JSES International 9 (2025) 380–384

Contents lists available at ScienceDirect

JSES International

journal homepage: www.jsesinternational.org

Space flight missions over 6 months significantly increase the risk of shoulder pathology and rotator cuff tears

Benjamin Fiedler, MD*, Meghana Jami, MD, Srikhar V. Chilukuri, BS, Abdullah Ghali, MD, Todd Phillips, MD, Adil Shahzad Ahmed, MD

Baylor College of Medicine, Joseph Barnhart Department of Orthopedic Surgery, Houston, TX, USA

A R T I C L E I N F O

Keywords:
Space flight
Astronaut
Shoulder
Rotator cuff
Impingement
Space suit
Scapulothoracic
Glenohumeral

Level of evidence: Level III; Retrospective Cohort Comparison; Prognosis Study

Background: The purpose of this study was to determine risk of shoulder injury in astronauts returning from space flight and highlight the need for further exploration of risk factors and preventative strategies.
Methods: Using The Lifetime Surveillance of Astronaut Health epidemiology database at National Aeronautics and Space Administration, a retrospective cohort study was conducted to assess the effect of space flight mission duration on rate of shoulder injury among astronauts. Inclusion criteria were all astronauts who participated in space flight regardless of age or space flight mission time. Exclusion criteria were all injuries occurring greater than 5 years following return to Earth. Patient demographics were compared between injured and noninjured cohorts with stratification by shoulder pathology.
Results: Of total 242 astronauts, 22 sustained a shoulder injury (9.09%) and 220 did not sustain a shoulder injury (90.91%). Average age of the noninjured cohort was 46 years and average age of the shoulder pathology cohort was 48 years. There were 8 rotator cuff tears, 5 cases of shoulder impingement, 5 shoulder contusions, and 4 rotator cuff sprains/strains. Compared to the noninjured cohort, incidence of all shoulder pathology was significantly associated with space flight missions greater than 6 months ($P < .001$). Rotator cuff tears in isolation, as well as rotator cuff and impingement pathology combined, were significantly associated with greater than 6 months in space flight ($P < .001$).
Conclusion: Space flight missions greater than 6 months were associated with increased risk of shoulder injury, especially rotator cuff tears. However, specific aspects of space flight that increase risk remain understudied. Shoulder injuries upon return to gravitational environments have the potential to negatively impact astronaut health and possibly jeopardize mission success, particularly as upper-extremity mobility is vital in the microgravity environment of space.

Humans have pushed the boundaries of space flight for decades. In recent years, the National Aeronautics and Space Administration (NASA) has prepared to embark on long-distance, long-duration space flights such as manned missions to Mars. Additionally, the recent advent of space tourism and commercial space flight permitted increased access to space flight for the general public.[1,24] While access and ambition in space flight have rapidly evolved, there are significant knowledge gaps in understanding the medical risk and injury profile of prolonged space travel, specifically regarding musculoskeletal health.[13]

Upper-extremity injuries are the most frequent orthopedic conditions in spaceflight.[20] In microgravity environments, humans can no longer rely on bipedal ambulation for mobility. As a result, astronauts utilize increased upper extremity–based propulsion and atypical shoulder movements to navigate and perform necessary work as functional quadrupeds. Furthermore, missions to the moon and Mars may require astronauts to forego the typical rehabilitation period upon return to gravitational environment given the need to perform immediate and more frequent extravehicular activity (EVA) and habitat building upon landing.[16,17] These requirements are postulated to significantly increase the risk of upper-extremity injuries.[3,6,10] As a result, NASA has upgraded "risk of injury and compromised performance due to EVA" to a red risk, or highest priority danger, for all surface exploring missions.[6]

This study is exempt from IRB approval at the authors' academic institution and National Aeronautics and Space Administration.

*Corresponding author: Benjamin Fiedler, MD, Department of Orthopedic Surgery, Baylor College of Medicine, 7200 Cambridge Street, Suite 10A, Houston, TX 77030, USA.

