Ultrasound Guided Lumbar Puncture and Remote Guidance for Potential In-Flight Evaluation of VIIP/SANS

David J. Lerner; Ranjit S. Chima; Kirang Patel; Allen J. Parmet

INTRODUCTION: Changes of visual function/neuro-opthalmic structures during spaceflight have been described as visual impairment and intracranial pressure syndrome (VIIP)/spaceflight-associated neuro-ocular syndrome (SANS). Although theories are suggested, the mechanism is unknown. Only indirect measurements of intracranial pressure (ICP) have been performed in spaceflight. Direct determination of in-flight ICP is crucial to understanding VIIP. Current "gold standard" is lumbar puncture (LP). The only direct evaluation has occurred with postflight LP. In-flight measurements would allow correlation of opening pressures/possible contributing factors. The only imaging modality on the International Space Station (ISS) is ultrasound. With appropriate methodology, remotely guided ultrasound-guided lumbar puncture (USGLP) may allow safe performance in flight. Therefore, we sought to develop a novel ultrasound approach for definitive placement of an LP needle, and to show this can be achieved with remote guidance by those without training.

METHODS: Literature review and round-table discussions with multiple medical fields was performed. Volunteers were scanned with ultrasound for optimizing technique. A cadaver was used to perform this technique by a radiologist, then taught to volunteers not experienced in image guided procedures, and finally was repeated multiple times by volunteers with simulated remote guidance.

RESULTS: Optimal visualization was in the fetal and seated lordotic positions. Technical success was achieved by the radiologist in all attempts and achieved in 9 of 11 attempts by the trainees.

DISCUSSION: Given ultrasound experience at NASA and the ability to educate non-image-guided trained personnel, these could make this technique feasible and aid in direct in-flight measurements to further research VIIP.

KEYWORDS: VIIP, visual impairment and intracranial pressure, image guided procedures, remote guided procedures, space surgery.

Lerner DJ, Chima RS, Patel K, Parmet AJ. *Ultrasound guided lumbar puncture and remote guidance for potential in-flight evaluation of VIIP*. Aerosp Med Hum Perform. 2019; 90(1):58–62.

Changes of decreased visual function and neuro-ophthalmic structures during prolonged spaceflight as well as increased postflight intracranial pressure (ICP) has been described as visual impairment and intracranial pressure syndrome (VIIP) and recently redefined at NASA as spaceflight-associated neuro-ocular syndrome (SANS). Although theories of underlying cause and contributing factors have been suggested, such as a microgravity-induced cephalad fluid shift, the exact mechanism is unknown.[17] Knowing the true pathophysiology is of particular importance as longer duration missions are being planned and performed. In the literature, 15 long-duration male astronauts have been reported as being diagnosed in flight and postflight with these symptoms.[1] Similar findings have also been reported in cosmonauts on Mir.[11] Postflight brain MRIs on 27 astronauts have shown multiple anatomical changes similar to idiopathic intracranial hypertension (IIH).[8] So far, only indirect, noninvasive measurements of ICP have been performed in spaceflight.[12,16] The only direct evaluation has occurred with postflight lumbar punctures; for example, on six crewmembers who had in-flight VIIP symptomatology, all of who had mildly elevated opening pressures, as reported by Alexander et al.[1] However, no preflight lumbar punctures were performed, limiting the value of these data points.[1,17]

Direct quantitative determination of ICP in space is crucial to understanding the pathogenesis of VIIP.[17] The current "gold standard" of this measurement on Earth is lumbar puncture.

From the Department of Diagnostic and Interventional Radiology, University of Missouri-Kansas City School of Medicine, Kansas City, MO, and the Department of Occupational Medicine, Saint Luke's Hospital of Kansas City, Kansas City, MO.

This manuscript was received for review in May 2018. It was accepted for publication in October 2018.

Address correspondence to: David Lerner, 8953 Linden Lane, Prairie Village, KS 66207; dlerner111@gmail.com.

