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NASA Human Research Program – Exploration Medical Capability: Approach to Musculoskeletal Injuries

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1 Introduction

Exploration-class missions will be longer in duration and farther away from Earth. These factors paired with labor-intensive tasks associated with the mission will increase the likelihood of musculoskeletal injuries such as sprains and strains. The diagnosis of musculoskeletal injuries is complex as it involves the need for a proper history, a physical examination, and the potential need for diagnostic imaging. However, a key concern is whether proper equipment will be afforded for such missions from the standpoint of treatment and rehabilitation.

2 Purpose

The purpose of this paper is to review and summarize the scope and incidence of in-flight musculoskeletal injuries while defining the requirements for terrestrial treatment. Additionally, the role of rehabilitation during recovery and the impact of not having the necessary equipment will be explored.

3 Physical Exam

The diagnosis of a musculoskeletal injury begins with an injury history and physical exam. Muscle and tendon strain injuries are detected by visual inspection for swelling (caused by inflammation or hematoma) or by palpation to elicit tenderness. Hydrostatic pressure plays a role in fluid distribution during normal upright activity and following injury on Earth. Extravascular fluid migrates distally under the influence of gravity as a bruise heals or as a hematoma is reabsorbed, and elevation to heart level or above is part of the recommended early Rest-Ice-Compression-Elevation (RICE) therapy. With a transition to microgravity, loss of the hydrostatic pressure gradient causes a cephalad fluid shift that leads to loss of plasma volume, thinning of the legs, and facial edema. The changes are sufficiently significant to alter the routine physical exam.[1] With the loss of hydrostatic pressure and gravity, edema and interstitial/extravascular fluid distribution during healing are expected to differ from that in 1 g.

4 Diagnostic Imaging

Radiographs, computed tomography (CT), magnetic resonance (MR) imaging, and ultrasound (US) imaging aid in the terrestrial diagnosis of musculoskeletal injury and other types of chronic musculoskeletal pathology. With true volumetric high-resolution imaging, MR is the gold standard for imaging musculoskeletal tissue. However, the equipment is not currently a practical option for space flight due to its size, power, and other technical limitations (e.g., no liquid helium).

Ultrasound, with the rapid development of digital phased-array systems and software diagnostics, has become the standard for structural imaging of musculoskeletal tissue with its low cost, small physical size, and accessibility to the medical community. A significant advantage for diagnosing soft-tissue injuries is real-time tissue imaging during functional manipulation of the limb and injured tissue. With the trained eye, a broad range of acute musculotendinous and ligamentous injuries are detectable such as junction (MTJ) tears, tendinopathy, enthesopathy, and avulsion fractures.[2-6]

Ultrasound has been, and will continue to be, a part of the onboard suite of medical diagnostic tools available to astronauts during long-duration space flight as its utility does not appear to be affected by changes in hydrostatic pressure and gravity.[7] However, lack of sufficient training is a serious concern. A crew medical officer (CMO) receives about 40 hours of medical training. With a fraction of this relevant to ultrasound imaging, there is a natural concern for operating and interpreting ultrasound images without assistance. Dr. Scott Dulchavsky at the Henry Ford Hospital and his team at the National Space Biomedical Research Institute (NSBRI) are developing just-in-time ultrasound training for NASA missions and for remote-location imaging on Earth. Just-in-time training consists of a 2.5 hour didactic and hands-on training session and one hour of computer-based learning (Onboard Proficiency Enhancement). The method pairs the remotely-located, just-in-time-trained individual with a skilled clinician who guides the procedure in near real time. The technique was successfully tested on the International Space Station (ISS). A comprehensive shoulder examination was conducted on two ISS crewmembers; one crewmember was the subject while the other took images with help from an experienced clinician on the ground. Furthermore, these were deemed to be good-quality images.[7]

5 General Diagnoses

Ligament sprains, and muscle and tendon strains are routinely encountered injuries, which result when fibers—collagen fibers in ligament and tendon, and both myofibers and connective tissue fibers in muscle—are stretched beyond their elastic limit and tear. A three-tiered system has been established to evaluate sprains and strains. The following table (http://www.orthoinfo.aaos.org) lists the criteria for characterizing ligament sprains:

Grade 1: (mild sprain) Minimal impairment, tenderness, and swelling; microscopic tearing of collagen fibers.

