ORIGINAL ARTICLE

Use of hyperbaric oxygen therapy in severe earthquake injuries

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ABSTRACT

BACKGROUND: Earthquakes are natural disasters that can often cause severe injuries and traumatic situations. These injuries can include crush injuries, fractures, tissue damage, and blood circulation problems. Hyperbaric oxygen therapy (HBOT) has recently become a frequently used treatment modality for individuals suffering from severe injuries. HBOT is a form of treatment that involves administering pure oxygen to the patient under high pressure. This treatment aims to promote tissue healing by increasing cellular oxygenation. It is thought to have a positive effect on factors such as accelerating tissue healing, reducing inflammation, and controlling infection in severe post-earthquake injuries, particularly crush injuries. This study aimed to retrospectively evaluate the clinical effects, contributions to the healing process, and potential advantages of HBOT in 35 patients with severe injuries after the Kahramanmaraş earthquake that occurred on 06.02.2023 and to contribute to the development of emergency intervention strategies.

METHODS: This study was carried out after ethics committee approval. In the study, the data of patients with a MESS Score between 7-14 who were admitted as earthquake victims and treated in the HBOT Unit due to severe earthquake-related injuries were obtained from records and retrospectively analyzed. Demographic information, general distribution of patient data, mean values, number of HBOT sessions, and functional outcomes were recorded.

RESULTS: The gender distribution of the 35 patients who received HBOT was 31.4% male and 68.6% female. 45.7% of patients were aged 18 years or younger, and 54.3% were aged 19 years or older. The most common injuries in the treated patients were observed in the lower extremities. After HBOT, sensory recovery (54.3%) and functional recovery (51.4%) were achieved in the majority of patients. The minor amputation rate was 20.0% and the major amputation rate was 11.4% after HBOT.

CONCLUSION: This study evaluated the possible effects of HBOT on patients with severe earthquake injuries in Türkiye, and the results showed that HBOT may have a beneficial effect on critical factors such as sensory recovery, functional recovery, and amputation rates in this particular group of patients, and that this benefit may be more pronounced in those who started treatment early.

Keywords: Crush injury; hyperbaric oxygen therapy; earthquake; MESS score; tissue injury.

INTRODUCTION

On 6 February 2023, the earthquake disaster that began at 04:17 Turkish time and continued with a second shock at 13:24 found its epicenter in the Pazarcık (Kahramanmaraş) and Elbistan (Kahramanmaraş) regions of Türkiye. This large-scale earthquake was recorded as one of the most destructive in the country's history.[1]

In the aftermath of an earthquake, healthcare systems must be prepared to respond to crush injuries with rapid and effective intervention. The management of severe earthquake injuries should utilize the most effective treatment options to

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minimize the process leading to limb loss.[2-5]

Compartment syndrome is a condition that results from increased pressure within muscle compartments, which can occur due to crush injuries. This condition can lead to impaired circulation and subsequent tissue damage. Symptoms of compartment syndrome include severe pain, swelling, and sensory deficits. In severe cases, emergency fasciotomy may be required to relieve the pressure and prevent permanent damage.[6]

Hyperbaric oxygen therapy (HBOT) is a treatment in which patients breathe pure oxygen in a pressurized chamber. This treatment can promote tissue healing by increasing cellular oxygenation in patients with crush injuries. Recent studies have indicated that HBOT can have beneficial effects on earthquake-related injuries, including enhanced tissue healing, reduced inflammation, and infection control. As a result, HBOT has become a preferred treatment modality, especially for managing crush injuries. It is believed that early application of HBOT can significantly reduce the need for amputation.[7-9]

Amputation is the surgical removal of all or part of a limb, typically necessitated by trauma, tissue diseases, or circulatory problems. There are two main types of amputation: minor and major. Minor amputation may involve the removal of a digit or part of a limb, whereas major amputation entails the removal of a significant portion of a limb, such as an entire leg or arm.[10]

The Mangled Extremity Severity Score (MESS) is a prognostic tool used to assess the severity of limb injuries and to determine the likelihood of salvaging the limb. A MESS score of 7 or higher is generally predictive of the need for amputation.[11]

The aim of this study was to retrospectively analyze the outcomes of HBOT in earthquake survivors with MESS scores ranging from 7 to 14. The primary focus was on patients with a MESS score of 7 or higher, examining the impact of HBOT on sensory and functional recovery, as well as on amputation rates. The study aimed to elucidate the potential benefits of HBOT for these patients and to contribute to the development of effective emergency response strategies.