DOI: https://doi.org/10.3357/AMHP.5170.2019

Direct in-flight measurements would allow direct correlation of opening pressures as well as additional possible contributing factors, which include: time duration in orbit, CO_2 levels, and access to biomarkers that would aid in understanding an underlying pathogenesis, as well as to validate multiple indirect measurements currently used which may depend upon physiological parameters that may be altered in microgravity. There has been discussion about the possibility of performing lumbar puncture (LP) in spaceflight within the literature.[2] The only imaging modality on the International Space Station (ISS), is ultrasound. There is also an associated significant amount of experience with using this modality to perform independent scanning and real time guided procedures. With the development of an appropriate methodology, remotely guided real-time ultrasound guided lumbar puncture (USGLP) may allow the safe performance of this procedure in flight. Therefore, we sought to develop a novel ultrasound guided approach for the definitive placement and visualization of an LP needle, and to then show that this can be achieved with remote guidance by those without specific training in image guided procedures.

METHODS

Initially, the ultrasound and lumbar puncture literature was reviewed across multiple specialties (Diagnostic Radiology, Interventional Radiology, Neuro Interventional Radiology, Emergency Medicine, Neurology, Anesthesiology, Physical Medicine and Rehabilitation, etc.). Roundtable discussion with fellowship trained staff in the above mentioned fields regarding potential techniques also occurred. Various techniques of ultrasound scanning of the anatomy of the thoracolumbar spine of volunteers was then performed (**Fig. 1**). Images and video clips were acquired during scanning and evaluated for optimal resolution, dynamic range, frequency, and imaging window for needle path in various positions with multiple transducers. This included prone, lateral decubitus, fetal, and seated lordotic views using curvilinear, linear, high megahertz linear, L-shaped "hockey-stick" very high megahertz linear, and phased array transducers.

Using a wireless ultrasound unit, Siemens Wireless Acuson Freestyle, (Siemens, Munich, Germany), the cadaver was scanned for anatomic evaluation and visualization of the spinal canal. Scanning was performed with a linear probe (3–8 MHz available bandwidth predominantly utilized in a 5–7 MHz range) in native and virtual convex scanning parameters. The procedure was performed in the following steps by a single individual. 1) The cadaver was placed in a fetal position. 2) A linear probe was used in the longitudinal position to scan the posterior midline at the lumbosacral junction to identify the sacrum and L5 posterior spinous process. 3) The probe was moved cranially still in a longitudinal midline position, counting the spinous processes to reach the L3–L4 level. 4) Once reaching this level, the transducer was moved lateral approximately 1 cm from the midline while maintaining the longitudinal position of the transducer. 5) The transducer was then swept (angled) medially to reveal the thecal sac in a paramedian longitudinal oblique position. 6) The access needle was placed with one hand along the caudal longitudinal edge of the transducer aligned with the scanning plane while holding the transducer and scanning with the other hand. 7) The needle was advanced under imaging guidance into the thecal sac (**Fig. 2** and **Fig. 3**). Using a paramedian longitudinal oblique (PLO) approach, a real-time ultrasound guided lumbar puncture was then performed 12 times by a fellowship trained staff radiologist using an 18-, 20-, and 22-gauge spinal needle. Four attempts were performed with each gauge. Then brief hands-on instruction was given over the course of 10 min to four volunteers in the medical field without image guided procedural training. These included a radiological technologist, a second-year radiology resident, and two second-year medical students. After this, each volunteer made multiple attempts to perform a lumbar puncture using the same technique. To simulate remote guidance, the radiologist stood at a distance of approximately 10 ft from the proceduralist. The radiologist viewed the ultrasound imaging monitor and made sequential verbal recommendations in a stepwise fashion to direct the optimal imaging location, as well as for needle placement and advancement. The total number of attempts by the volunteers equaled 11:2 attempts with 18 gauge, 5 attempts with 20 gauge, and 4 attempts with 22 gauge.

