the ISS, astronauts live in a near-Earth-normal atmosphere of approximately 14.7 psi with 21% oxygen.

In-flight vision testing was performed on flight days (FD) 30, 90, and R-30 (30 d before return). Distance (15 ft) visual acuity was measured with an onboard laptop using Acuity Pro software (Acuity Pro, Inc., Elk City, OK, United States) and near (40 cm) visual acuity (**Fig. 1**) was tested using a logMAR chart (Precision vision, Woodstock, IL, United States), and results were recorded by a remote guider on the ground. Two different charts were used for each test to discourage memorization. Compared with preflight visual acuity, both distance and near visual acuity remained stable or improved in orbit.

Visual symptoms were evaluated using a comprehensive questionnaire that was completed on FD30, FD90, and R-30. This digital in-flight questionnaire was created by NASA specifically for spaceflight-associated neuro-ocular syndrome ocular surveillance[1] and has been used on prior space missions. The questionnaire assessed visual symptoms, including visual distortions, trouble seeing in dim light, fluctuating vision throughout the day, difficulty with depth perception, double vision, change in visual acuity up close (0–3 ft), change in visual acuity at intermediate distances (3–10 ft), and change in visual acuity at distance (>10 ft). Other than a mild subjective change in distance vision, as documented in the questionnaire, none of these symptoms were reported at any time.

Fig. 1. ISS near visual acuity test.

The return trip from the ISS to Earth occurred ∼6 mo post-launch, took 4 h, and was uneventful with no visual complaints. Postflight testing was performed 5 d after landing and ocular parameters were essentially unchanged from the preflight examination, including IOP (10 mmHg OD and 11 mmHg OS, measured at 10:30), uncorrected distance acuity of 20/15 OU, cycloplegic refractions Plano OD, Plano OS, keratometry 39.61 D at 008, 40.27 D at 098 OD, and 39.52 D at 160, 40.18 D at 070 OS, axial length 25.14 mm OD, 25.37 mm OS, central corneal thickness 468 μm OD and 496 μm OS, and unchanged corneal topography. The remainder of the ocular examination, including dilated fundus examination and visual fields, was normal.

Astronaut 2, a 34-yr-old white woman, had bilateral LASIK for hyperopia and astigmatism in 2013 without complications. Her preoperative refractive errors were +1.75 − 2.25 × 180 OD and +1.75 − 2.75 × 002 OS. She had a VISX CustomVue procedure with a superior corneal flap, 6.0 × 6.0-mm optical zone and a 9.0-mm ablation zone OU. She had no operative complications and her postoperative course was uneventful. Her spaceflight took place several years following her LASIK procedure.

Her pre-mission eye examination, performed ∼6 mo prior to launch, documented uncorrected distance visual acuities of 20/15 OD and 20/20 + OS, and cycloplegic refractions of +0.50 − 0.25 × 40 and +0.75 − 0.75 × 175 with corrected visual acuities of 20/15 OD and 20/15 OS. Visual acuity, cycloplegic refraction, keratometry, IOP, axial length, and corneal thickness were all measured using the same instruments and methods as case 1. The cornea was clear OU. Corneal topography was consistent with post-LASIK surgery in both eyes. Keratometry was 43.72 D at 017 and 44.29 D at 107 OD, and 43.21 D at 177 and 44.35 D at 087 OS. Axial lengths were 23.27 mm OD and 23.35 mm OS. The IOP was 11 mmHg OD and 10 mmHg OS at 1100. The central corneal thickness was 500 μm OD and 497 μm OS. The remainder of the ocular examination, including dilated fundus examination and visual fields, was normal.

The launch took place on a SpaceX Falcon 9 rocket from launch complex 39A at the Kennedy Space Center and the Dragon capsule docked with the ISS less than 2 d thereafter. This crewmember reported no specific vision complaints in transit and once on the ISS lived in a near-Earth-normal atmosphere of approximately 14.7 psi with 21% oxygen.