MATERIALS AND METHODS

This study was carried out following ethics committee approval. It examines the data of patients with a Mangled Extremity Severity Score (MESS) ranging from 7 to 14, who presented to the city hospital closest to the earthquake-affected areas and received treatment in the Hyperbaric Oxygen Therapy (HBOT) unit for severe injuries related to the earthquake. The research was conducted retrospectively, based on data obtained from past records of these patients. Demographic information, the general distribution and mean values of patient data, the number of HBOT sessions, and functional outcomes were recorded.

Data Analysis: The data obtained from the study were analyzed using the SPSS version 22.00 package. In the analysis, descriptive statistics (number, percentage, mean) and the Shapiro-Wilk test were used to assess the normality of the data distribution. The Mann-Whitney U test was employed due to the data not being normally distributed. Spearman's correlation analysis was utilized to examine the relationships between post-earthquake patient data. The results were considered significant within a 95% confidence interval and a significance level of $p<0.05$.

RESULTS

The total number of patients treated with Hyperbaric Oxygen Therapy (HBOT) was 35. The gender distribution was 31.4% male and 68.6% female. Regarding age, 45.7% of the patients were 18 years old or younger, and 54.3% were 19 years old or older. The mean age was 25 years, with an age range from a minimum of 1 year to a maximum of 85 years.

It was observed that the most common injuries among the 35 treated patients were in the lower extremities. On average, all patients had been trapped under rubble for 41.69±28.55 hours and subsequently developed compartment syndrome. The left and right lower extremities were the areas most commonly affected. Prior to commencing HBOT, 14.3% of patients underwent a minor amputation, and 11.4% underwent a major amputation of other extremities (Table 1).

Sensory recovery was observed in 54.3% of the patients and

Table 1. Treatment results related to patient data: sensory recovery, functional recovery, and amputation status (n=35)

Patient Data	Yes		No	
	n	%	n	%
Sensory Recovery	19	54.3	16	45.7
Functional Recovery	18	51.4	17	48.6
Minor Amputation Before HBOT	5	14.3	30	85.7
Major Amputation Before HBOT	4	11.4	31	88.6
Minor Amputation After HBOT	7	20	28	80
Major Amputation After HBOT	4	11.4	31	88.6

Table 2. Patient Data: affected anatomical region localisation and fasciotomy localisation (n=35)

Affected Anatomical Region Localisation	**n**	**%**
Right lower extremity	9	25.7
Left lower limb	12	34.3
Right upper limb	4	11.4
Left upper limb	5	14.3
Right/left lower extremity	2	5.7
Right lower extremity/Left upper extremity	1	2.9
Left lower extremity/Left upper extremity	1	2.9
Right lower extremity/Right/left upper extremity	1	2.9
Fasciatomy Localisation	n	%
None	10	28.6
Right lower limb	5	14.3
Left lower limb	10	28.6
Right upper limb	3	8.6
Left upper limb	4	11.4
Right/left lower extremity	2	5.7
Right/left upper extremity	1	2.9

functional recovery in 51.4% following HBOT. When considering the amputation rates before and after HBOT, the minor amputation rate was 14.3% and the major amputation rate was 11.4% before HBOT. Post-HBOT, the minor amputation rate increased to 20.0%, while the major amputation rate remained at 11.4% (Table 2).