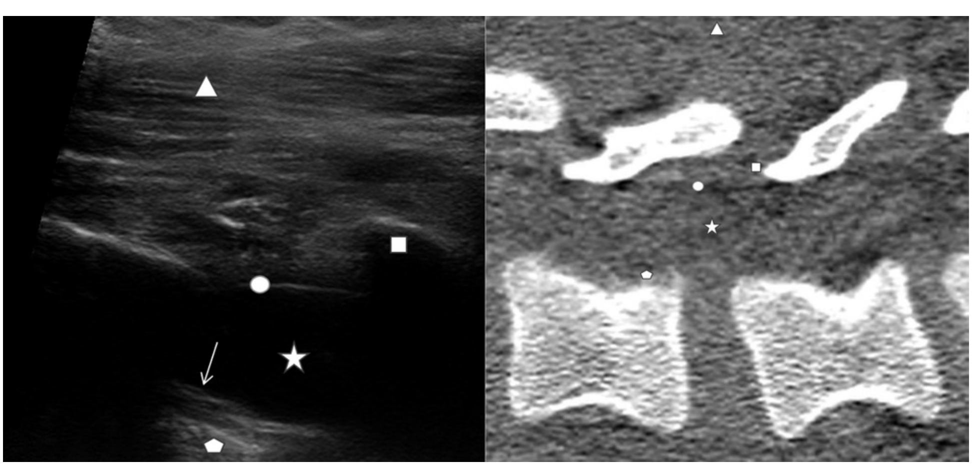

Fig. 1. Ultrasound (right) and corresponding anatomical CT (left) images of the lumbar spine in a paramedian longitudinal oblique approach. Star: cerebrospinal fluid in the intrathecal space; circle: thecal sac; square: bony facet; arrow: nerve roots within the csf; triangle: paraspinal musculature; pentagon: posterior aspect of vertebral body/posterior longitudinal ligament.

RESULTS

Optimal visualization was in the fetal and seated lordotic positions. Technical success was demonstrated by return of fluid through