Grade 2: (moderate sprain) Moderate impairment, tenderness, and swelling; complete tears of some collagen fibers.

Grade 3: (severe sprain) Severe impairment and significant swelling and tenderness; complete rupture of the ligament.

Tendon and muscle strains are similarly graded with the exception that myofibers are torn in muscle.

Sites of sprains/strains include the following:

- Shoulder
- Elbow
- Wrist
- Hip

- Knee
- Ankle

a. Back/Neck Injury

Scheuring et al.[8] have compiled a comprehensive database of U.S. astronaut in-flight musculoskeletal injuries spanning the entire history of NASA's human space flight experience, from the Gemini program up to the ISS program. The authors identified 219 musculoskeletal injuries: 70 abrasions (32%); 67 contusions (31%); 53 sprains/strains (24%); 28 lacerations (13%); and one finger dislocation. See Table II[9] for the source of the data. Contusions and sprains/strains comprise 55% of the total from this data set (120 injuries out of 219). The 120 contusion/sprain/strain injuries occurred during the performance of the following activities:

- General spacecraft crew activity (30/120, 25%)
- Routine daily exercise (30/120, 25%)
- Interactions with Extravehicular Activity (EVA) and Launch and Entry (LES) space suits (43/120, 36%); and EVA activity, independent of space-suit interaction (4/120, 3%)

The remaining 13 incidents (11%) were either of unknown etiology or occurred while performing experiments.

Furthermore, neck injuries, back injuries, and space adaptation back pain may impact mission success and crew member health during space flight missions due to the potential impairments associated with these conditions. Retrospective analyses of in-flight data revealed the following.

Scheuring et al.[9] reported the relatively high incidence of in-flight neck injuries as 0.34 events/person-year, and the incidence of in-flight back injuries as 1.17 events/person-year. Although the majority of the injuries were minor and no in-flight musculoskeletal injury to date has caused a failure to complete mission objectives, reports from astronauts suggest that such injuries could impact mission objectives given the right circumstances, such as extended mission operations.[9]

A space adaptation back pain incidence of 52% was reported among U.S. astronauts.[10] The majority of these episodes was mild or moderate and had no mission impact.

A large number of back injuries have occurred on the ISS, with most of these injuries being minor muscle strains caused while using the Interim Resistive Exercise Device (IRED). In-flight neck injury has been associated with injuries that occurred pre-flight or even prior to the astronaut's selection into the astronaut corps. A fracture of the vertebral spine is thought to be an unlikely event as it would only be expected with significant forces of a traumatic injury or development of osteopenia/osteoporosis during the mission.

Back pain is one of the most common diagnoses across gender, socioeconomic background, age, and ethnic groups with more than 70% of people in developed countries who will be afflicted during their lifetime. Nevertheless, most patients should recover quickly, without residual loss of function; however, recurrence is common.[11] Determining the etiology of back pain is paramount as this ultimately guides treatment. The patient's history and physical examination are critical in deciphering the underlying cause of their back pain, which may be placed into one of three categories: nonspecific back pain, back pain associated with radiculopathy or spinal stenosis, or back pain associated with another cause.[12]

Additionally, back pain may be subcategorized by the length of symptomatology – acute (<4 weeks), sub-acute, or chronic (>4 weeks). For the purposes of this paper, it is important to be aware of other causes of back pain; however, the incidence of these etiologies may be sparse. Other causes that should be considered, although unlikely, would be abdominal aortic aneurysm, pancreatitis, cholelithiasis, discitis, tumor, fracture, and cauda equina syndrome.