E-mail address: Benjamin.fiedler@bcm.edu (B. Fiedler).

https://doi.org/10.1016/j.jseint.2024.11.002

The increased demand and reliance upon the shoulder for more frequent and atypical activity is accompanied by space flight related physiologic change[5,15] and space suit–related changes in kinematics (Fig. 1).[23] The space flight environment has been implicated in reducing bone mineral density,[9] causing significant muscular atrophy,[14] increasing tendon laxity, and inciting enthesis degradation.[13,18] Space suit design has similarly been linked to increased risk for shoulder injury, as the pressurized suit inhibits anatomic mobility at the expense of increased force requirement within a standard arc of motion.[6]

Intramission and postmission shoulder injuries are not immediately life-threatening to astronauts. However, these injuries have the potential to severely limit the functional capacity of astronauts and jeopardize mission success.[6,25] Despite this, no study to date has identified the incidence of post–space flight shoulder injury, or variables that may increase injury risk. As a result, the present study sought to determine the risk of shoulder injury in astronauts returning from space flight and highlight the need for further exploration of risk factors and preventative strategies. It was hypothesized that increased mission duration and age at time of spaceflight would increase risk for shoulder injury.

Materials and methods

A retrospective cohort study was performed to compare and quantify rate of shoulder injury after return to earth among astronauts based on space flight mission duration. Study was granted approval by the Institutional Review Board. The Lifetime Surveillance of Astronaut Health (LSAH) epidemiology database at NASA was queried to provide data of shoulder injury in astronauts upon return from space. Inclusion criteria included all persons who participated in space flight regardless of age or space flight mission time. All injuries occurring greater than 5 years after return to earth were excluded given that there have been no data to support that injuries past the 5-year mark being associated with prior space travel. NASA epidemiologists reviewed and compiled the astronaut medical records, encompassing 1210 total person-years.

Due to safety and government-regulated data sharing confidentiality restrictions, astronaut epidemiological information was parsed into dichotomous categories by NASA LSAH before the study team was given access. Subjects were categorized by age greater than or less than 45 years at time of spaceflight, duration of single space flight mission greater than or less than 6 months, and time to injury from space flight of less than 1 year, 1 to 2 years, and 2 to 5 years. To maintain appropriate deidentification of data, NASA LSAH similarly provided categories of shoulder injuries related to rotator cuff partial or full thickness tears, shoulder impingement, shoulder muscle or ligament sprain or strain, and nonmuscular or ligamentous soft tissue shoulder injury.

Statistical analysis

With the available data, patient demographics were compared between injured and noninjured cohorts with stratification by shoulder pathology. Descriptive statistics were utilized to analyze differences in injury rates for each cohort. Student's t-test was used to determine differences in continuous variables. Chi-square was used to determine differences in categorical variables. Were the assumptive conditions of the chi-square not met, Fisher's Exact Test was used to determine statistical differences. Alpha was set to a significance level of 0.05 for all analyses. Statistical analyses were performed with IBM SPSS Statistics V.27.0 (IBM Corp., Armonk, NY, USA) and R software 3.6.1 (R Project; University of Auckland, Auckland, New Zealand).

Results

A total of 242 astronauts met inclusion criteria—220 in the noninjured cohort and 22 in the shoulder pathology cohort. The average age of the noninjured cohort was 46 years, while that of the shoulder pathology cohort was 48 years. Table I outlines cohort demographics.

In total, there were 8 rotator cuff tears, 5 cases of shoulder impingement, 5 shoulder contusions, and 4 rotator cuff sprains/strains as documented by the NASA LSAH. Table II highlights the comparison of shoulder pathology by mission length. Compared to the noninjured cohort, all shoulder pathology was significantly increased with space flight missions of greater than 6 months ($P < .001$). In stratification, rotator cuff and impingement injuries combined were significantly more frequent among individuals with greater than 6 months in space ($P < .001$). Similarly, rotator cuff tears in isolation were significantly more prevalent in astronauts with space flight greater than 6 months ($P < .001$); additionally, impingement in isolation was significantly dependent upon accrued space flight time ($P = .038$).