Results of Mangled Extremity Severity Scores (MESS)

MESS Score and Number of Patients (n=35):

- Number of patients with MESS 7: 2 (5.71%)
- Number of patients with MESS 8: 17 (48.57%)
- Number of patients with MESS 9: 5 (14.29%)
- Number of patients with MESS 10: 8 (22.86%)
- Number of patients with MESS 11: 1 (2.86%)
- Number of patients with MESS 12: 1 (2.86%)
- Number of patients with MESS 13: 1 (2.86%) was determined.

The patients were found to have remained under the rubble for an average of 41.69 hours, and their average MESS score was 8.89. Patients underwent an average of 15.14±7.65 sessions of HBOT, with the number of sessions ranging from 1 to 30 depending on the severity of the extremity injury. The treatment was administered once a day at 2.6 ATA for 90 minutes (Table 3).

Result of Comparison of MESS Score and Related Variables

The differences between the MESS score and sensory recovery (p=0.264), functional recovery (p=0.086), minor amputation after HBOT (p=0.675), and major amputation after HBOT (p=0.085) were not statistically significant.

Results of the Comparison of Time Under Debris and Related Variables

Table 3. Distribution of patient data after the earthquake (n:35).

Patient data	**Min.-Max.**	**$\bar{X}$ ±SS**
MESS Score	7.00-13.00	8.89±1.35
Number of HBOT sessions	1.00-30.00	15.14±7.65
The hour he was under the rubble	1.00-100.00	41.69±28.55
The Time Between Leaving The Wreck and The Start of The First Session of HBOT (Hour)	12.00-475.00	94.34±89.50

$\bar{X}$: Arithmetic Mean SS: Standard Deviation

Table 4. Distribution of patient data according to the number of HBOT sessions, duration of time under debris, and time between debris exit and HBOT first session entry and comparison of related variables (n:35)

	Patient data		**The hour he was under the rubble**	**t***	**p**
			X̄±SS		
	Sensory Recovery	There is	36.47±29.88	1.184	0.245
		None	47.88±26.44		
Findings on the	Functional Recovery	There is	34.67±29.29	1.525	0.137
Comparison of Time		None	49.12±26.58		
Under Debris and	Minor Amputation	There is	68.00±28.96	-3.038	<0.05
Related Variables	After HBOT	None	35.11±24.92		
	Major Amputation	There is	50.25±18.63	-0.632	0.532
	After HBOT	None	40.58±29.64		
	Minor+Major Amputation	There is	61.55±26.22	-3.124	<0.05
	After HBOT	None	32.58±25.13		
Patient data			**Time Between Exit from the Wreckage and Entry to the First Session of HBOT**	**U****	**p**
			X̄±SS		
Findings for the Comparison	Sensory Recovery	There is	72.58±53.75	111.000	0.174
of Time and Related		None	120.19±115.66		
Variables between Exit from the	Functional Recovery	There is	62.06±50.32	70.000	<0.05
Wreckage and Entry to the		None	109.16±26.48		
First Session of HBOT	Minor Amputation	There is	54.71±43.00	56.500	0.087
	After HBOT	None	104.25±95.74		
	Major Amputation	There is	110.50±49.33	36.500	0.186
	After HBOT	None	92.26±93.78		
	Minor+Major Amputation	There is	75.00±51.30	116.000	0.569
	After HBOT	None	103.21±102.16		

* Independent Groups t Test ** Mann Whitney U Test; X̄: Arithmetic Mean; SS: Standard Deviation.

There was a statistically significant difference in the average time spent under debris when comparing groups with minor amputation after HBOT and those with both minor and major amputation after HBOT ($p<0.05$). The duration under debris was significantly longer for patients who had a minor amputation after HBOT than for those who did not have a minor amputation. Similarly, the time under debris was significantly longer for the group with both minor and major amputations after HBOT compared to the group with no amputations.

