Influence of Adjuvant Hyperbaric Oxygen Therapy on Short-term Complications During Surgical Reconstruction of Upper and Lower Extremity War Injuries: Retrospective Cohort Study

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Aim To determine the effects of hyperbaric oxygen (HBO) therapy on short-term complications of complex war wounds to the upper and lower extremities in patients who were and those who were not treated according to North Atlantic Treaty Organization (NATO) emergency war surgery recommendations.

Method We retrospectively analyzed data of 388 male patients undergoing reconstructive surgery for Gustilo type III A, B, and C war wounds to the extremities at the Department of Reconstructive Surgery, Split University Hospital Center, between 1991 and 1995. The occurrence of main wound complications (deep infection, osteomyelitis, skin grafts lyses, and flap necrosis) during hospitalization and time from wounding to granulation formation were analyzed with respect to the use of HBO therapy as a risk factor. Odds ratio (OR) with 95% confidence intervals (CI) was calculated for the occurrence of wound complications with respect to HBO therapy and adjusted for NATO surgical strategy by logistic regression.

Results Of 388 patients, 310 (80%) were initially treated according to the NATO surgical strategy and 99 (25%) received HBO therapy. Deep soft-tissue infection developed in 196 (68%) patients who did not receive HBO therapy and in 35 (35%) who received it ($P<0.001$, χ^2 test). Osteomyelitis developed in 214 (74%) patients who did not receive HBO therapy and in 62 (63%) who received it ($P=0.030$). Skin graft lysis occurred in 151 (52%) patients who did not receive HBO therapy and in 23 (23%) who received it ($P<0.001$). Flap necrosis occurred in 147 (51%) patients who did not receive HBO therapy and in 15 (15%) who received it ($P<0.001$). Median time to granulation formation was 9 (5-57) days in patients who received HBO therapy, and 12 (1-12) days in those who did not ($P<0.001$, Mann-Whitney test). These results were consistent over the groups of patients stratified according to the wound severity and remained unaltered after the adjustment for NATO surgical strategy. The effect of HBO therapy was greater in non-NATO than in NATO treated patients in case of deep soft-tissue infection (OR, 10.7 vs OR, 3.8; $P=0.031$ for interaction).

Conclusion HBO therapy reduced the frequency of wound complications in patients with Gustilo type III wounds and shortened the time to granulation formation. HBO therapy was more effective in non-NATO than in NATO treated patients for the prevention of deep soft-tissue infection but not flap necrosis.

Hyperbaric oxygen (HBO) has been used as adjunctive therapy in the treatment of wounds and injuries for over 40 years (1). Due to its beneficial effects on healing, it is applied in the treatment of compartment syndrome (2,3), crush and avulsion injuries (4), ischemic-reperfusion injury (5), and wound infection, especially gas gangrene (5). Multiple injuries of several organic systems, trauma accompanied by traumatic or hemorrhagic shock, and complex wounds consisting of injuries to soft tissues and deep functional structures (bones, blood vessels, tendons, joints, and nerves) of the extremities, particularly lower ones, were often encountered in the casualties of the 1991-1995 war in Croatia and the war in the neighboring Bosnia and Herzegovina (6). Many of these war casualties were treated at the Split University Hospital (6). The wounded from Croatia received surgical care provided according to the Croatian strategy for emergency war medicine (7), based on the North Atlantic Treaty Organization (NATO) emergency war surgery handbook (8). This surgical strategy allowed for optimal timing and method of treatment and was used at medical facilities that provided third and fourth-echelon medical care.

War casualties in Bosnia and Herzegovina were treated under far more difficult conditions than those in Croatia (6,7). NATO strategy of emergency war surgery was not followed (6), often leading to numerous complications during the wound healing, with an unpredictable final result of the therapy, mostly due to delayed primary treatment and presence of devitalized tissue, injuries to blood vessels and nerves, and compound fractures (6,9,10). War wounds were sometimes treated primarily (definitive surgical treatment), but rarely within optimal time frames. Due to these circumstances, even the wounds that had not initially been serious and complex often became complicated and problematic. Primary and secondary amputations were also considerably more frequent (6,7).