Discussion

As NASA continues to push the boundaries of space flight and a greater proportion of the population gains access to space flight via commercialization, understanding the medical risk profile of prolonged space flight becomes increasingly important. The majority of orthopedic space flight research focuses on bone mineral density alterations of the axial skeleton in microgravity environments.[22] However, there is a paucity of data exploring effects of space flight on nonaxial musculoskeletal systems and soft tissues, including the shoulder.[13] The present study sought to assess the impact of space flight duration on shoulder pathology and determined that missions longer than 6 months were associated with increased risk of shoulder injury upon return to Earth, especially rotator cuff tears.

No study to date has assessed the impact of space flight on shoulder injury upon return to Earth. However, limited research from space flight training and microgravity animal models provide useful data to understand potential contributing factors for increased risk of shoulder injury found in the present study. These include altered kinematics from pressurized space suits as well as possible physiologic changes in prolonged microgravity environments related to muscle atrophy and soft tissue laxity.[18,21]

Space suit–induced limitations to glenohumeral and scapulothoracic motion and required EVA are well documented causes of astronaut shoulder injury.[2,23] Nearly all studies on astronaut spacesuit and EVA-induced shoulder injury are from preflight training period with no postflight studies to date. A survey of 22 astronauts found that 64% experienced some degree of shoulder pain that they attributed to EVA training,[11] and 14% of the symptomatic group required preflight surgical intervention to address rotator cuff and labral pathology. This is a potentially serious concern given the cost and time required for astronaut selection, length and resources for training, and need for increased upper-extremity reliance to complete mission critical tasks. Further analysis of astronaut training–related injury determined an overall injury incidence of 9.67 EVA training–related shoulder injuries per 100 astronauts over 10 years.[12] NASA Tiger Team analysis of these preflight shoulder injuries determined that various spacesuit and training requirements increased risk for space flight training injury. Risk factors from the Tiger Team analysis identified limitations in normal shoulder kinematics in hard upper torso planar suit, inverted body positions, performing overhead tasks, use of heavy tools, repetitive motions, and increased frequency of training.[25]

