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Hyperbaric Oxygen Therapy for Earthquake Victims

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ABSTRACT

Earthquakes are catastrophic natural disasters. Staying under rubble for a long time may cause compartment syndrome, especially in the extremities, and crush injuries due to severe trauma. In addition, frostbite injuries may occur due to extreme climate in the winter. In hyperbaric oxygen therapy (HBOT), patients breathe 100% oxygen in a closed chamber at pressures greater than 1 atmosphere absolute. HBOT provides elevated partial oxygen pressure, increased oxygen diffusion distance, decreased edema of the areas with circulatory disorder, augmented bactericidal effect, additive-synergistic effect with antibiotics, and enhanced wound healing. HBOT is a successful adjunctive treatment option for crush injuries, acute skeletal compartment syndromes, and frostbite injuries.

Keywords: Hyperbaric oxygen therapy, earthquakes, compartment syndrome, crush injuries, frostbite

Introduction

Earthquakes are catastrophic natural disasters. Severe earthquakes cause many deaths and serious traumatic injuries. Each year, approximately one million earthquakes occur, which indicates that every 2 minutes, an earthquake occurs (1). Earthquakes are an immutable fact of Turkey, and many devastating earthquakes have occurred throughout the history of Turkey. The latest earthquake disaster on February 6th, 2023, destroyed many buildings, resulting in thousands of deaths and severe injuries due to demolitions. There was an inevitable overload of healthcare services in the earthquake region due to damaged hospitals, injured medical personnel, ongoing search and rescue operations, and thousands of emergency applications to hospitals. Earthquake victims were distributed throughout Turkey quickly, and multidisciplinary treatment was provided to the patients.

Many physical injuries, such as being trapped under rubble, being stuck between objects, burns, and frostbites, are reported in earthquakes (2). Staying under rubble for a long time may cause compartment syndrome, especially in the extremities, and crush injuries due to severe trauma. Victims may have multiple or isolated injuries. Patients should be treated multidisciplinary (1). Hyperbaric oxygen therapy (HBOT) has been used in traumas, particularly crush injuries and compartment syndrome.

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Hyperbaric Oxygen Therapy

HBOT is a treatment modality in which patients breathe 100% oxygen in a closed chamber at pressures higher than 1 atmosphere absolute (ATA) (3). Monoplace and multiplace pressure chambers are used for HBOT. After reaching the desired treatment pressure, patients begin to breathe 100% oxygen through a mask, hood, or endotracheal intubation tube.

Increased ambient pressure and increased partial oxygen pressure are the two fundamental mechanisms of HBOT. Increased ambient pressure eliminates gas bubbles formed in the body due to decompression sickness, gas gangrene, or gas embolism. However, the main HBOT effects are related to the increased partial pressure of oxygen. An increase in oxygen diffusion distance, decrease in edema in the areas with circulatory disorder, increase in bactericidal effect, and additive-synergistic effect with antibiotics are the effects that occur due to the increase in partial oxygen pressure (3,4). In severe crush injuries, HBOT is accepted as an adjunctive treatment for saving the extremity or preventing amputation (4). The following sections will discuss the effects of HBOT in cases such as crush injuries, compartment syndrome, burns, and frostbite seen in earthquakes.

1. Crush Injuries

The most common earthquake-related injuries are musculoskeletal trauma (65%), fractures (22%), and soft tissue contusions or sprains (6%). Open fractures were reported to be between 11% and 54%. While 36% of patients with bone fractures have multiple fractures, 6% have accompanying neurovascular damage (1).

Crush injuries occur due to high-energy impact, especially on the extremities and trunk. It varies from skin tissue trauma to bone, muscle, and tendon injuries. Trauma is caused by high-pressure force (4). In massive earthquakes, crush injuries occur in 3-20% of the population (1). Direct tissue damage due to impact and subsequent ischemic tissue damage occurs. Direct tissue damage may result in tissue edema, muscle necrosis, and nerve damage in the damaged area.

For an injury to qualify as a crush injury, the following criteria must be met:

(i) Two or more tissues (e.g., muscle, bone, skin, ligament, nerve) must be involved.

(ii) The injury must be severe enough to question tissue survival.

(iii) There is a gray area between irreversibly damaged and minimally traumatized tissues. Increasing the survival of gray zone tissue is the most crucial aspect of crush injury treatment (5).

The treatment of crush injury involves two steps. First, it is necessary to immediately manage traumatic necrotic tissues. These include orthopedic and vascular surgical procedures such as debridement, repair of injured vessels, stabilization of broken bones, and soft tissue repair. At the same time, tissue perfusion must be ensured. Anticoagulants, fluid replacement, blood transfusion, and agents that support tissue perfusion should be used. Antibiotic use and dressings are significant in open wounds (5). During periods of muscle breakdown, patients may develop acute renal failure (6).