Results of the Comparison of Variables Related to the Time Between Exit from Debris and Entry into the First Session of HBOT

The average time from exiting the rubble to the first session of HBOT was statistically significant concerning the functional recovery status of patients after the earthquake ($p<0.05$). Patients who showed functional recovery had a significantly shorter interval between exit from the rubble and the first HBOT session compared to patients without functional recovery (Table 4).

Photographs of patients with severe injuries taken before and after the treatment are shown in Figure 1.

DISCUSSION

The most common injuries associated with earthquakes are fractures, dislocations, sprains, and soft tissue injuries of the musculoskeletal system. Severe injuries sustained during earthquakes can lead to the loss of limbs and even death. To manage these serious conditions, rapid and effective treat-

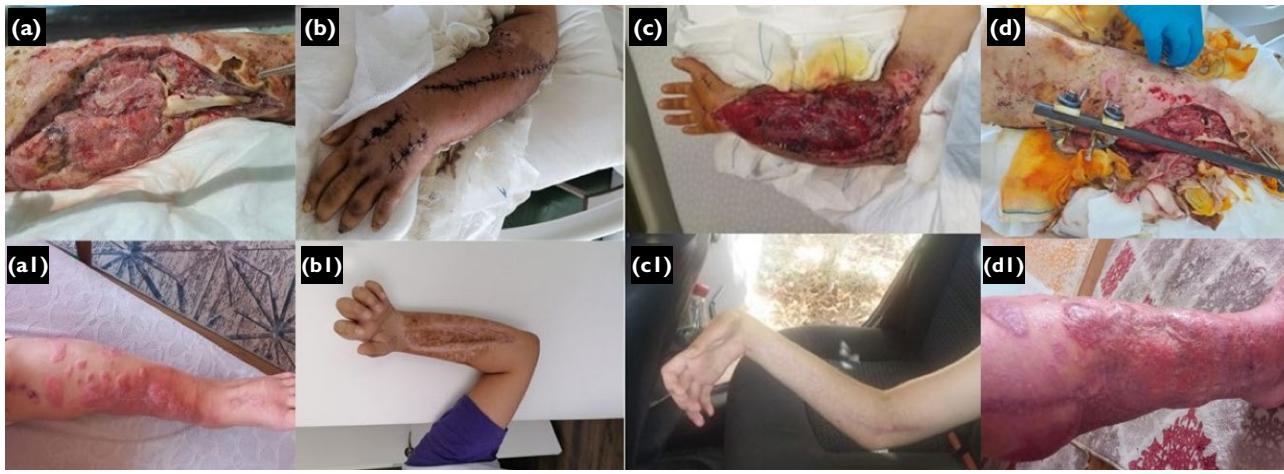

Figure 1. Pre-treatment (a, b, c, d) and post-treatment (a1, b1, c1, d1) images of patients receiving hyperbaric oxygen therapy.

ment should be initiated in health facilities following an earthquake. The most common major injuries that require tertiary care include open fractures of long bones, compartment syndrome, crush injuries, and gangrene.[12,13]

Patients with crush injuries are at risk of sepsis, intravascular coagulation, respiratory distress syndrome, and death. Multiple organ failure due to crush syndrome and sepsis is the most common cause of death.[12]

Treatment of acute traumatic peripheral ischemia is one of the 13 HBOT indications approved by the Underwater and Hyperbaric Medicine Society.[14] Following acute traumatic limb injury, damage to blood vessels can cause clotting and tissue bleeding, leading to hypoxia and the inability to meet metabolic demands. Hypoxia and the accumulation of extravascular fluid can lead to edema, increased pressure, ischemia, and cell death. When blood flow is restored, ischemia-reperfusion injury can occur. HBOT helps reduce fluid flow through vasoconstriction and increases oxygen delivery by raising dissolved oxygen levels, contributing to decreased edema and enhanced oxygen diffusion. Additionally, HBOT helps attenuate ischemia-reperfusion injury by reducing neutrophil adhesion to the injured vessel walls.[15-16]

Bouachour et al.[7] have reported theoretical and limited experimental evidence suggesting that HBOT may improve wound healing and decrease the need for multiple surgical interventions in crush injuries.