In addition to surgical care provided to the patients with war wounds admitted to Split University Hospital between 1991 and 1995, adjuvant HBO therapy was also applied. However, during the war in Croatia, adjuvant HBO therapy had not been adopted as a standard treatment approach. In addition, the facility for HBO therapy was occasionally out of function due to war-related circumstances. Thus, our study included also the patients who were not treated with HBO but were roughly comparable to patients who received HBO. Because little is known about the effects of HBO on war wound complications, we decided to determine the influence of HBO therapy on short-term complications of complex war wounds to the upper and lower extremities in patients being initially treated according to the NATO or non-NATO strategy of emergency war surgery.

Patients and methods

Patients

Of a total of 1220 patients with war wounds treated at the Department of Surgery, Split University Hospital Center – Križine, between 1991 and 1995, only 388 with more complex wounds of Gustilo type III A, B, and C (11) to the upper or lower extremities, or both, were included in the study. All patients were men aged between 19 and 56 years (median, 29 years) who had actively served either in Croatian Army during the 1991-1995 war in Croatia or in Croatian Defense Council during the 1992-1995 war in Bosnia and Herzegovina. They had all received initial surgical treatment before the admittance to the Department of Reconstructive Surgery. Most patients had wounds to the legs caused by explosives (Table 1). In 310 (80%), initial surgical treatment was performed according to

Table 1. Characteristics of 388 patients with war wounds treated at Split University Hospital between 1991 and 1995, divided into four groups according to the complexity, severity, and primary characteristics of extremity war wound*

	No. (%) of patients†			
Characteristic	group I (n = 79)	group II (n = 111)	group III (n = 100)	group IV (n = 98)
Army:				
Croatia	63 (80)	94 (85)	83 (83)	78 (80)
Bosnia and Herzegovina	16 (20)	17 (15)	17 (17)	20 (20)
Wound etiology:				
bullets	25 (32)	32 (29)	26 (26)	31 (32)
explosive	54 (68)	79 (71)	74 (74)	67 (68)
Wound localization:				
arm	12 (15)	17 (15)	14 (14)	15 (15)
leg	57 (72)	92 (83)	70 (70)	63 (64)
arm and leg	10 (13)	12 (11)	16 (16)	20 (21)
Surgical strategy:				
NATO	58 (73)	93 (84)	81 (81)	78 (80)
non-NATO	21 (27)	18 (16)	19 (19)	20 (20)
Adjuvant HBO therapy:				
yes	20 (25)	26 (23)	27 (27)	26 (27)
no	59 (75)	85 (77)	33 (73)	62 (73)
No. of HBO treatments (median, range)	6 (3-10)	5 (3-7)	4 (3-7)	4 (2-6)

*Abbreviations: NATO – North Atlantic Treaty Organization surgical strategy; HBO – hyperbaric oxygen; SD – standard deviation.
†Patients were grouped according to the complexity, severity, and primary wound characteristics as presented in Table 2.

Table 2. Classification of 388 patients with extremity war wounds treated at the Split University Hospital between 1991 and 1995 into four groups according to the complexity, severity, and primary characteristics of the war wound*

	Type of injury			
Wound characteristics	group I (n = 79)	group II (n = 111)	group III (n = 100)	group IV (n = 98)
Ischemia, compartment syndrome, complex soft tissue injury, and open bone fracture	+	+	+	+
Blood vessel injury	+	+		
Nerve injury	+	+		
Crush syndrome	+			
Guillotine amputation of the extremities	+			
Initial soft tissue infection		+	+	

*Group I had the most complex and severe wounds, whereas group IV had the least severe and complex wounds. The purpose of this classification was to reduce the confounding influence of wound severity and complexity in the analysis of hyperbaric oxygen therapy results.

the NATO strategy of emergency war surgery (Table 1). HBO therapy was administered to 99 (25.5%) patients.