Low back pain associated with radiculopathy or spinal stenosis may be associated with neurologic symptoms. The assessment of a patient with radicular symptoms should include an evaluation of the motor function of the L4 (dorsiflexion at the ankle), L5 (extension of the large toe), and S1 (plantarflexion at the ankle) regions. Lumbar stenosis, however, generally has a history of patients with back pain that is either relieved by leaning forward or sitting.[12]

In cases involving either radiculopathy or spinal stenosis, further work-up and surgical intervention may be necessary. These etiologies of back pain are worth noting; however, they are potentially less common in our population. As a result, the majority of this paper shall focus on nonspecific back pain.

Risk factors have been identified amongst athletes for lumbar back pain, and these may have close similarities to the risks within the astronaut population. Risk factors include history of back injury, poor conditioning, abrupt increase in training, and excessive or repetitive loading.[13] Therefore, preventive measures should be considered for those who meet the aforementioned risk profile.

Nonspecific back pain may be the result of a strain, sprain, or spasm. The history for these patients may include pain with specific movements without accompanying neurologic symptoms.[13] The peak incidence of pain for these patients will be in the first 24 to 48 hours, which gradually resolves. Treatments include non-steroidal anti-inflammatory medications, narcotics, topical analgesics, oral corticosteroids, activity modification, massage therapy, antidepressants, injections, traction, physical therapy, cognitive behavioral therapy, cryotherapy, electrical stimulation through high voltage pulse galvanic stimulation, and transcutaneous electric nerve stimulation.[11,13] Although many treatment options are available, Shen et al.[11] stated that 70-90% of patients would have improvement in back pain within the first month regardless of treatment. Dreisinger and Nelson[14] have also stated that acute injuries will generally resolve spontaneously, while chronic injuries may need some level of rehabilitation. Additionally**,** other studies have indicated that there is insufficient evidence to support any particular rehabilitation for the treatment of low back pain.[15,16] Patient education cannot be overlooked as part of the treatment cocktail as this allows the patient to be more engaged and an active participant in their care. The strongest evidence supports the utilization of nonsteroidal anti-inflammatory drugs (NSAIDs), patient education, and advocating patients to remain active as the first line of treatment for acute low back pain.[11-13] A table constructed by Hopkins and White[17] found below effectively outlines how to manage the athlete with low back injuries. The content of the table may be helpful and should be considered as a guideline for the astronaut patient population.

Three-Cycle System for treatment of non-radicular low back pain in athletes as described by Hopkins and White[17]	
Cycle IA	Immediate return to full activity; games and practices are not missed
Cycle IB	Games and body contact are prohibited; practice is reduced by 75% (duration, intensity, frequency); NSAIDs, physical therapy optional; back to competition in four days
Cycle IC	Games and body contact are prohibited; practice is reduced by 50%; NSAIDs, physical therapy optional; advance to Cycle B in four days
Cycle II	Games and practice are prohibited; NSAIDs, two days of bed rest followed by physical therapy for abdominal strengthening for five days; advance to Cycle I
Cycle III	Games and practice are prohibited; NSAIDs, two days of bed rest followed by physical therapy for abdominal and paraspinal strengthening, stationary bicycling, walking, or swimming

b. Shoulder Sprain/Strain

According to Scheuring et al.[9], 22 events of shoulder sprain or strain have occurred in 26.45 person years with a calculated incidence of 0.83 events per person-year and are the most common injuries experienced by astronauts. Rotator cuff disorders are very common in the general population, and it is likely that these injuries may be responsible for the majority of the shoulder injuries that Scheuring discussed. The rotator cuff is made up of four muscles – the supraspinatus, infraspinatus, teres minor, and subscapularis. There are several physical examination techniques that may be employed to locate the specific muscle responsible for an individual's pathology; however, imaging has been the mainstay in providing an adequate diagnosis. MRI is considered the "gold standard" in providing these diagnoses, yet this is a modality that will be unavailable during space flight. Therefore, activity modification, NSAIDs, and physical therapy exercises that focus on the rotator cuff should be employed liberally. For individuals whose pain remains refractory, a corticosteroid injection should be considered.

c. Elbow Sprain/Strain

Scheuring et al.[9] also described 12 events of elbow sprain or strain that occurred in 26.45 person years with a calculated incidence of 0.45 events per person-year.