Smith et al. (7) reported the promising effects of HBOT in addition to surgical treatment in crush injuries. Székely et al. (8) applied HBOT to 19 patients with serious injuries to the arms and legs, vascular damage, severe skin loss, and anaerobic infection due to open fractures. The authors stated that they treated extremities that would require amputation according to their experience. They also emphasized that HBOT enhanced skin graft healing in necessary patients. An average of 10 sessions of HBOT were administered to each patient, and promising therapeutic outcomes were documented in 13 cases (68%) (8). Monies-Chass et al. (9) presented a case series of 7 patients with severe vascular trauma in the extremities. Although standard vascular repair was successful in this study, HBOT was applied to patients with critical ischemia in the extremities after surgery. The authors reported that gangrene development was prevented in all cases, complete recovery was achieved in 6 patients, and toe amputation was required in only one patient (9).

A few randomized studies have analyzed the efficacy of HBOT in crush injuries. One study by Bouachour et al. (10) included 36 patients with crush injuries. Patients were randomly divided into two groups within the first 24 hours after surgery. The first group was treated with HBOT at 2.5 ATA for 90 minutes twice daily for six days. The placebo group received treatment with 21% oxygen at 1.1 ATA for 90 minutes twice daily for six days. All patients were administered the same standard treatments (anticoagulants, antibiotics, wound dressings). Complete recovery was achieved in 17 patients in the HBOT group and 10 patients in the placebo group ($p<0.01$). One patient in the HBOT group and six patients in the placebo group underwent new surgical procedures (skin flaps and grafts, vascular surgery, and amputation) ($p<0.05$). This study demonstrates the promising outcomes of HBOT in improving wound healing and reducing the number of repetitive surgeries. HBOT is a beneficial adjunctive therapy for treating severe (stage III) crush injuries in the extremities in patients over 40 years of age (10). In another randomized controlled trial, patients with open tibia fractures were randomized to receive 12 sessions of HBOT in addition to standard trauma care or standard care within the first 48 hours of injury. One hundred and twenty patients were included. In the HBOT group, necrosis and infection were significantly less in the postoperative four days ($p<0.05$). Patients who received HBOT had fewer late complications, including delayed fracture. In the first and second years, quality of life measures were superior in HBOT patients (11).

The Marmara earthquake occurred on August 17th, 1999, and was one of the most destructive earthquakes in our country's history. In a related study, 52 earthquake victims with fasciotomy due to compartment syndrome received HBOT. Forty-five patients had crush injuries. Only five patients progressed to amputation, whereas the extremities were preserved in other patients. HBOT was applied at 2.5 ATA for 3 to 70 sessions (12). In another study, the authors reviewed the outcomes of seven patients with lower extremity trauma. HBOT has many benefits regarding wound healing in lower extremity traumas, returning to daily activities, and preventing complications (13).

Hyperbaric Oxygen Indication for Crush Injuries

The Underwater and Hyperbaric Medical Society (UHMS) recommends using standard classification systems for crush injuries. Currently, the Gustilo Grading System is frequently used. According to UHMS, the HBOT recommendations begin with grade I for decompensated hosts, grade III-A for impaired hosts, and grade III-B for healthy persons. The details are explained in Tables 1, 2.

HBOT should be applied once in the first 24 hours, at pressures of 2.2-2.8 ATA, and twice daily for the next three days. Transferring patients for HBOT in the first 24 hours can be challenging. Post-anesthesia recovery after significant surgeries, transferring them to HBOT units, and stabilizing in the pressure chamber require experienced teamwork. It may be necessary to continue HBOT after the first 4 days because of infection, delayed wound healing, and ischemic complications at the operation site (14).

HBOT should be applied as soon as possible. When reperfusion starts again, reperfusion damage begins in the first 4-6 h and damages the microcirculation. In addition to the circulatory disorder at the time of the initial trauma, reperfusion injury should not be ignored. Therefore, it is crucial to start HBOT from the first day of reperfusion injury (14).