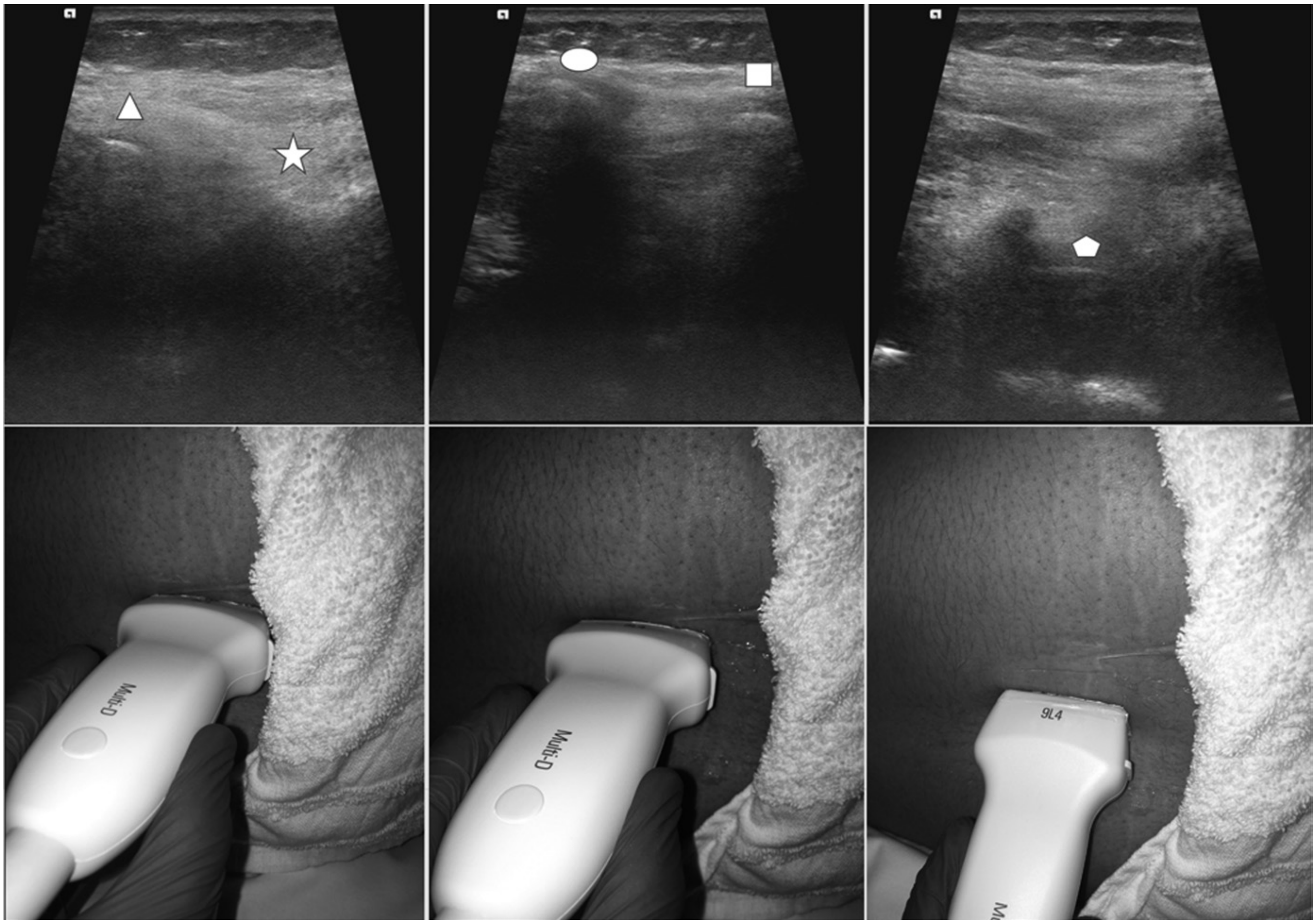

Fig. 2. PLO view. Left—star: superior end of sacral bone; triangle: posterior spinous process of L5. Middle—square: posterior spinous process of L4; oval: posterior spinous process of L3. Right—pentagon: thecal sac.

the needle after removal of the inner stylet as well as visualization of the needle tip within the intrathecal space (**Fig. 4**). While static images are more difficult to interpret, these would be considered of diagnostic image quality to document needletip location during a procedure for keeping in the patient's medical record, as routinely done at our institution for Interventional Radiologic procedures (the real-time scanning video found online at https://doi.org/10.3357/amhp.5170sd.2018 makes this easier to appreciate). Technical success was achieved in all approaches on the first attempt by the fellowship trained radiologist, where the first attempt is defined as single skin puncture of the access needle. Needle redirection was required 1 time in 2 of the 12 first attempts (1 of 4 attempts with the 18-gauge needle, and 1 of 4 attempts with the 22-gauge needle), where needle redirection is defined as retraction of the needle to reposition in the soft tissues. Repositions were due to the needle tip hitting prominent facet joints abutting the spinal canal secondary to facet hypertrophy. Expected technical success approached 100% based on previous experience with ultrasound-guided procedures by the fellowship trained radiologist. Although the 22-gauge needle was slightly more difficult to visualize compared to the 18- and 20-gauge needle when the needle was not in motion, qualitatively there was no significant increased difficulty between the 18-, 20-, and 22-gauge needle sizes to achieve technical success by the radiologist. When advancing through tissues, there was no perceived increase in difficulty for needle control between the needle sizes.

Technical success was achieved in all but two attempts by the volunteers. Technical failure was defined as multiple failed redirections or more than one attempt. No redirections were needed with the 18-gauge needle. One redirection was needed with three of the five attempts with the 20-gauge needle. With the 22-gauge needle, two attempts required one redirection, and two were considered technically failed after multiple attempted redirections. The failed attempts were qualitatively secondary to perceived difficulty seeing the needle when not in motion, hitting prominent facet joints, and too steep of an initial angle of approach.

DISCUSSION

There is increasing accumulation of data in regards to VIIP.[1,8,17] However, only indirect, noninvasive measurements of ICP have been performed in spaceflight.[12,16] Direct quantitative determination of ICP in space is crucial to understanding the pathogenesis of VIIP.[17] The current "gold standard" is lumbar puncture. Direct in-flight measurements would allow direct

Fig. 3. Needle position at the longitudinal edge angled in the scanning plane to the transducer.

correlation of opening pressures, time duration in orbit, CO_2 levels, access to biomarkers, and to validate multiple indirect measurements currently used.

Direct measurement over already performed in-flight indirect measurements do carry increased risk of complications as well as the use of restraints to adapt to the special environmental challenges of microgravity, such as translational forces during the procedure. Additional consideration must be given

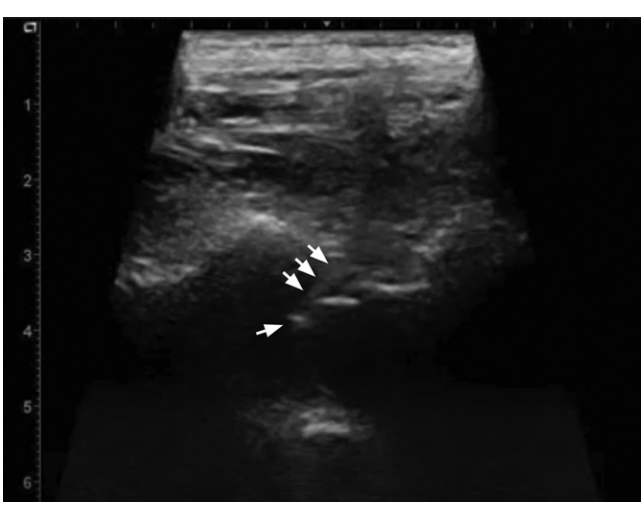

Fig. 4. Ultrasound image with access needle and tip confirmation within the thecal space.