For those individuals presenting with medial/lateral epicondylitis, activity modification should be considered as a first-line treatment, with 83% success rate at 1 year, and which may be used in conjunction with NSAIDs.[18] For individuals who have symptoms that are recalcitrant to this therapy, corticosteroid injections (Triamcinolone 10 mg) may be considered. Rehabilitation may also be used as an adjuvant, with isotonic eccentric hand exercises (for lateral epicondylitis) and concentric hand exercises (for medial epicondylitis). Once again, in a microgravity environment elastic bands may be employed, as they do not require gravity as a source of resistance.

d. Wrist Sprain/Strain

Scheuring et al.[9] described five events of wrist sprain or strain, which occurred in 26.45 person years with a calculated incidence of 0.18904 events per person-year. Tendinopathy from repetitive motion is a common cause of wrist pain. All tendinopathies may be treated with activity modification, splints, NSAIDs, and the potential corticosteroid injection. The wrist may succumb to overuse injuries such as De Quervain's tenosynovitis or carpal tunnel syndrome. Advanced stages may require surgical intervention; however, it is neither urgent nor emergent and conservative care may suffice until definitive care is available.

e. Hip Sprain/Strain

According to Scheuring et al.,[9] four events of hip sprain or strain occurred in 26.45 person years with a calculated incidence of 0.15 events per person-year. It is hypothesized that muscles that cross two joints are more likely to sustain a strain (i.e., rectus femoris, gracilis, and sartorius), as they are found to be less flexible.

The table below demonstrates a rehabilitation protocol for lower extremities as proposed by Nuccion, Hunter, and Finerman.[19] Applying the same principles to the upper extremity may also be considered.

Phase	Goals	Treatment	Time Frame
I	Reduce Pain, inflammation and bleeding	Rest, ice, and compression; crutches as needed*	48-72 hours
II	Regain range of motion	Passive range of motion, heat, ultrasound, electrical muscle stimulation	72 hours to 1 week
III	Increase strength, flexibility and endurance	Isometrics, well-leg cycling	1-3 weeks
IV	Increase strength and coordination	Isotonic and isokinetic exercises	3-4 weeks
V	Return to competition	Sport specific training	4-6 weeks

* Unnecessary in an anti-gravity situation

The focus of rehabilitation should be improved mobility, stability, and strengthening of the muscles surrounding the injured joint. However, the ultimate goal of any rehabilitation protocol is a rapid, yet safe return to prior activities with an overall improvement in performance.

f. Knee Sprain/Strain

Scheuring et al.[9] reported seven events of knee sprain or strain, which occurred in 26.45 person years with a calculated incidence of 0.26465 events per person-year.

The knee, as any joint, is provided its dynamic stability by its musculotendinous attachments, and its static stability is provided by its ligamentous attachments. However, the menisci, which are seated upon the tibial plateau, are unique and may be an additional source of pathology that must be considered when evaluating the painful knee.

In general, knee sprains and strains may be treated with NSAIDs, RICE therapy, a brace (hinged knee brace or knee immobilizer), and progressive weight bearing exercises. A hinged knee brace may be preferable as this allows the individual to initially restrict motion, yet progressively increase the range of motion, as full extension should occur within the first week. If an individual requires rehabilitation, it should focus on quadriceps and hamstring strengthening. If a complete ligament tear is suspected, the protocol remains unchanged. Complete ligament tears do not require acute surgical intervention, and strengthening of the quadriceps and hamstrings is still recommended as a first-line treatment.