2. Acute Skeletal Muscle Compartment Syndrome

Acute skeletal muscle compartment syndrome (SCMS) is another significant challenge of earthquakes. It occurs when the increased pressure within a compartment disturbs the circulation and function of tissues within the same space (15). When a limb is stuck under rubble, the pressure of the compartments in the trapped limb increases both by external mechanical pressing stress and secondary cellular events such as worsening tissue edema related to fluid extravasation. The injured limb might not be painful, swollen, or tense immediately after the extrication of the earthquake victim. The limb is often numb with a peripheral pulse. It will quickly become tense and swollen within the following hours. The crushed limb can be bruised and discolored with intact skin. Pain will develop gradually. The intracompartmental pressure can be measured. The classical management of acute SCMS includes immediate fasciotomy to achieve decompression, thereby improving local and distal blood circulation. Turning a closed injury into an open wound carries clear risks, including profuse bleeding, aggravating coagulopathy, complicating

Table 1. Gustillo grading system and criteria for the use of adjuvant HBOT in crush injuries

Gustillo type	I	II	III (Crush injuries)		
			III-A	III-B	III-C
Findings (soft tissue injury with fractures)	Minimal (<1 cm wide) puncture wound from inside to outside	Laceration with minimal deep soft tissue damage	Sufficient soft tissue to close the wound (after debridment)	Flaps and/or grafts needed for bone coverage	III-B injuries with major vascular damage
HBOT indication					
Healthy host[1]	-	-	-	+	+
Impaired host[1]			+	+	+/-[2]
Decomposed host[1]	+	+	+	+/-[2]	+/-[2]

Adapted from UHMS Hyperbaric Oxygen Therapy Indications (14th ed, p. 139) by R.E. Moon, 2019. HBOT may help with the primary healing of amputation flaps. [1]Refer to the health status score table, [2]Consider primary amputation in decompensated hosts with grade III-B and III-C injuries. HBOT: Hyperbaric oxygen therapy, UHMS: Underwater and Hyperbaric Medical Society

Table 2. Health status score table

Assessment	2 Points	1 Points	0 Points
	Use half points if mixed or intermediate between 2 grades		
Activities of daily living	Full	Some	None
Ambulation	Community	Household	None
	Subtract $^1/_2$ point if aids are used		
Comorbidities	No significant	Impaired	Decompensated
	Omit neurological deficits, which is a separate assessment below		
Inhibitors Smoking, collagen vascular diseases, and immunosuppressors	None	Past	Current
Neurological deficits	None	Some/minor Sensation, imbalances	Major Cognitive, paralysis

Adapted from UHMS Hyperbaric Oxygen Therapy Indications (14th ed, p. 139) by R.E. Moon, 2019. Five assessments are each graded from 2 points (best) to 0 points (worst) and summated to generate a score of 0-10. Scores between $7^{1/2}$ and 10 points indicate "healthy host", scores between $3^{1/2}$ and 7 points indicate "impaired host", and scores between 0 and 3 points indicate "decompensated host". UHMS: Underwater and Hyperbaric Medical Society

dialysis for myoglobinuric acute renal failure, infections, and limb-threatening sepsis (16). Görmeli et al. (17) reported five (24%) cases of sepsis, seven (24%) of amputations, and seven (33%) of mortality after urgent fasciotomy among 21 patients who experienced the Van earthquake in 2011. In the study by Duman et al. (18), the amputation rate was 25% among 16 patients who underwent urgent fasciotomy after the Marmara earthquake in 1999. Due to the massive burden on hospitals, clinicians may decide to perform prophylactic fasciotomy because they usually do not have enough time to perform frequent physical examinations for patients with suspected/impending stage SMCS (19). However, this overwhelming demand on surgeons may lead to inadequate follow-ups after fasciotomies, resulting in post-fasciotomy complications. In this respect, HBOT may provide better outcomes in the early stages of SCMS by preventing surgical complications (3,20).

HBOT increases tissue fluid oxygenation 10-fold, reduces edema by 20%, increases oxygen diffusion distances 3-fold, and enhances wound healing. In this respect, HBOT might break the self-perpetuating vicious cycle of edema-ischemia. HBOT may prevent SCMS in its early stages, improve outcomes, and be used as adjunctive therapy for wound management and residual problems after fasciotomy (3,20).

In the study by Strauss et al. (21), dogs with induced SCMS were exposed to HBOT, and muscle damage was significantly reduced. The authors suggested that HBOT may be beneficial when immediate surgical decompression is unavailable, in the impending stage of SCMS with no surgical indication, and after surgical decompression (21). Another canine compartment syndrome study by Skyhar et al. (22) demonstrated that HBOT significantly reduced tissue edema and necrosis even in a hypotensive state. Strauss et al. (23) reported that 2 hours of delayed HBOT significantly reduced edema and muscle necrosis in a model compartment syndrome. In a study by Bartlett et al. (24), muscle function significantly improved in a canine SMCS with a combination of HBOT and fasciotomy versus the fasciotomy group alone. Aydin et al. (25) reported that combining HBOT and fasciotomy led to a more significant reduction in intracompartmental pressures than HBOT alone, fasciotomy alone, and control.