In-flight testing of visual performance was performed on FD30, FD90, and R-30. As with astronaut 1, distance (15 ft) and near visual acuity was recorded by a remote guider on the ground. Compared with preflight visual acuity, both distance and near visual acuity remained stable in orbit. Visual symptoms were evaluated using the previously described questionnaire and no visual symptoms were reported at any time.

The return trip from the ISS to Earth occurred ∼6 mo post-launch, took 4 h, and was without incident or vision complaints. Postflight testing was performed 5 d after landing and ocular parameters were essentially unchanged from the preflight examination, including IOP (10 mmHg OD and 10 mmHg OS at 11:30), cycloplegic refraction (+0.50 sphere OD, +0.75 − 0.75 × 170 OS), keratometry (43.62 D at 010, 44.50 D at 100 OD, and 43.37 at 175, 44.75 at 085 OS), and corneal topography. Axial lengths were 23.14 OD and 23.24 OS. The central corneal thickness was 502 μm OD and 496 μm OS. The remainder of the ocular examination, including dilated fundus examination and visual fields, was normal.

Both astronauts completed multiple EVAs lasting ~6.5 h. The spacesuits used for the EVAs operate in a microgravity environment at a gas pressure of 4.3 psi (29.6 KPa) and 100% oxygen. Neither astronaut noted any visual changes during their EVAs.

DISCUSSION

The optimal method for the correction of refractive errors in astronauts and cosmonauts has been elusive due to the unique environment of spaceflight. Glasses have been commonly used on Space Shuttle and ISS flights, but in the microgravity environment they can be difficult to correctly position and are prone to fogging and displacement during EVAs. Contact lenses are also commonly used on the ISS, but storage, cleaning, insertion, and the potential for ulcerative keratitis complicate their use.

Over the last 40 yr there has been a gradual evolution and refinement of refractive surgery procedures for the correction of refractive errors. Radial keratotomy, which consisted of multiple radial incisions in the peripheral cornea to flatten the central cornea, was initially performed on millions of myopic patients. However, due to diurnal visual fluctuations and a sometimes pronounced hyperopic shift with altitude exposure from hypoxia-induced peripheral corneal expansion,[6] this procedure was quickly eliminated for use in flight personnel. Also, a recent case report documented the first successful use of an implantable collamer lens to correct refractive error in a spaceflight participant during a 12-d spaceflight.[3] In this procedure, an intraocular lens is surgically inserted through a limbal incision and positioned anterior to the natural lens and posterior to the iris.

Given the long and well-documented history of surgical precision in the use of PRK and LASIK, there are potentially many benefits to these procedures as a method of visual correction in astronauts. Both are currently approved surgical procedures for civilian aviation and all branches of the military. This includes their use by pilots of high-performance terrestrial aircraft. In 2007 NASA approved PRK and LASIK for astronaut selection and retention.

PRK is a nonreversible procedure in which the surface of the cornea is reshaped using an excimer laser to produce a desired refractive error. PRK has been used for the correction of a spectrum of refractive errors, including myopia, hyperopia, and astigmatism, and there has been a gradual refinement in PRK technology over time. Since the optical zone diameter must be at least as large as the entrance pupil to preclude parafoveal glare, the initially small optical zone ablation diameters of 4–5 mm, used in early cases, led to sometimes severe glare, halos, and ghost images that became more prominent with increased pupil size at night. Residual central islands, corneal haze, and myopic regression were also reported with early versions of this procedure. The gradual expansion of the optical ablation zone to 6.00 mm, in conjunction with more precise ablation technology, including higher order aberration correction, has mitigated many of these complications. However, the need for retreatment of residual refractive error following PRK after myopia correction is 6.8% and increases with higher degrees of myopia.[12] Stable vision during high altitude exposure, without diurnal fluctuation, has been demonstrated following PRK[6] and it has a well-documented history of successful use in aviation.[10] It is interesting to note that the PRK cornea does increase in thickness during exposure to hypoxia. However, as in the normal cornea, this corneal expansion occurs uniformly so that the corneal surface maintains its normal refractive power.[6] Documentation of PRK use in astronauts during spaceflight has thus far been limited to a single case report describing one spaceflight participant with bilateral PRK who flew on a 12-d Russian Soyuz mission to the ISS in 2012.[4] Our correspondence documents the first use of PRK in an astronaut during a 6-mo Soyuz LDSF to the ISS.