Knee rehabilitation may utilize either open chain or closed chain modalities. In closed chain exercises, the terminal end of the kinetic chain remains at a fixed point; therefore, in the lower extremity the feet are fixed to the ground. Currently, closed chain modalities are considered preferable for lower extremity rehabilitation as these mimic the physiologic and biomechanical properties of axial loads.[20] Conversely, open chain exercises, when the terminal end of the kinetic chain is not fixed (i.e., seated leg extensions), may be of greater utility in space flight as it may be more difficult to simulate the normal physiologic and biomechanical properties of the lower extremity in the absence of gravity.

Tendinopathies about the knee include both the patellar tendon and quadriceps tendon. These injuries also will benefit from RICE therapy. Additionally, stretching and isometric exercises may be employed immediately; however, isokinetic and isotonic exercises should only be utilized after the pain has improved.

Meniscal tears may be an additional source of knee pathology and may be identified with joint line tenderness. Without the use of an MR scan in space flight, diagnosis of meniscal pathology may rely heavily on physical exam. As the meniscus is a relatively avascular structure, meniscal tears generally do not heal; therefore, unlike the aforementioned knee injuries, meniscal pathology requires surgical intervention. Consequently, those who are considered to have a meniscal tear should be treated with appropriate analgesics for symptomatic relief.

g. Ankle Sprain/Strain

Scheuring et al.[9] also reported 11 events of ankle sprain or strain have occurred in 26.45 person years with a calculated incidence of 0.42 events per person-year.

The current favored treatment method for ankles strains/sprains follows the general RICE protocol as outlined below. Additionally, NSAIDs should be considered a first line analgesic during the acute inflammatory phase. A short period of immobilization, generally 48 hours, may be employed, as motion at the site of injury may exacerbate the individual's symptomatology. Immobilization may include the use of an aircast, a cast boot [i.e., controlled ankle motion (CAM) boot], ace bandage or tape, or a Velcro brace. Early mobilization is strongly recommended to prevent subsequent stiffness and a delayed recovery phase, and to provide a quicker return to work.

For individuals with chronic or recurrent ankle sprains, physical therapy should still be considered the treatment modality of choice, as there is currently no role for surgical intervention during space flight. Functional bracing may be considered in conjunction with a physical therapy protocol that focuses on motor strength of the lateral compartment (peroneal muscles) of the lower extremity, and coordination. Since space flight precludes resistance exercises that require gravity, exercises that employ elastic bands should be considered as this may facilitate the strengthening of muscle groups required for dorsiflexion, plantarflexion, inversion, and eversion.

6 Injury Prevention

Injury prevention is the most effective mitigation strategy for musculoskeletal sprains/strains, neck pain, and back injuries. The following factors are activity modifications that may assist in the reduction of injury incidence.

a. Functional exercise

The most significant injury-prevention factor, especially for sprains and strains, is a well-conditioned musculoskeletal system prepared for the activities to be undertaken. A sudden increase in the daily frequency and magnitude of musculoskeletal loading increases the risk of injury. Astronauts receive individualized preflight and in-flight training regimens. Safety training in EVA and Intravehicular Activity (IVA) procedures is presumed to have mitigated the likelihood and severity of back injuries that have occurred in flight; however, safety training is not expected to decrease the likelihood of developing space adaptation back pain. In order to minimize the risk of injury and the inability to complete a task, the NASA Astronaut Strength, Conditioning, and Rehabilitation (ASCR) group tailors preflight and in-flight exercise routines to fitness levels and mission objectives. Astronaut performance is monitored throughout the flight and feedback provided to the astronaut. A number of recommendations for improving astronaut performance and safety were put forward at the 2005 NASA Musculoskeletal Summit;[21] however, full capability to conduct functional exercise activity in space is not yet feasible with the current onboard hardware. Efforts are focused on developing equipment and protocols that deliver greater intensity (higher forces) to maintain the musculoskeletal system and reduce exercise time. Higher levels of force applied during daily exercise will likely increase the injury incident rate and severity of soft-tissue injuries. Connective tissue injuries are of particular concern because of their propensity to become chronic and because of the length of time it takes to heal. Risks within the Human Health and Countermeasures (HHC) Element of the Human Research Program (HRP) target decrements in performance (strength, endurance, aerobic capacity)[22] and not specifically risk of injury, although the two are certainly related.