There is no existing randomized controlled trial about SMCS and HBOT. Currently, there are only case reports that are primarily non-traumatic, as listed in Table 3 (26,27,28,29,30,31,32). In contrast, Korambayil et al. (33) reviewed their compartment syndrome experiences due to snake bites. Among 112 snake bite cases, 24 patients presented with SCMS. HBOT sessions were administered after the initial treatment with anti-snake venom and antibiotics, and no fasciotomy was required. The authors concluded that HBOT is a successful treatment modality for managing "impending" compartment syndrome, which may require later fasciotomy (33).

The HBOT indication for SMSC is considered as class 1, level C according to The American Heart Association, with the benefits outweighing the risks, the treatments are helpful based on expert opinion (including laboratory data), and case studies support HBOT use, but no randomized controlled trial exists (20).

Table 3. Case reports on HBOT use for compartment syndrome

Authors	Number of patients	Diagnosis and etiology	Symptoms	Surgical interventions	HBOT	Final outcome
Lee et al. (26) 2020	1 patient	Compartment syndrome due to acute isocyanate inhalation (severe rabdomyolisis resulting in bilateral lower leg compartment syndrome)	Pain, stiffness, numbness, paralysis, and lower leg tissue pressure increased to 180 mmHg/170 mmHg (right/left)	Fasciotomy (all four compartments for both legs)	HBOT started the next day, 2.0 ATA, 90 mins, twice a day up to 7 seven days	No amputation. Walks with slight weakness and without major complications
Han et al. (27) 2018	1 patient	Compartment syndrome in unconscious acute carbon monoxide poisoning	Swelling, pulses +, normal capillary refill time, motor weakness, sensory impairment	Fasciotomy was performed with 12 h delay after diagnosis (the medial and the lateral sides of the left forearm)	HBOT started immediately because of carbon monoxide poisoning. 3 sessions	Left median, ulnar, radial, and musculocutaneous nerve pathology and neurological sequelae including wrist drop
Mendes et al. (28) 2018	1 patient	Bilateral upper extremity compartment syndrome after intense physical training	Swelling and pain	None	2.3-2.5 ATA 90 min, twice daily	Asymptomatic, able to perform intense physical trainings
Hoy et al. (30) 2018	1 patient	Severe supraspinatus muscle rhabdomyolysis following overexertion	Pain, right shoulder weakness	Fasciotomy (intraoperative notes; poorly contracting muscles)	Three HBOT sessions within 24 h post-fasciotomy, completing 7 HBOT sessions over a 5-day period.	One month later, the patient had a full active range of motion of the right shoulder in the absence of painful symptoms
Abdullah et al. (31) 2006	1 patient	Heroin-induced severe bilateral compartment syndrome	Severe pain, burning sensation, severe swelling, tenderness, weakness, and absent plantar reflexes	Fasciotomy (all four compartments for both legs)	2.4 ATA, 90 min, daily	Wounds were closed after 10 days and healed. There was mild improvement in the strength of the lower extremities
Al et al. (29) 2012	1 patient	Upper extremity compartment syndrome in an unconscious acute carbon monoxide poisoning case	Swelling, rash, weakened pulses, paresthesia, paralysis, pallor, and pain in the arm during passive movements	Fasciotomy (four compartments), pulses returned after fasciotomy	HBOT started immediately because of carbon monoxide poisoning. Total number of sessions unknown	A skin graft was administered 10 days after fasciotomy. The patient discharged without any motor or sensorineural symptoms
Fitzpatrick et al. (32) 1998	1 patients	Compartment syndrome associated with acute exertional injury	Pain to the anterior right lower leg, with good pulses and normal sensation to the right foot, 33 h of progressive ischemia	Fasciotomy (four compartment release). Intraoperative notes: muscle purple to deep red and slightly hemorrhagic; no muscle contractility during electrocautery	Referred for HBOT 6 days after surgery (due to minimal reduction in edema to the surgical site) 2.4 ATA, 90 min, daily, 7 sessions	Edema reduced, and no further surgery or grafts were required. The patient could resume his full military duties with restrictions on running

HBOT: Hyperbaric oxygen therapy, ATA: Atmosphere absolute, h: Hour, min: Minute

HBOT Indication for SCMS

The clinical presentation of SCMS may be divided into three stages, "suspected", "impending", and "established", in which the self-perpetuating edema-ischemia cycle is a unifying feature. In the "suspected stage", the SCMS is not present, but the severity of the injury or circumstances reveals the suspicion of SCMS. In this stage, HBOT is not indicated, but frequent neurocirculatory checks must recognize the progression to compartment syndrome. Increasing pain, hypesthesia, muscle weakness, discomfort with passive stretching of the toes/fingers, and/or tautness of the compartment's contents need to be evaluated. Muscle compartment tissue pressure measurements should be performed. If fasciotomy is not required, HBOT should be initiated to prevent progression to the "established stage". If pressure testing is not available in the "impending stage", three or more clinical findings are required for HBOT initiation. These clinical findings are listed in Figure 1 (20).