Gökmen and Uluöz[17] reported on the management of 1,092 musculoskeletal injuries during the first week after the Kahramanmaraş earthquake, noting the successful outcomes of HBOT, especially in patients with fasciotomies, soft tissue injuries, open fractures, and crush injuries.

Kapısız et al.[18] reported their observations and experiences of pediatric surgeons working in the field during the first 7 days after the Kahramanmaraş earthquake. They noted that amputation or fasciotomy was not performed on patients due to the inability to conduct postoperative follow-up during that period. Instead, patients were referred to well-equipped centers where facilities such as interventional angiography and HBOT were available. It was believed that this led to a reduction in limb loss and that when amputations were necessary, they were performed at more distal levels. Essentially, their approach aimed to prevent limb loss by directing patients to more specific and effective treatments.

Bartels and VanRooyen[19] reviewed earthquake-related complications and noted that the use of fasciotomy and amputation for crush injuries is controversial. Some advocates of fasciotomy argue that it improves circulation and reverses muscle necrosis, while other experts recommend against its use in non-essential situations due to the risks of infection, sepsis, and death. Proponents of amputation maintain that it is necessary because necrotic tissue can release potentially dangerous substances and act as a source of infection. In contrast, some argue that amputation should play a minor role in the treatment of crush syndrome because it often does not improve patient outcomes.

Ceylan et al.[20] presented their observations and recommendations on earthquake injuries and amputation, reporting that the decision to preserve or amputate a limb following acute traumatic peripheral ischemia presents a significant challenge for orthopedic and traumatology specialists, as well as for patients and their families. They advocated for protective treatments in cases where crush syndrome develops, but also noted that in scenarios unresponsive to such treatments, where the risk of loss of life is high, limb amputation may be unavoidable.

It is widely recognized that establishing criteria for fasciotomy and amputation in earthquake-related injuries remains a contentious issue in medical literature. This study does not seek to draw definitive conclusions on these sensitive matters. However, we wish to emphasize the potential benefits of HBOT in situations where surgeons face difficult decisions. Notably, our country possesses a considerable number of HBOT facilities, surpassing that of many other countries

worldwide.

Our research focused on severe earthquake injuries and found no correlation between the severity of trauma and the necessity for amputation in patients who received HBOT. An 11.4% major amputation rate across all severe injuries examined indicates that HBOT may have a limb-preserving effect irrespective of trauma severity. Furthermore, our findings revealed a significant association between the expedited removal of debris and the early commencement of HBOT with improved functional recovery, underscoring the importance of initiating treatment promptly.

Our main point, which we have endeavored to clarify through examples from the literature, is that Hyperbaric Oxygen Therapy (HBOT) may offer a potential benefit, particularly in the treatment of severe traumatic conditions, such as crush injuries. Future research should aim to determine more precise indications, dosages, and durations for the administration of this treatment modality to tailor it more effectively to the individual needs of patients. In this vein, further multidisciplinary studies and standardized clinical trials are essential for developing customized treatment protocols that align with patients' clinical conditions, injury types, and the capabilities of healthcare systems.

CONCLUSION

This study assessed the potential effects of Hyperbaric Oxygen Therapy (HBOT) on patients with severe earthquake injuries. The findings indicate that HBOT may positively influence critical factors such as sensory recovery, functional recovery, and amputation rates in these patients. Furthermore, the benefits of HBOT appear to be more pronounced in those who began treatment early.

Ethics Committee Approval: This study was approved by the Niğde Ömer Halisdemir University Ethics Committee (Date: 29.11.2023, Decision No: 2023/18-39).

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Conflict of Interest: None declared.