b. Warm-up and stretching

The evidence for stretching (ballistic and static) and warm-up activities, while generally accepted as good practice, is inconsistent. The prevailing view has been that stretching and warm-up activities increase joint range of motion, increase muscle temperature, and alter the passive viscoelastic properties of the musculotendon unit, which protect the muscle from strain injury.[23,24] Witvrouw et al.[25] argue that the benefit of a long-term consistent stretching program, shown to increase musculotendon compliance, is activity specific. More compliant musculotendon units store more strain energy and reduce peak forces during a stretch-shortening cycle (SSC) characteristic of explosive activities (such as jump-like activities), reducing the risk of injury in these types of activities. For low-intensity activities with little or no SSCs, the benefit of increasing musculotendon compliance is minimal and may hinder performance, but then these activities have a lower incidence of injury. The value of pre-activity stretching is less clear. Compliance increases immediately following stretching, but is not sustained and is not affected by an increase in muscle temperature of three to four degrees (physiologic range).[26,27] These results indicate that if a pre-activity stretching warm-up is to be effective, its action must be preventative in the first, approximately, ten minutes of activity. Astronauts begin their preflight and in-flight exercise protocols with a warm-up phase consisting of the exercise performed at a reduced intensity.

c. Ergonomic factors

Poor design contributes to muscle strains and repetitive stress injuries. Scheuring et al.[9] suggest that designers could/should use injury incidence data to reduce injuries through better design for zero-g and partial-g activities. The Extravehicular Mobility Unit (EMU)—the space suit used for EVAs—is an important and illustrative example of hardware that, when used as designed, nonetheless induced overuse injuries in the shoulder. Problems were first noted with the suit during preflight EVA training activity in the Neutral Buoyancy Laboratory. A number of actions were recommended to mitigate the risk including suit re-design, reduced high-risk activities, and enhanced conditioning.[28] HRP has an ongoing effort within HHC to develop an EVA suit that optimizes human health and performance.[22] Problems with the EMU highlight the importance of understanding the unique ergonomics of living and carrying out activities in space.

d. Nutrition

Trappe et al.[29] expressed concern that inadequate energy intake among astronauts may lead to muscle wasting. Nutrition, hydration, and electrolyte balance affect performance, fatigue, injury, and recovery.[30] The HHC Element of HRP is studying the influence of nutritional factors on the "Risk of impaired performance due to reduced muscle mass, strength, and endurance." [See HRP Integrated Research Plan (IRP)[22] and the Standing Review Panel (SRP) Final Report[31]] Hence, a focus of the nutrition gaps is mitigating reduced muscle mass and loss of performance, which relate indirectly to muscle injury.

e. Screening for risk factors

With the exception of screening for pre-existing conditions that may cause functional impairment of crew members during training or in flight, asymptomatic crew members are not screened for risk factors related to predisposition to various injuries.

7 Treatment of Injury and Rehabilitation

a. RICE

RICE therapy is the universally practiced initial-stage treatment for soft-tissue sprains and strains applied immediately after injury and throughout the inflammatory stage of healing (24-72 hours). The rationale for applying intermittent ice, compression, and elevation immediately post-injury is to reduce pain, edema, and inflammation. The end objective, however, is not edema or inflammation reduction; rather it is to enhance the healing response of soft tissue injuries. Rest may allow the healing process to occur and simultaneously provide symptomatic relief. A period of immobilization (i.e., a night splint) should be considered during the resting phase.[32]