HBOT has also been indicated in the "impending stage" when the compartment pressures have been increasing with serial measurement, but the threshold level for fasciotomy has not yet been reached. In addition, the patient's Wellness score might be paired with compartment pressure measurements when deciding on HBOT (Figure 1, Table 2) (20).

In the "established stage", immediate fasciotomy is indicated. After fasciotomy, HBOT should be considered as an adjunctive therapy for wound management if significant residual problems remain. Post-fasciotomy HBOT indications include ischemic muscle, unclear demarcation between viable and non-viable tissue, massive swelling/prolonged (more than 6 hours) ischemia time, threatened skin flap or graft, residual neuropathy, and/or significant comorbidities as determined by the Wellness score (20).

3. Frostbite

The victims of the Maraş earthquake had to endure extreme climate during the winter. On February 6th, 2023, the lowest temperature was 0 °C and there was intermittent snowfall in the northern parts of the region affected by the earthquake. The air temperature dropped below 0 °C in the following days (34). While people were trying to survive with light clothes under rubble in winter, many other surviving people were left homeless and stayed in tents under freezing weather conditions. Hypothermia became a growing problem. We treated a frostbite injury in a victim of the Maraş earthquake using HBOT (Figure 2). Physicians should be aware of frostbite in earthquake victims, although it has been mainly reported in military populations and homeless people (35).