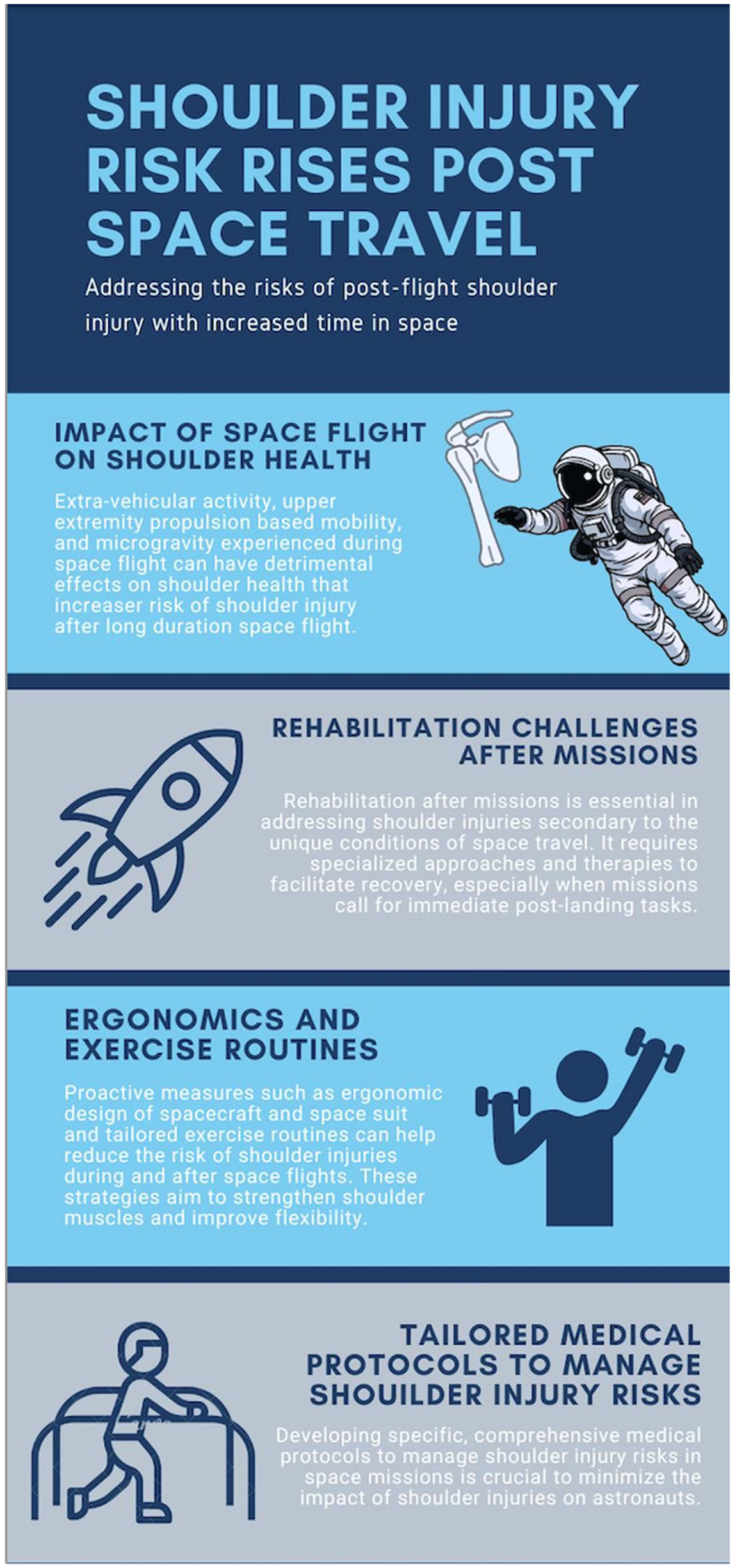

Figure 1 Infographic of shoulder injury after space flight.

While these risk factors have only been analyzed in the context of preflight training injury, they similarly apply to intraflight EVA. Additionally, the microgravity environment requires astronauts to repetitively use their arms and shoulders in all planes of motion, particularly overhead for propulsion-based mobility. They essentially function as obligate quadrupeds while suited during EVA and within spacecrafts. Astronauts participating in longer-duration space flight are inherently required to perform these higher risk

Table I
Demographic data of astronaut cohorts by shoulder injury vs. no shoulder injury including age, space flight time, and time to injury.

	Noninjured	Shoulder pathology	*P* value
N (%)	220 (90.9%)	22 (9.1%)	
Age			—[†]
<45 y	—[*]	10 (45.5%)	
>45 y	—[*]	12 (54.5%)	
Space flight			.001
<6 mo	200 (90.9%)	15 (68.2%)	
>6 mo	20 (9.1%)	7 (31.8%)	
Time to injury			—[†]
<1 y	—[*]	11 (50.0%)	
1-2 y	—[*]	4 (18.2%)	
3-5 y	—[*]	7 (31.8%)	

[*]Data not provided by NASA LSAH.
[†]Unable to calculate due to no injuries.
NASA, National Aeronautics and Space Administration; *LSAH*, Lifetime Surveillance of Astronaut Health.

Table II
Breakdown of specific astronaut shoulder pathology by single space flight mission length.

	< 6 mo	> 6 mo	*P* value
Rotator cuff tear[*]	3 (37.5%)	5 (62.5%)	.001
Impingement[*]	3 (60%)	2 (40%)	.038
Contusion	5 (100%)	0 (0%)	—[*]
Sprain/strain	4 (100%)	0 (0%)	—[*]
Noninjured	200 (90.09%)	20 (9.1%)	—[*]

[*]Unable to calculate due to no injuries.

activities at increased rates compared to astronauts on shorter-duration missions. It is likely that increased space suit time requirements and increased upper-extremity mobility activities contribute to elevated risk of postspace flight shoulder injury.[19]