to the limited ability in microgravity's remote environment to treat potential complications. Potential complications include postlumbar puncture headache, infection, hemorrhage, cerebral herniation, radicular pain/numbness, and back pain. An in-depth discussion of these are outside of the scope of this article. Please refer to Barr's article for a complete evaluation of this topic.[2] Technical approaches previously discussed for LP in microgravity include the "blind" palpation based approach, ultrasound assisted, and portable X-ray guidance.[2,9,10] Previous articles describing ultrasound-assisted LP have shown some improvement in outcomes compared to the blind approach.[13] However, described ultrasound-assisted techniques do not use real-time needle guidance. Only longitudinal and transverse midline images are obtained to determine the limited anatomy seen on these views; the skin is then marked, at which point the procedure is identical to a blind approach, in which the access needle is inserted over the expected path of the interspinous space and advanced. PLO views with appropriate patient positioning allows visualization of the soft tissues, adjacent osseous structures, spinal canal into thecal sac, spinal cord, nerve roots, and posterior aspects of the vertebral bodies to facilitate complete planning of needle trajectory. The needle is then visualized along this path in real time with continued ultrasound use to assure true guidance throughout the entire procedure. Visual confirmation of the needle entering the thecal sac and final needle location is also achieved. This technique is currently used by anesthesiologists and pain treatment clinicians for epidural and articular facet injections and could be potentially applied for the use of achieving spinal anesthesia on a long duration mission.[4,6] However, there is currently no standard accepted use of this technique to access the thecal sac.

There have been few investigations in the Neurology literature qualitatively describing a PLO approach with real-time guidance for lumbar puncture. However, these articles report inconsistent results, including difficulty of true final needle tip visualization within the thecal sac.[14,15] A search of the literature did not reveal a previously published study that shows a proof of concept of this approach to lumbar punctures using a PLO approach with a linear probe and reproducibility of success and final needle tip visualization in the thecal sac (100% with the radiologist, and 82% with procedurally naïve volunteers: 100% with 18-guage, 100% with 20-guage, and 50% with 22-guage). We were also unable to locate prior published work stating that this technique can effectively be taught to people with medical training without any specific prior education in performing image-guided procedures with associated technical success while using remote guidance from a trained radiologist. This data has valuable implications for use in spaceflight as there are currently no radiologists within the astronaut program; however, there are many trained in the medical field. This study was conducted only as a proof of concept. While this research proves the concept that this technique can be performed, further evaluation with multiple repeated attempts should be obtained to assess statistical significance, including power analysis. While remote guidance was simulated, a more thorough simulation would be optimal for further research. This would include time delayed responses to commands in a stepwise function and monitoring ultrasound images as well as limited video visualization in a separate location.

The only imaging modality on the ISS is ultrasound. The frequency range used in this study overlaps with available MHz bandwidth on the ISS ultrasound unit.[7] Continued, complete real-time imaging with ultrasound could allow specialists in Mission Control to visually confirm needle placement and guidance throughout an LP procedure in an incremental stepwise function, and could facilitate ground approval prior to advancement to the next procedural step. Given the current experience with this modality for independent scanning and real-time guided procedures at NASA, as well as the ability described above to educate nonimage guided trained people in the paramedian longitudinal oblique USGLP technique, these could make remote image guided LPs technically feasible. With the development of an appropriate methodology, remote guided USGLP may allow the safe performance of this procedure in flight. Using only the imaging component of this technique, this could next be performed in flight on the ISS to confirm all of the parameters and visualization of the thecal sac remain similar to ground-based investigation. This could be performed with minimal medical risk and minimal mission time (approximately 15–30 min). This technique can also further be evaluated by application in remote terrestrial environments as many of these locations may only have ultrasound access.

ACKNOWLEDGMENTS

The authors would like to thank Tiffany Smitheran, RDMS, RVT, B.S., of Saint Luke's Hospital of Kansas City; Sirius Saeedipour, B.A., and Sean Lacy, B.S., of the Kansas City University School of Medicine; and Dave Hess, B.S., RDMS, RVT, of RT Siemens.