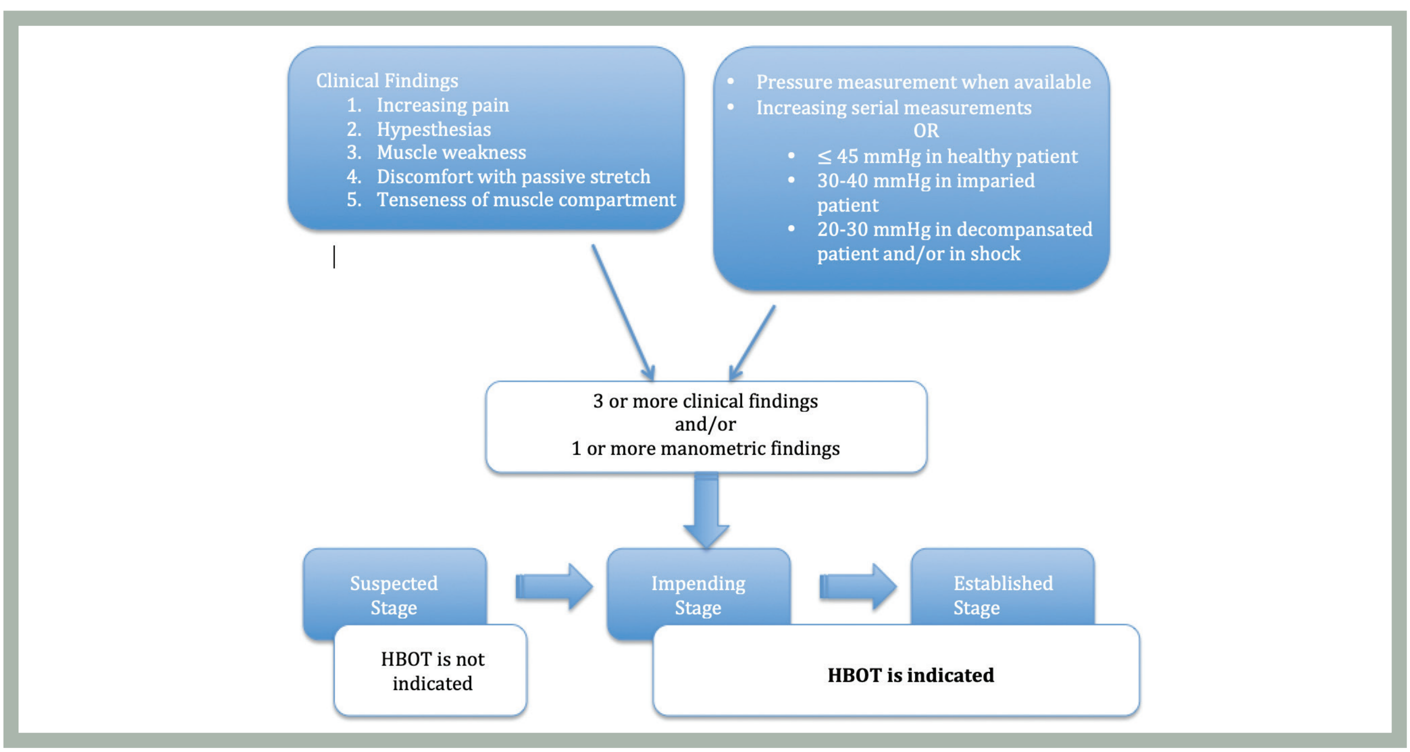

Figure 1. HBOT indication algorithm for SMCS

HBOT: Hyperbaric oxygen therapy, SMCS: Acute skeletal muscle compartment syndrome

Figure 2. Frostbite injury on the left foot in an earthquake victim

Frostbite is a localized cold thermal injury caused by exposure to low temperatures that cause ice crystal formation in tissues, damaging cell membranes and osmotically dehydrated cells (35). Indirect injury by cold-induced vasoconstriction increases blood viscosity, resulting in sludging of erythrocytes and thrombus formation. As a result, tissue hypoxia and inflammation occur. Further congestion and stasis result in circulatory collapse and endothelial plasma leakage with downrange tissue ischemia (36). Frostbite is another subgroup of acute traumatic peripheral ischemias in which HBOT may be a therapeutic option. There is a plausible mechanism of action that suggests effective treatment using HBOT. The evidence mainly includes animal studies and case reports (Table 4) (36,37,38,39,40). Only two case-controlled studies have been published (41,42,43). Magnan et al. (44) conducted a multicenter prospective single-arm study. Stage 3 or 4 frostbite patients whose medical care was initiated in the first 72 hours were included. Although 28 patients underwent HBOT and standard care with iloprost, 30 patients received only standardized frostbite treatment with iloprost. Combination of HBOT and iloprost was associated with higher benefits in patients with severe frostbite. The number of preserved segments was two-fold higher in the HBOT combination with iloprost-only group than in the iloprost group (mean of 13 preserved segments vs. 6), and the reduction of amputation was more significant in patients treated by HBOT combination with iloprost than in those treated by iloprost alone (41). In a multicenter retrospective cohort study, there was no statistically significant difference between the HBOT and non-HBOT groups regarding amputation characteristics. Hospital stay was longer in the HBOT group than in the non-HBOT group (42). To our knowledge, no earthquake-related frostbite injury case has been reported to be treated with HBOT in the existing literature.

4. Special Considerations for Earthquake Survivors During HBOT Procedures

HBOT has been successfully applied to earthquake survivors for several indications (2). Due to the massive destructive nature of earthquakes, numerous patients might be consulted for urgent HBOT in local hospitals. Hyperbaric physicians should be aware of the massive burden and have taken immediate precautions to ensure a carefully planned organization. In this respect, we will highlight some special considerations regarding HBOT applications in this patient group, summarized in Table 5.

a. Organization

Many patients were consulted for emergency HBOT from several hospitals and cities affected by the earthquake. This situation presented several challenges for clinicians. First, evaluating a patient from another hospital or city without performing a physical medical examination was compelling. Second, clinicians had to consider transportation risks and arrange other ongoing therapies such as hemodialysis and requirements such as intensive care unit (ICU) in the transferred hospital. Besides, hyperbaric chambers may not meet the HBOT need despite working 24 hours due to the patient capacity limit of the chambers. Moreover, many patients were on stretchers, resulting in less capacity for hyperbaric chambers. After the Maraş earthquake, patients seats inside the hyperbaric chamber were dismantled in most HBOT centers to make more field for more stretchers inside the hyperbaric chamber (Figure 3).

b. Technical Issues

Most patients required other therapies with medical devices continuously or for long durations, including vacuum-assisted closure (VAC) techniques, infusion pumps, and mechanical ventilation. Only HBOT-approved medical devices can be operated inside a hyperbaric chamber during sessions because of fire predisposition inside chambers (51). VAC therapies with special arrangements can be maintained without interruption during HBOT sessions. Many HBOT centers have HBOT-approved mechanical ventilators. All medical requirements should be discussed with a hyperbaric physician before treatment.