A cohort of 388 severely wounded patients was retrospectively identified and the occurrence of wound complications during the period of hospitalization analyzed with respect to the use of adjuvant HBO therapy (study group; n = 99) or non-use of adjuvant HBO therapy (control group; n = 289). To minimize the differences between the study and control group that could confound the effects of HBO therapy, the patients were further divided into four subgroups according to the complexity, severity, and primary characteristics of the war wound (Table 2). Such patient stratification allowed for more detailed distinction between the primary wound characteristics than that provided by the relatively simple Gustillo classification, developed primarily for the classification of wounds to lower extremities. The Group I had the most complex and severe wounds, whereas the Group IV had the least complex and severe wounds. Thus, each group of patients with the same complexity and severity of initial war wound consisted of those who did and those who did not receive HBO therapy.

HBO therapy was performed by inhaling 100% oxygen in hyperbaric chamber, at the pressure exceeding 1.0 bar. In 92 wounded, HBO pressure of 2.2 bar was applied, whereas in 7 cases the applied pressure was 2.8 bar. The number of HBO sessions depended on the clinical picture (12,13).

Method

The data on the wounds, NATO or non-NATO surgical treatment strategies, and adjuvant HBO therapy use were taken from the medical documentation of the wounded treated at the Split University Hospital and from the HBO therapy protocol of the Croatian Navy Institute of Marine Medicine in Split. Etiology, type, localization, and characteristics of the wound were recorded, including the presence of soft tissue destruction and defect, blood vessels injury, nerves injury, compartment and crush syndrome, complicated open bone fracture and segmental bone defects, soft tissue primary infection, and primary guillotine extremity amputation (Table 2). Complications that occurred between the time of wounding and discharge from hospital, such as deep soft tissue infection, osteomyelitis, skin graft lyses, and flap necrosis, were obtained from patient medical charts. The period between wounding and formation of fresh granulations was also recorded, as well as the type of initial surgical treatment, ie, NATO or non-NATO, adjuvant HBO therapy, and the number of HBO therapy sessions.

Statistical analysis

Data were presented as means (medians) and frequencies. The difference in complications between patients receiving HBO and those not receiving HBO was evaluated with χ^2 test. Mann-Whitney test was used to compare the time from primary debridement of the wound to granulation formation due to asymmetrical data distribution. The odds ratios (OR) with 95% confidence intervals (CI) were calculated for occurrence of complications with respect to HBO therapy protocol established by the Undersea and Hyperbaric Medical Society in 1999 (5). Adjustment for the influence of covariables was performed by logistic regression for NATO surgical strategy and by explicit control via subgroup analyses for initial wound characteristics. The effects of HBO therapy were compared between NATO-treated and non-NATO treated patients, after demonstrating the significance of interaction between these predicting variables by logistic regression. All statistical analyses were performed with the Statistical Package for the Social Sciences, version 10 for Windows (SPSS Inc, Chicago, IL, USA). The type 1 error due to multiple testing was controlled by performing only pre-specified subgroup analyses and by using multivariate algorithms. The level of significance was set at $P<0.05$.

Results

Wound etiology, wound localization, surgical treatment strategy, and adjuvant HBO therapy were similar in all four groups of patients (Table 1). The distribution of NATO surgical treatment did not differ between those who did and those who did not receive adjuvant HBO therapy (Table 3).

Short-term complications of war wounds were significantly less frequent in patients who received adjuvant HBO therapy than in those who did not receive it (Table 4). In patients receiving HBO therapy, deep soft-tissue infections and skin graft lyses were twice less frequent, and flap necrosis more than three

Table 3. Use of North Atlantic Treaty Organization (NATO) strategy of emergency war surgery according to the application of adjuvant hyperbaric oxygen (HBO) therapy in each group of patients with extremity war wounds treated at the Split University Hospital between 1991 and 1995

	No (%) of patients treated according to NATO surgical strategy	
Patient groups:*	without HBO therapy	with HBO therapy
group I	43 (73)	15 (75)
group II	73 (86)	20 (77)
group III	62 (85)	19 (70)
group IV	59 (82)	19 (73)

*Groups are described in detail in Table 2.