Authors and affiliations: David J. Lerner, M.D., Assistant Professor, Ranjit S. Chima, M.D., and Kirang Patel M.D., Residents, Department of Diagnostic and Interventional Radiology, University of Missouri-Kansas City School of Medicine, Kansas City, MO, and Allen J. Parmet, M.D., Department of Occupational Medicine, Saint Luke's Hospital of Kansas City, Kansas City, MO.

REFERENCES

1. Alexander DJ, Gibson CR, Hamilton DR, Lee SMC, Mader TH, et al. Evidence report: risk of spaceflight induced intracranial hypertension and vision alterations. Houston (TX): NASA Lyndon Johnson Space Center, Human Research Program, Human Health Countermeasures Element; 2012.
2. Barr YR. Lumbar puncture during spaceflight: operational considerations, constraints, concerns, and limitations. Aviat Space Environ Med. 2014; 85(12):1209–1213.
3. Campbell MR, Billica RD. Surgical care in spaceflight. In: Barratt MR, Pool SL, editors. Principles of clinical medicine for space flight. New York: Springer; 2008.
4. Chin KJ, Karmakar MK, Peng P. Ultrasonography of the adult thoracic and lumbar spine for central neuraxial blockade. Anesthesiology. 2011; 114(6):1459–1485.
5. Eskey CJ, Ogilvy CS. Fluoroscopy-guided lumbar puncture: decreased frequency of traumatic tap and implications for the assessment of CT-negative acute subarachnoid hemorrhage. AJNR Am J Neuroradiol. 2001; 22(3):571–576.
6. Grau T, Leipold RW, Horter J, Conradi R, Martin E, Motsch J. The lumbar epidural space in pregnancy: visualization by ultrasonography. Br J Anaesth. 2001; 86(6):798–804.
7. Human Research Facility Ultrasound on the International Space Station 2 (Ultrasound 2). [Accessed April 2018]. Available from https://www.nasa.gov/mission_pages/station/research/experiments/749.html.
8. Kramer LA, Sargsyan AE, Hasan KM, Polk JD, Hamilton DR. Orbital and intracranial effects of microgravity: findings at 3-T MR imaging. Radiology. 2012; 263(3):819–827.
9. Lerner DJ, Parmet AJ. Interventional radiology: the future of surgery in microgravity. Aviat Space Environ Med. 2013; 84(12):1304–1306.
10. Lerner DJ, Parmet AJ, Don S, Shimony JS, Goyal MS. Technique for performing lumbar puncture in microgravity using portable radiography. Aerosp Med Hum Perform. 2016; 87(8):745–747.
11. Myasnikov VI, Stepanova SI. Features of cerebral hemodynamics in cosmonauts before and after flight on the MIR Orbital Station. In: Orbital Station MIR, Space Biology and Medicine, vol. 2, biomedical experiments. Moscow (Russia): Institute of Biomedical Problems of the Russian Academy of Sciences; 2008:300–305.
12. Ragauskas A, Matijosaitis V, Zakelis R, Petrikonis K, Rastenyte D, et al. Clinical assessment of noninvasive intracranial pressure absolute value measurement method. Neurology. 2012; 78(21):1684–1691.
13. Shaikh F, Brzezinski J, Alexander S, Arzola C, Carvalho JC, et al. Ultrasound imaging for lumbar punctures and epidural catheterisations: systematic review and meta-analysis. BMJ. 2013; 346:f1720.
14. Soni N, Arntfield R, Kory P. Point-of-care ultrasound, 1st ed. Philadelphia: Saunders; 2014.
15. Soni NJ, Franco-Sadud R, Schnobrich D, Dancel R, Tierney DM, et al. Ultrasound guidance for lumbar puncture. Neurol Clin Pract. 2016; 6(4):358–368.
16. Visual IIPSR. Houston (TX): NASA Lyndon B. Johnson Space Center; 2011. [Accessed June 2016]. Available from www.nasa.gov/pdf/581115main_2011%20VIIP%20Summit%20Report_Final%20June.pdf.
17. Zhang LF, Hargens AR. Spaceflight-induced intracranial hypertension and visual impairment: pathophysiology and countermeasures. Physiol Rev. 2018; 98(1):59–87.