LASIK is also a nonreversible procedure in which a hinged anterior corneal flap is created with a laser or mechanical blade. This flap is then gently lifted and an excimer laser is then used to reshape the underlying cornea. Thereafter, the hinged corneal flap is repositioned onto the cornea. As with PRK, LASIK is an approved procedure for the correction of refractive error in civilian aviation, all four military services, and NASA. Although LASIK exposure to a hypoxic environment does result in increased central corneal thickness, a trend toward steepening of the central cornea, and a small myopic shift, the magnitude of this shift during normal terrestrial aviation exposure is not clinically significant.[11] There have been no previous reports of post-LASIK individuals participating in spaceflight.

The physiological stress of a rocket launch, acute and chronic exposure to microgravity, EVAs, and the abrupt deceleration of a parachute-assisted landing each have a unique impact on ocular physiology and anatomy not seen during terrestrial flight. These changes, including choroidal expansion, increased IOP, shallowing of the anterior chamber, and globe flattening, have the potential to impact the curvature and stability of the PRK or LASIK cornea. During launch of the Soyuz or SpaceX vehicle, the astronaut is exposed to 3.5–4.5 $+G_x$ of forward acceleration that forcefully pushes the eyes toward the rear of the bony orbit. This rearward "eyeballs in" thrust during the 10-min launch sequence quickly dissipates upon reaching the microgravity environment where the eye rapidly undergoes measurable physiological changes. These changes, during the first 30 s of microgravity exposure, include a sudden rise in IOP of about 20–58%.[8] Head-down tilt[9] and parabolic flight studies[8] suggest that this initial pressure spike results from abrupt choroidal expansion within a rigid globe caused by a microgravity-induced venous stasis that inhibits the normal terrestrial gravity-dependent vortex venous drainage from the highly vascular choroid. The continued, sustained IOP increase during the first days of flight[2] may result from choroidal expansion, increased episcleral venous pressure, orbital pressure on the globe, or a combination of these mechanisms. This increased IOP gradually returns to normal during LDSF possibly because of a compensatory decrease in anterior chamber volume that offsets the volume increase within the choroid.[7–9] In support of this notion, decreased anterior chamber depth was recently reported in astronauts following LDSF.[5] Increased peripapillary choroidal thickness, as measured by OCT, was also documented during early LDSF, persisted throughout the mission, and required 45–90 d after flight to return to normal levels.[5] Wostyn recently hypothesized that the delay in resolution of peripapillary choroidal thickness following LDSF may result from the transudation of fluid from the choroidal vasculature, resulting in some degree of choroidal interstitial edema that may only slowly dissipate following a return to the 1-G environment.[13]

Following LDSF, as the space capsule plummets toward Earth during face-up descent, a deceleration of 3.5–4.5 G occurs, which again drives the globe posteriorly (eyeballs in). The rapid descent is slowed by a series of parachute deployments. Thus, a spectrum of distinctive forces acts upon astronaut eyes from launch, through acute and chronic microgravity exposure and re-entry. The magnitude of these forces, in conjunction with the ocular structural changes associated with LDSF, could potentially impact the relatively thin cornea created by PRK as well as the surgically manipulated LASIK cornea.

The astronauts' post-PRK and LASIK corneas in our report were subjected to an extremely wide spectrum of ocular physiological and anatomical changes. It was not possible to objectively evaluate visual changes that may have occurred during liftoff, ascent into low Earth orbit, EVAs, and descent. However, both astronauts subjectively described excellent vision during all phases of their missions. In both PRK and LASIK corneas there was no significant change in corneal curvature or thickness following LDSF. In the eyes of both astronauts there was a very slight decrease in axial length following their missions, which is consistent with spaceflight-associated neuro-ocular syndrome changes during spaceflight.[13] During their 6-mo exposure to microgravity, both astronauts were exposed to a great spectrum of light conditions and work at variable distances within the ISS. This report suggests that modern PRK and LASIK procedures are safe, effective, and suitable for use by astronauts during LDSF.

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