Prolonged microgravity exposure may also alter the physiology of the rotator cuff and shoulder motion, thus increasing injury risk. Unfortunately, no data exist to date exploring the effects of microgravity on the human shoulder, and hypotheses are extrapolated from animal models. Murine studies of rats subjected to microgravity found altered expression of genes involved in myogenesis of the shoulder muscles.[21] Of note, altered gene expression was not associated histologic change or gross change. While some murine studies in microgravity or simulated microgravity found minimal alterations in enthesis capacity to tolerate anatomic loading after short-duration space flight, other studies found increased risk for rotator cuff enthesis injury or tear after unloading.[5] As no data exist on humans, it is difficult to truly assess the histologic and physiologic impact of space flight and microgravity on the human shoulder. Another area yet to be explored is the combined effect of known muscle atrophy and deconditioning in space flight and the increased reliance on upper extremity mobility. As space flight duration increases, the muscles further decondition and atrophy. Yet reliance on upper-extremity propulsion for mobility and mission critical task completion remains. It is possible that continued repetitive supraphysiologic upper-extremity use in the setting of deconditioning further contributes to shoulder pathology.

Astronaut age is another variable to consider. Age at time of rotator cuff injury in the present study suggests increased risk of accelerated cuff degradation in space flight. Current literature suggests degenerative rotator cuff tears are highly correlated with age, occurring at an average age of 58.7 years in the United Stats.[26] Yamaguchi et al illustrated that average age of patients without rotator cuff tears in their cohort was 48.7.[26] Conversely, in the present study the average age of astronauts with rotator cuff tears was 48 years old. Whether this proclivity for accelerated degeneration occurs as a result of spacesuit related motion constraints, microgravity induced physiologic change, or unique upper-extremity propulsion-based mobility requirements in space flight remains unknown. However, the answer is likely multifactorial. Each component requires further study to develop countermeasures.

Implications of the present study are numerous. Roughly 10% of astronauts included in the study suffered a functionally limiting shoulder injury within 5 years upon return from spaceflight. However risk of all cause shoulder injury and rotator cuff injury increased as a function of time in space with 17.9% of astronauts who participated in space flights greater than 6 months sustaining a rotator cuff tear, and 28.6% of astronauts who participated in space flights greater than 6 months experiencing any functionally limiting shoulder injury within 5 years upon return from space flight. For comparison, analysis of over 3000 professional baseball players that sustained an injury requiring placement on the disabled list found 17% of injured players sustained a shoulder injury.[7] Long distance, long-duration space flights such as missions to Mars have expected travel times greater than 6 months. Astronauts in these missions are further anticipated to forego the current return-to-Earth rehabilitation period, as they must initiate immediate habitat building and EVA on arrival.[4] Shoulder injuries limiting astronaut capacity to perform mission critical tasks may jeopardize mission success and astronaut well-being. Furthermore, while astronauts are typically exceptionally physically fit and well trained, commercial space flight and space tourism are surging in popularity as companies like Space X, Virgin Galactic, Axiom, and Blue Origin rapidly expand. These trends aim to increase access to space flight for the general population, who do not undergo similar selection and training. These variations in fitness and training level may place untrained and unprepared members of the general population at increased risk of shoulder injury in space flight. The consequences and frequency of shoulder injury after space flight highlight the need to better understand the underlying causes and risk factors of space flight—related shoulder injury to mitigate risk and optimize astronaut health, improve likelihood of mission success, and ensure safe commercial space travel for the general public. These findings similarly highlight the need to improve space suit design to better allow anatomic glenohumeral and scapulothoracic motion during activity.

The present study is not without limitations. To appropriately maintain confidential astronaut information, data were bucketed with broad categorization of type of injury and time in space flight. Information regarding specific tendons were injured, tear size, traumatic vs. degenerative, and impact on function were unavailable. Similar limitations occur when classifying space flight as short or long duration. 6 months was determined as the cut off by NASA LSAH. However, it is possible that the risk of shoulder injury is increased at shorter time periods between 0-6 months, but this was unable to be assessed by the present study. Furthermore, demographic data such as gender and race were not provided and these may impact results. Lastly, all injuries reported in the present study occurred within 5 years of return from space flight. It may be valuable to see longer-duration outcomes following space flight to determine lifetime incidence of shoulder injury and potential lasting effects of space flight.