b. Cold therapy

Studies have investigated the effectiveness of 1) cold gels compared to placebo gel: cold gel reported better;[33] 2) icing 20 minutes every hour or alternating 10 minutes on/10 minutes off/10 minutes on: no difference;[34] 3) icing with and without therapeutic exercise: with exercise better;[35] and 4) immediate compression (no ice) compared to no treatment: no difference.[36] Matsen et al.[37] reported no reduction in swelling at any temperature decrease in a rabbit limb model following 24 hours of water-immersion cooling. In fact, a reduction in temperature of 15 °C or more led to a significant increase in swelling. McMaster and Liddle are cited in reviews as providing evidence that ice therapy reduces edema, but their data actually support Matsen et al. at the colder immersion temperature of 20 °C, and provide weak evidence at best of a positive cooling effect on edema. In addition, their intermittent cooling experiment, similar to what is advocated today, increased swelling.[38]

The data are inconclusive and contradictory. While some insight is gained from the results, these studies beg the question: Does early ice therapy improve soft tissue healing? Judging from recent reviews on the subject,[39-41] the jury is out on whether cryotherapy (i.e., RICE) actually promotes healing or not, in spite of its widespread application.

c. Heat therapy

No evidence exists to suggest that heat therapy or cycling hot and cold enhances soft tissue healing during the early inflammation stage of injury recovery.[42] As part of the comprehensive strategy for treating sprains and strains in space, the role of heat therapy—if it is to have a role—must be identified.

If the above reviews are representative of the state of science, these issues need to be addressed prior to moving forward with the design of a cooling or heating system for long-duration space flight.

d. Cold/Heat therapy technologies

There are several commercial cold pack technologies. The standard treatment is ice at 0 °C, which is a safe temperature for cooling tissue. An ice-water cold pack is effective because it is a phase change system with a high solid-to-liquid latent heat of fusion. Changing ice at 0 °C to water at 0 °C requires a considerable amount of absorbed heat. Phase change systems are effective because the liquid remains at approximately the transition temperature, 0 °C for an ice-water system, until the transformation is complete. Common gel packs are also phase change systems with additives to produce a gel. Typically, a chemical and a solvent (e.g., ammonium chloride and water), are kept separate in a pack until needed. When allowed to mix, the system undergoes an endothermic reaction, absorbing ambient heat and reducing the temperature of the solution. The reaction is not reversible; thus, the chemical reaction system is for one-time use only. Thermoelectric cooling is another potential cooling technology; however, the drawback is low efficiency and the necessity to dissipate the heat from the skin and heat produced by the inefficient system. Additionally, hot/cold packs (SofTouch Wraps) contain a form-fitting clay-like material that can be heated and cooled repeatedly using vehicle resources; this pack is currently on ISS. Whether these heating and cooling systems are adequate to treat soft-tissue injuries during an exploration-class mission will be determined from an upfront analysis of expected injury incidence rate, resulting treatment requirements, and vehicle space and power availability.

e. Pharmaceuticals

Classically, corticosteroids have been utilized for tendinopathy refractory to conservative measures and are still considered a mainstay for care. Over-the-counter and prescription analgesics and NSAIDs may be used to reduce inflammation from strains and sprains and are considered the first line treatment for mild to moderate back injuries. However, back injuries can encompass a wide range of possible scenarios, ranging from muscle strain to spinal cord injury.

f. Immobilization

Additionally, immobilization at night may be used for tendon tears as these injuries may cause pain that is refractory to NSAIDs and elevation. Immobilization may be achieved utilizing various methods including slings, splints, and bracing devices. Appropriate spine stabilization techniques and non-surgical treatments of fractures (i.e., traction devices, c-collar, back board) for the microgravity environment should also be available.

g. Platelet-rich plasma

Platelet-rich plasma has become an area of increasing interest as an agent that may potentially enhance muscle and tendon healing; however, there has been little clinical evidence to support this theory.[43]

h. Extracorporeal shock wave (ECSW) therapy

Treatment of chronic tendinopathies has also been explored with the use of ECSW therapy.[44] This has proven to be beneficial in the use of calcific tendinosis and plantar fasciitis; however, its utility in other tendinopathies has not been fully explained.

i. Physical therapy

Physical therapy should be considered as a treatment for all injuries (strains and sprains), which may be provided by an Astronaut Strength, Conditioning and Rehabilitation Specialist (ASCRS) to the astronaut through e-mail, video uplink, or during a private medical conference. For example, effective treatment measures for space adaptation back pain [fetal positioning for space adaptation back pain, acetaminophen, ibuprofen, spine loading on the treadmill or the Advanced Resistive Exercise Device (ARED)] can be addressed by ASCRS during ARED training sessions in conjunction with consultations with the Flight Surgeon.