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ORİJİNAL ÇALIŞMA - *ÖZ*

Depreme bağlı şiddetli yaralanmalarda Hiperbarik Oksijen Tedavisi'nin kullanımı

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AMAÇ: Depremler, genellikle şiddetli yaralanmalara ve travmatik durumlara neden olabilen doğal afetlerdir. Bu yaralanmalar arasında ezilme yaralanmaları, kırıklar, doku hasarı ve kan dolaşımı problemleri bulunabilir. Hiperbarik oksijen tedavisi (HBOT), bu tür şiddetli yaralanmalara maruz kalan bireylerde son zamanlarda sıklıkla kullanılan bir tedavi yöntemi haline gelmiştir. HBOT, hastaya yüksek basınç altında saf oksijen verilmesini içeren bir tedavi şeklidir. Bu tedavi, hücresel oksijenlenmeyi artırarak doku iyileşmesini teşvik etmeyi amaçlar. Deprem sonrası şiddetli yaralanmalarda, özellikle ezilme yaralanmalarında, doku iyileşmesini hızlandırma, iltihap azaltma ve enfeksiyon kontrolü gibi faktörlerde olumlu etkileri olabileceği düşünülmektedir. 06.02.2023'teki Kahramanmaraş depreminin ardından şiddetli yaralanmalara maruz kalan 35 hastanın hiperbarik oksijen tedavisi sonuçlarını inceleyerek, tedavinin klinik etkilerini, iyileşme sürecini ve potansiyel avantajlarını retrospektif olarak değerlendirmek ve acil durum müdahale stratejilerini geliştirmeye katkı sağlamayı amaçlamaktadır.

GEREÇ VE YÖNTEM: Bu çalışma etik kurul onayı alındıktan sonra gerçekleştirilmiştir. Çalışmada, depremzede olarak başvurusu alınan ve depreme bağlı şiddetli yaralanması nedeniyle Hiperbarik Oksijen Tedavi Ünitesinde tedavi gören Mess Skoru 7-14 arasında olan hastaların verileri, geçmiş kayıtlardan elde edilmiş ve geriye dönük olarak incelenmiştir. Demografik bilgiler, hasta verilerinin genel dağılımı, ortalama değerleri, Hiperbarik Oksijen Tedavisi (HBOT) seans sayıları ve fonksiyonel sonuçlar, kayıt altına alınmıştır.

BULGULAR: Hiperbarik Oksijen tedavisine alınan 35 hastanın cinsiyet dağılımında %31.4'ü erkek, %68.6'sı kadındı. Yaş dağılımına göre, hastaların %45.7'si 18 yaş ve altında, %54.3'ü ise 19 yaş ve üstündeydi. Hastaların yaş ortalaması 25 olup, yaş dağılımı, minimum 1 ve maksimum 85 arasında değişmekteydi. Tedavi edilen hastalarda en sık yaralanmalar alt ekstremitelerde gözlemlendi, özellikle sol alt ve sağ alt ekstremite etkilendi. Hiperbarik Oksijen tedavisi sonrasında, hastaların çoğunda his geri kazanımı (%54.3) ve fonksiyonel geri kazanım (%51.4) elde edildi. HBOT öncesi ve sonrası amputasyon oranları incelendiğinde, HBOT öncesi minör amputasyon oranı %14.3, majör amputasyon oranı %11.4 iken, HBOT sonrası minör amputasyon oranı %20.0 ve majör amputasyon oranı %11.4 olarak belirlendi.

SONUÇ: Bu çalışma, depremde şiddetli yaralanmaları olan hastalarda Hiperbarik Oksijen Tedavisi'nin (HBOT) olası etkilerini değerlendirdi ve elde edilen bulgular, HBOT'un bu özel hasta grubunda his geri kazanımı, fonksiyonel iyileşme, minör amputasyon oranları ve enkaz altında geçirilen süre gibi kritik faktörler üzerinde olumlu etkiler sağlayabileceğini göstermiştir.

Anahtar sözcükler: Crush yaralanması; deprem; doku yaralanması; hiperbarik oksijen tedavisi; MESS skoru.

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