Further research should seek to identify demographic risk factors related to age, gender, ethnicity, etc. and patient specific risk factors such as previous shoulder injury, or history of overhead athletics that may increase risk of space flight associated shoulder injury. Immediate preflight and postflight imaging of all astronauts with MRI better elucidate measurable changes in the shoulder as a result of space flight. If astronauts later suffer a shoulder injury, reference to preflight and immediate postflight imaging may help determine radiographic risk factors for injury and future prevention measures. Ultrasound may be a valuable tool to characterize intraflight anatomic change to the shoulder. Although less sensitive than MRI, the portable nature allows for real time, useful assessment of the rotator cuff intraflight,[8] and ultrasound is already a commonly utilized modality for separate conditions in space flight.

Conclusion

Space flight duration greater than 6 months was associated with increased risk of shoulder injury, especially rotator cuff tear. However, specific aspects of space flight that increase risk remain understudied. Shoulder injuries upon return to gravitational environment have the potential to negatively impact astronaut health and possibly jeopardize mission success.

Disclaimers:

Funding: No funding was disclosed by the authors.
Conflicts of interest: The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

References

1. Ahmed AS. Bezos and Branson: a cautionary tale for space exploration. 2021. KevinMD.com. [cited 2024 Aug 5];Available from: https://www.kevinmd.com/2021/07/bezos-and-branson-a-cautionary-tale-for-space-exploration.html.
2. Anderson AP, Newman DJ, Welsch RE. Statistical Evaluation of causal factors associated with astronaut shoulder injury in space suits. Aerosp Med Hum Perform 2015;86:606-13. https://doi.org/10.3357/AMHP.4220.2015.
3. Antonsen EL, Myers JG, Boley L, Arellano J, Kerstman E, Kadwa B, et al. Estimating medical risk in human spaceflight. NPJ Microgravity 2022;8:8. https://doi.org/10.1038/s41526-022-00193-9.
4. Bowman A. Hazard: distance from earth - NASA [cited 2024 Jul 31];Available from: https://www.nasa.gov/hrp/hazard-distance-from-earth/.
5. Deymier AC, Schwartz AG, Cai Z, Daulton TL, Pasteris JD, Genin GM, et al. The multiscale structural and mechanical effects of mouse supraspinatus muscle unloading on the mature enthesis. Acta Biomater 2019;83:302-13. https://doi.org/10.1016/j.actbio.2018.10.024.
6. Dunn J, Benson E, Norcross J, Newby N. Evidence report: risk of injury and compromised performance due to EVA operations. 2022 [cited 2024 Mar 31]. Available from: https://ntrs.nasa.gov/citations/20220004017.
7. Fares MY, Fares J, Baydoun H, Fares Y. Prevalence and patterns of shoulder injuries in major League baseball. Phys Sportsmed 2020;48:63-7. https://doi.org/10.1080/00913847.2019.1629705.
8. Farooqi AS, Lee A, Novikov D, Kelly AM, Li X, Kelly JD, et al. Diagnostic Accuracy of Ultrasonography for rotator cuff tears: a systematic review and meta-analysis. Orthop J Sports Med 2021;9:23259671211035106. https://doi.org/10.1177/23259671211035106.
9. Genah S, Monici M, Morbidelli L. The effect of space travel on bone metabolism: considerations on today's major challenges and advances in pharmacology. Int J Mol Sci 2021;22:4585. https://doi.org/10.3390/ijms22094585.
10. Gernhardt ML, Jones JA, Scheuring RA, Abercromby AF, Tuxhorn JA, Norcross JR. Risk of compromised EVA performance and Crew health due to Inadequate EVA suit systems. 2009. Available from, https://humanresearchroadmap.nasa.gov/evidence/reports/eva%20suit.pdf.