Table 4. Short-term complications of extremity war wounds with respect to adjuvant hyperbaric oxygen (HBO) therapy in 388 patients treated at Split University Hospital between 1991 and 1995, with adjustment for North Atlantic Treaty Organization (NATO) strategy of emergency war surgery

	No. (%) of patients in the group			OR (95% CI)*	
Complications	without HBO therapy (n = 289)	with HBO therapy (n = 99)	*P*	raw	adjusted for NATO
Deep soft tissue infection	196 (68)	35 (35)	<0.001†	3.8 (2.3-6.1)	3.9 (2.4-6.2)
Osteomyelitis	214 (74)	62 (63)	0.030†	1.7 (1.1-2.8)	1.5 (1.0-2.4)
Skin graft lyses	151 (52)	23 (23)	<0.001†	3.6 (2.1-6.1)	3.8 (2.2-6.4)
Flap necrosis	147 (51)	15 (15)	<0.001†	5.8 (3.2-10.5)	6.2 (3.4-11.2)
Time to granulation formation (days; median, range)	12 (1-12)	9 (5-57)	<0.001‡	–	–

*Odds ratio (OR) with 95% confidence intervals (95% CI) for short term complications of war wounds when HBO therapy was not applied and when it was applied. The adjustment for use of NATO surgical strategy was performed by multiple logistic regression, with HBO therapy and NATO surgical strategy as the binary independent variables.
†χ^2 test.
‡Mann-Whitney test.

times less frequent than in those not receiving HBO therapy. Osteomyelitis was also less frequent in patients receiving HBO therapy, but only by 15%. Median time to granulation formation was shorter by 25% in patients receiving adjuvant HBO therapy. These results were only slightly affected by the adjustment for NATO surgical strategy (Table 4).

The analyses of patients stratified by wound severity produced consistent results over the groups. In all four groups, deep soft-tissue infections, flap necrosis, and skin graft lysis were less frequent in patients who received HBO therapy than in those who did not receive it (Tables 5-8). However, the effects of HBO therapy were more pronounced in some patient groups than in others. In particular, HBO therapy was most efficient in preventing deep soft tissue infection in group III, which included patients with initial soft

Table 5. Short-term complications of extremity war wounds with respect to adjuvant hyperbaric oxygen (HBO) therapy and adjustment for North Atlantic Treaty Organization (NATO) strategy of emergency war surgery in Group I of patients treated at the Split University Hospital between 1991 and 1995*

	No. (%) of patients in the group			OR (95% CI)†	
Complications	without HBO therapy (n = 59)	with HBO therapy (n = 20)	*P*	raw	adjusted for NATO
Deep soft tissue infection	44 (75)	9 (45)	0.015‡	3.6 (1.2-10.3)	3.6 (1.2-10.3)
Osteomyelitis	29 (49)	9 (45)	0.748‡	1.2 (0.4-3.3)	1.2 (0.4-3.3)
Skin graft lyses	28 (48)	4 (20)	0.031‡	3.6 (1.1-12.0)	3.6 (1.1-12.3)
Flap necrosis	39 (66)	4 (20)	<0.001‡	7.8 (2.3-26.0)	8.6 (2.4-31.3)
Time to granulation formation (days; median, range)	11 (8-21)	10 (6-13)	<0.001§	–	–

*Group I is described in Table 2.
†Odds ratio (OR) with 95% confidence intervals (95% CI) for short term complications of war wounds when HBO therapy was not applied and when it was applied. The adjustment for use of NATO surgical strategy was performed by multiple logistic regression, with HBO therapy and NATO surgical strategy as the binary independent variables.
‡χ^2 test.
§Mann-Whitney test.