Table 4. Case reports and case series of frostbites treated with HBOT (35,43,44,45,46,47,48,49,50)

Authors	Patient no.	Etiology	Delay in HBOT	HBOT	Other Treatments	Outcome
Ghumman et al. (35) 2019	22	Alcohol intoxication and psychiatric illnesses	-	2.5 ATA, 90 min, 2 or 3 times daily, total HBOT sessions 3-43	Antiplatelet or anticoagulant therapy	In 50% of the cases requiring amputation, the final amputation level was more distal to the predicted level from pretreatment bone scans
Higdon et al. (43) 2015	1	Alcohol intoxication and falling unconscious in a snowy field	-	2.0 ATA, 90 min, 40 HBOT sessions	Tissue plasminogen activator therapy, abciximab	Of his six digits with extensive, deep frostbite, one digit eventually required partial amputation, and another had protracted osteomyelitis treated with intravenous antibiotics
Magnan et al. (44) 2022	1	Climbing (grade 3 frostbite of both hands)	3 days	HBOT daily for 3 weeks	Lioprost infusion for 7 days	No amputation required, able to climb again and play volleyball
Davis et al. (45) 2022	1	Climbing (8 digits of both hands; 5 of these were grade 3 frostbite)		2.0 ATA, 90 min, 32 HBOT sessions	Aspirin	Underwent amputation of three digits
Robins (46) 2019	1	Hiking (toes of both feet and plantar surface of left foot)	HBOT initiated 2 h from the estimated time of rewarming	2.4 ATA, 90 min, 13 HBOT sessions	Oral pentoxiphylline	At the 12-month follow-up, the patient had a durable healing, with complete recovery of sensation in the left foot and toes. Some surface sensory loss was reported
Kemper et al. (47) 2014	1	Climbing (1st toes of both feet)	21 days	2.5 ATA, 90 min, 19 HBOT sessions	-	No surgical intervention is required. The patients toes recovered almost completely. With a minor cosmetic defect and some impairments in flexion of the right. First digit
Lansdorp et al. (48) 2017	2	Hiking (both forefeet)	28 days	2.5 ATA 80 min, patient a received 25 HBOT sessions and Patient B received 30 HBOT sessions	Vasodilatators, pentoxiphyllin, LMWH, analgesic, antibiotics	Patient A: Only partial surgical amputation of the second toe on the right. Patient B: Both forefeet were surgically amputated
von Heimburg et al. (49) 2001	1	Working without gloves during a hunt in Poland (3rd-degree frostbite on 4 fingers of right and 2 fingers of left hand)	1 week	2.4 ATA 90 min, daily sessions, 14 sessions		Complete resolution. Only 2 finger nails were lost
Folio et al. (50) 2007	1	Climbing (all fingers of both hand)	2 weeks	21 HBOT sessions		All fingers recovered, except that one finger remained slightly misshapen. No amputation required. Normal neurological motor function and only mildly decreased sensation (hardly noticeable except under cold conditions) on the tip of the misshapen finger

HBOT: Hyperbaric oxygen therapy, ATA: Atmosphere absolute, h: Hour min: Minute

Table 5. Special Considerations for the HBOT

1. Organization	Planning
	Triage
	Transportation
	Multiple strecthers in the same HBOT session
2. Technical issues	HBOT-approved medical devices
	Continuing VAC during HBOT
3. Providing frequent HBOT sessions without delay in other required medical therapy/ interventions	Frequent blood transfusions
	Pain management
	Frequent surgeries/surgical debridements
	Long-lasting hemodialysis and hemofiltration
4. Adverse events and contraindications	Pulmonary barotrauma
	• Managing patients with chest trauma and chest tubes
	• Mechanical ventilation
	Continuing ICU requirements during HBOT sessions for critically ill patients
	• Mechanical ventilation
	• Monitorization
	• Inotropic support
	• Pain management
5. Therapy aims	Therapy aims
6. Phsycosocial aspects	Medical staff
	• Working full time, overwhelming schedule
	• Stress management
	Patients
	• claustrophobia
	• Reaching out to other family members
	• Approval for HBOT for unidentified child
	• Post-traumatic physicological problems

HBOT: Hyperbaric oxygen therapy, VAC: Vacuum-assisted closure, ICU: Intensive care unit

c. Providing Frequent HBOT Sessions without Delay for other Medical Therapies/Interventions

Earthquake survivors may need frequent surgical debridements, blood transfusions, and long-lasting hemodialysis or hemofiltrations. These interventions cannot be postponed or interrupted for HBOT sessions. Note that one HBOT session lasts for two hours. Therefore, providing the recommended frequent HBOT schedule for these patients might be challenging. Physicians must carefully evaluate patients' clinical status and therapy aims.