8 Role of Rehabilitation

The implication of strains and sprains for individuals who do not receive physical therapy has yet to be fully explained. Currently, there are some studies that suggest muscle strains and sprains may resolve spontaneously[45] and most of the current treatment modalities are employed empirically without clinical or basic scientific research to determine the effects of these treatments.[46] In a best evidence summary of systematic reviews concerning the effects of exercise therapy by Smidt et al.,[47] the authors determined that there was insufficient evidence to support or refute therapy for shoulder pain, neck pain, repetitive strain injury, and acute low back pain. However, they did find therapy effective for sub-acute (6-12 weeks) and chronic (>12 weeks) back pain.

As discussed previously, acute back sprains and strains will resolve spontaneously without a directed rehabilitation program; however, in the setting of chronic back pain, rehabilitation may be useful in improving mobility and decreasing pain. The Hopkins and White table may be a useful guideline as a potential rehabilitation protocol for low back pain and should be considered accordingly.

Additionally, a study reviewed the literature in regards to knee pain and physical therapy and only found one randomized control study that evaluated the use of physical therapy in the setting of patellar tendonitis. However, the randomized control trial did not provide clinically relevant outcomes nor did it evaluate knee sprains and other types of strains; therefore, it is difficult to support or refute the role of physical therapy in these settings.[48]

In a randomized controlled trial of physical therapy versus education on early mobilization for ankle sprains, Holme et al.[49] demonstrated a difference in postural control and isometric ankle strength at 6 weeks. However, there were no differences noted at 4 months and the most compelling evidence was that the risk of re-injury was significantly reduced for those who participated in supervised physical therapy. Guillodo et al.[50] also concluded that rehabilitation may not affect healing of patients at 1 year, and additionally did not note any increase in the prevention of re-injury.

A thorough literature search did not demonstrate any studies that evaluated the utility of physical therapy in the setting of wrist and hip sprain/strain. Therefore, the literature does not currently provide enough evidence to support or refute the role of physical therapy in these settings.

9 Conclusion

An individual’s impairment status without physical therapy is difficult to assess as there are many factors that must be considered: 1) nature of the injury (Grades I, II, or III), 2) ability to compensate for an injury, 3) pre-functional levels, 4) and age.[51] Therefore, it may be difficult to assess the potential sequelae of impairment that occur for those who do not undergo rehabilitation. However, physical therapy may still be considered for these individuals, as the literature has not demonstrated any harm, though the benefits remain unclear.

Lastly, the requirements to provide physical therapy in space may be facilitated without extensive equipment or expense while the benefits may include an expeditious return to previous activity levels with improved strength and motor control. Therefore, although the evidence may not be clear, the potential benefits of physical therapy outweigh any potential harm.

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13. ABSTRACT *(Maximum 200 words)*

Exploration-class missions will be longer in duration and farther away from Earth. These factors paired with labor-intensive tasks associated with the mission will increase the likelihood of musculoskeletal injuries such as sprains and strains. The diagnosis of musculoskeletal injuries is complex as it involves the need for a proper history, a physical examination, and the potential need for diagnostic imaging. However, a key concern is whether proper equipment will be afforded for such missions from the standpoint of treatment and rehabilitation. The purpose of this paper is to review and summarize the scope and incidence of in-flight musculoskeletal injuries while defining the requirements for terrestrial treatment. Additionally, the role of rehabilitation during recovery and the impact of not having the necessary equipment will be explored.

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