Table 6. Short-term complications of extremity war wounds with respect to adjuvant hyperbaric oxygen (HBO) therapy and adjustment for North Atlantic Treaty Organization (NATO) strategy of emergency war surgery in Group II of patients treated at the Split University Hospital between 1991 and 1995*

	No. (%) of patients in the group			OR (95% CI)†	
Complication	without HBO therapy (n = 85)	with HBO therapy (n = 26)	*P*	raw	adjusted for NATO
Deep soft tissue infection	58 (68)	10 (38)	0.006‡	3.4 (1.4-8.6)	3.4 (1.4-8.5)
Osteomyelitis	78 (92)	25 (96)	0.449‡	0.5 (0.1-3.8)	0.4 (0.1-3.6)
Skin graft lyses	35 (41)	4 (15)	0.016‡	3.9 (1.2-12.2)	3.9 (1.2-12.2)
Flap necrosis	36 (42)	1 (4)	<0.001‡	18 (2.4-14.2)	18 (2.3-14.2)
Time to granulation formation (days; median, range)	13 (8-19)	10 (6-57)	<0.001§	–	–

*Group II is described in Table 2.
†Odds ratio (OR) with 95% confidence intervals (95% CI) for short term complications of war wounds when HBO therapy was not applied and when it was applied. The adjustment for use of NATO surgical strategy was performed by multiple logistic regression, with HBO therapy and NATO surgical strategy as the binary independent variables.
‡χ^2 test.
§Mann-Whitney test.

Table 7. Short-term complications of extremity war wounds with respect to adjuvant hyperbaric oxygen (HBO) therapy and adjustment for North Atlantic Treaty Organization (NATO) strategy of emergency war surgery in Group III of patients treated at the Split University Hospital between 1991 and 1995*

	No. (%) of patients in the group			OR (95% CI)†	
Complications	without HBO therapy (n = 73)	with HBO therapy (n = 27)	*P*	raw	adjusted for NATO
Deep soft tissue infection	45 (62)	5 (19)	<0.001‡	7.1 (2.4-21)	6.6 (2.2-19.6)
Osteomyelitis	59 (82)	15 (56)	0.011‡	3.4 (1.3-8.8)	3.3 (1.5-8.8)
Skin graft lyses	42 (58)	8 (30)	0.013‡	3.2 (1.3-8.3)	3.3 (1.3-8.5)
Flap necrosis	38 (52)	7 (26)	0.020‡	3.1 (1.2-8.2)	3.0 (1.1-8.1)
Time to granulation formation (days; median, range)	13 (1-21)	8 (5-12)	<0.001§	–	–

*Group III described in Table 2.
†Odds ratio (OR) with 95% confidence intervals (95% CI) for short term complications of war wounds when HBOT was not applied and when it was applied. The adjustment for use of NATO surgical strategy was performed by multiple logistic regression, with HBO therapy and NATO surgical strategy as the binary independent variables.
‡χ^2 test.
§Mann-Whitney test.

Table 8. Short-term complications of extremity war wounds with respect to adjuvant hyperbaric oxygen (HBO) therapy and adjustment for North Atlantic Treaty Organization (NATO) strategy of emergency war surgery in Group IV of patients treated at the Split University Hospital between 1991 and 1995*

	No. (%) of patients in the group			OR (95% CI)†	
Complications	without HBO therapy (n = 72)	with HBO therapy (n = 26)	*P*	raw	adjusted for NATO
Deep soft tissue infection	49 (68)	11 (42)	0.021‡	2.9 (1.2-7.3)	3.0 (1.2-7.6)
Osteomyelitis	38 (53)	13 (50)	0.810‡	1.1 (0.5-2.7)	1.4 (0.5-3.9)
Skin graft lyses	46 (64)	7 (27)	0.001‡	4.8 (1.8-12.9)	5.4 (1.9-15.4)
Flap necrosis	34 (47)	3 (12)	0.001‡	6.9 (1.9-25)	8.9 (2.3-34.5)
Time to granulation formation (days; median, range)	12 (8-25)	9 (7-48)	<0.001§	–	–

*Group IV described in Table 2.
†Odds ratio (OR) with 95% confidence intervals (95% CI) for short term complications of war wounds when HBO therapy was not applied and when it was applied. The adjustment for use of NATO surgical strategy was performed by multiple logistic regression, with HBO therapy and NATO surgical strategy as the binary independent variables.
‡χ^2 test.
§Mann-Whitney test.

tissue infection (Table 7), as well as in preventing flap necrosis in group II, which was composed of patients who had blood vessel and nerve injuries in addition to infection. The only case of a complication that occurred more frequently in HBO treated patients was osteomyelitis in group II (Table 7). Acceleration of granulation formation was most pronounced in group III and least pronounced in the most severely wounded patients in group I; adjustment for NATO surgical strategy had minor effects.