d. Adverse Events and Contraindications

HBOT has several complications with varying degrees of seriousness. Pulmonary barotrauma is a rare but one of the most significant complications of HBOT. Overdistension and rupture of alveoli due to gas trapping can result in pneumothorax, pneumomediastinum, or even arterial gas embolism (20). In this respect, significant air trapping in the lungs, or anything that leads to pulmonary overinflation and a history of spontaneous pneumothorax, are concerning for hyperbaric physicians (20,52). Nevertheless, untreated tension pneumothorax is the only absolute contraindication for HBOT (53). Pulmonary barotrauma is also a feared complication of mechanical ventilation, particularly in patients with severe underlying lung disease (54). Cakmak et al. (55) reported tension pneumothorax in an intubated and mechanically ventilated earthquake survivor during the decompression phase of the seventh HBOT session. The patient was successfully treated with a chest tube. In addition, earthquake victims may have accompanying significant thoracic injuries (56). In this respect, earthquake victims' pulmonary examinations should be carefully performed before HBOT. We applied HBOT to many patients with accompanying thoracic injuries without complications (Figure 4).

Continuing care for ICU patients who may require mechanical ventilation, inotropic support, and continuous monitoring inside a hyperbaric chamber is another challenge for hyperbaric physicians. Precautions should be taken concerning the hyperbaric chamber-approved medical equipment, required drugs, adverse events related to drugs applied during HBOT and patient-ventilator asynchrony, or other symptoms such as agitation and hallucinations related to inadequate sedation. In addition, epileptic seizures might be reported as related to oxygen toxicity. Physicians should be fully prepared for severe shocks despite the use of inotropic drugs and cardiopulmonary arrests (57).

Figure 3. Four patients with stretchers were receiving HBOT in the multiplace chamber at Gülhane Training and Research Hospital

HBOT: Hyperbaric oxygen therapy

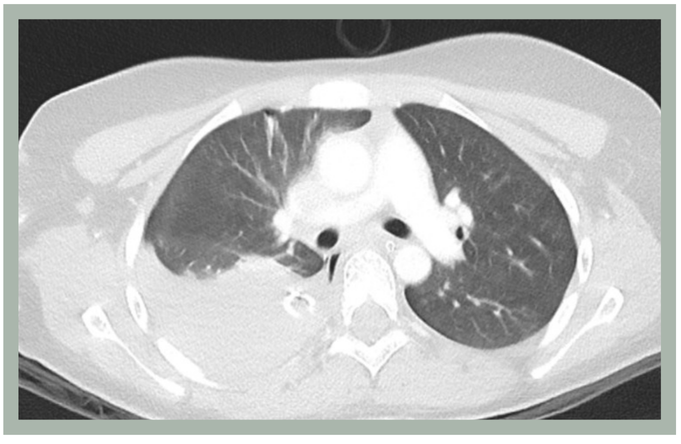

Figure 4. Computed tomography image of the chest of an earthquake victim. Hemopneumothorax in right lung and minimal pneumothorax in left lung

e. Therapy Aims

Hyperbaric physicians should determine their final HBOT expectations at the beginning of therapy. In this regard, the HBOT schedule can be organized effectively. Aktas (2) defined the therapy aims as follows:

(i) To save and conserve all tissues and functions,

(ii) To save all tissues,

(iii) To save from amputation,

(iv) To treat late complications,

(v) To save only one life (2).

f. Psychosocial Aspects

Working full-time with an overwhelming schedule can be challenging for medical staff's physical and mental health. In addition, significant worries about their families and continuous aftershocks could be distractive (2). Stress management by medical staff should be considered.

On the other hand, patients may be unwilling to attend HBOT sessions because of claustrophobia after extraction from rubbles. Post-traumatic psychiatric problems may arise. In addition, children patients without family members may be agitated during treatments.

Conclusion

In severe earthquakes, in addition to many casualties, the number of serious trauma patients is usually very high. Many crush injuries and compartment syndrome cases happen because of being under debris, and limb frostbite because of being under debris for a long time, depending on the temperature in the earthquake area. Approaching the treatment of these patients from a multidisciplinary perspective and planning their treatment is important in preventing limb loss, shortening hospital stays, and achieving functional extremities. Although limited publications support the use of HBOT in addition to surgical interventions, many experts report that starting HBOT as soon as possible has positive benefits for patients.

The workload of centers providing HBOT increases significantly during these periods. The fact that most patients are on stretchers limits the number of patients who can receive HBOT. It is important to plan the treatment of patients and act in coordination with the clinics where the patients are followed.

Ethics

Peer-review: Externally peer-reviewed.

Authorship Contributions

Concept: K.Ö.K., A.A., Design: K.Ö.K., A.A., Data Collection or Processing: K.Ö.K., A.A., Analysis or Interpretation: K.Ö.K., A.A., Literature Search: K.Ö.K., A.A., Writing: K.Ö.K., A.A.

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