11. Johnson B, Williams D, Cupples JS. Results from an Investigation into extravehicular activity (EVA) training related shoulder injuries. In: Space 2004 Conference and Exhibit. American Institute of Aeronautics and Astronautics [cited 2024 Jul 31]. Available from: https://arc.aiaa.org/doi/abs/10.2514/6.2004-5887.
12. Laughlin MS, Murray JD, Foy M, Wear ML, Van Baalen M. Shoulder injury incidence rates in NASA astronauts. 2014 [cited 2024 Mar 31];Available from: https://ntrs.nasa.gov/citations/20150003018.
13. Lee Satcher R, Fiedler B, Ghali A, Dirschl DR. Effect of spaceflight and microgravity on the musculoskeletal system: a review. J Am Acad Orthop Surg 2024;32:535-41. https://doi.org/10.5435/JAAOS-D-23-00954.
14. Lee S-P, Chien L-C, Chin T, Fox H, Gutierrez J. Financial difficulty in community-dwelling persons with lower limb loss is associated with reduced self-perceived health and wellbeing. Prosthet Orthot Int 2020;44:290-7. https://doi.org/10.1177/0309364620921756.
15. Loflin B, Cluff K, Griffith J, Mohammed N. Identification of shoulder joint clearance in space suit using electromagnetic resonant spiral proximity sensor for injury prevention. Acta Astronaut 2020;170:46-54. https://doi.org/10.1016/j.actaastro.2020.01.013.
16. Nieschwitz B, Guilliams ME, Hoellen D, Loehr J. Post flight reconditioning for US astronauts returning from the International space station. 2011 [cited 2024 Aug 5];Available from: https://ntrs.nasa.gov/citations/20110020318.
17. Petersen N, Lambrecht G, Scott J, Hirsch N, Stokes M, Mester J. Postflight reconditioning for European Astronauts − a case report of recovery after six months in space. Musculoskelet Sci Practice 2017;27:S23-31. https://doi.org/10.1016/j.msksp.2016.12.010.
18. Roffino S, Camy C, Foucault-Bertaud A, Lamy E, Pithioux M, Chopard A. Negative impact of disuse and unloading on tendon enthesis structure and function. Life Sci Space Res 2021;29:46-52. https://doi.org/10.1016/j.lssr.2021.03.001.
19. Scheuring R, McCulloch P, Van Baalen M, Watson R, Bowen S, Blatt T. Shoulder injuries in US astronauts related to EVA suit design. 2012 [cited 2024 Jul 31];Available from: https://ntrs.nasa.gov/citations/20120009404.
20. Scheuring RA, Mathers CH, Jones JA, Wear ML. Musculoskeletal injuries and minor trauma in space: incidence and injury mechanisms in U.S. astronauts. Aviat Space Environ Med 2009;80:117-24. https://doi.org/10.3357/asem.2270.2009.
21. Shen H, Lim C, Schwartz AG, Andreev-Andrievskiy A, Deymier AC, Thomopoulos S. Effects of spaceflight on the muscles of the murine shoulder. FASEB J 2017;31:5466-77. https://doi.org/10.1096/fj.201700320R.
22. Stavnichuk M, Mikolajewicz N, Corlett T, Morris M, Komarova SV. A systematic review and meta-analysis of bone loss in space travelers. NPJ Microgravity 2020;6:13. https://doi.org/10.1038/s41526-020-0103-2.
23. Strauss S, Krog RL, Feiveson AH. Extravehicular mobility unit training and astronaut injuries. Aviat Space Environ Med 2005;76:469-74.
24. Weinzierl M, Sarang M. The commercial space age is Here [cited 2024 Aug 5]; Available from: https://hbr.org/2021/02/the-commercial-space-age-is-here.
25. Williams DR, Johnson BJ. EMU shoulder injury Tiger team report. 2003 [cited 2024 Mar 31]. Available from: https://ntrs.nasa.gov/citations/20040200968.
26. Yamaguchi K, Ditsios K, Middleton WD, Hildebolt CF, Galatz LM, Teefey SA. The demographic and morphological features of rotator cuff disease. A comparison of asymptomatic and symptomatic shoulders. J Bone Joint Surg Am 2006;88:1699-704. https://doi.org/10.2106/JBJS.E.00835.