The effect of HBO therapy was greater in non-NATO than in NATO-treated patients in case of deep soft-tissue infection (OR, 10.7 vs OR, 2.8; $P = 0.031$ for interaction) but not for flap necrosis (OR, 9.5 vs OR, 5.4; $P = 0.061$ for interaction) (Table 9). Time to granulation formation was significantly shorter in patients receiving HBO therapy than in those who did not receive it, irrespective of NATO surgical strategy ($P<0.001$ for both).

Table 9. Odds ratios of short-term complications of extremity war wounds with respect to the use of adjuvant hyperbaric oxygen therapy in 388 patients treated the Split University Hospital between 1991 and 1995 together and stratified according to type of primary surgical treatment

	Odds ratio (95% confidence interval)		
Complications	all patients	non-NATO*	NATO
Deep soft-tissue infection	3.8 (2.3-6.1)	10.7 (3.5-32)	2.8 (1.7-4.8)
Osteomyelitis	1.7 (1.1-2.8)	1.1 (0.37-3.1)	1.7 (0.99-2.9)
Skin graft lyses	3.6 (2.1-6.1)	2.2 (0.85-5.7)	4.5 (2.4-8.54)
Flap necrosis	5.8 (3.2-10.5)	9.5 (2.9-31)	5.4 (2.7-10.8)

*North American Treaty Organization (NATO) surgical strategy.

Discussion

We found that HBO therapy significantly reduced the frequency of deep soft-tissue infections, osteomyelitis, skin graft lysis, and flap necrosis in patients with complex Gustilo type III A, B, and C war wounds. It also reduced the time to granulation formation, which is a prerequisite for early surgical reconstruction. The HBO-related prevention of deep soft-tissue infection and flap necrosis were greater in patients primarily not treated according to the NATO strategy of emergency war surgery than in those who were treated according to the NATO strategy.

This is the first quasi-controlled study of effects of HBO therapy on short-term complications of complex war wounds. There have been a few scientific reports on application of hyperbaric oxygenation in the treatment of war wounds, particularly those to the extremities (5,12,13). The use of adjuvant hyperbaric oxygenation in the treatment of complex war wounds in NATO medical care echelons III and IV during the war in Iraq was reported to be effective in reversing ischemia and limiting wound healing complications in hospital-based clinical care settings (14). HBO therapy applied according to the Amsterdam Protocol (15) has been shown effective in limiting the incidence of wound infection and spread of refractory infections (16,17). Our study corroborates these findings. However, HBO therapy has not yet been included into the NATO surgical strategy (14).

The criteria for using HBO therapy in acute traumatic peripheral ischemia are not well established. The early application of HBO therapy, preferably within 4-6 hours after injury, is essential for reaching maximum effects on ischemic tissue and early wound reconstruction (5,9,18).

HBO therapy is the primary mode of treatment or adjuvant to surgical or antibiotic treatment (5). Although data from animal studies support the use of HBO therapy in the treatment of ischemic flaps, compromised grafts, and preparation of the wound for skin grafting, there has not been a single prospective clinical trial performed to test its validity (19,20). Early use of adjuvant HBO therapy contributes to graft and flap survival and provides a more favorable outcome (17,19,21). Although each flap problem is unique, the key factor in flap necrosis is tissue hypoxia (5). HBO therapy not only improves tissue oxygenation, but also contributes to flap survival by enhancing fibroblast and collagen synthesis, neovascularization, and closure of arterial-venous shunts (11). It also has favorable effects on microcirculation (11). Flap necrosis is an expected consequence of pathological changes in complex war wounds that have not been timely and adequately treated. Secondary partial muscle necrosis may develop due to thrombosis of collateral circulation, which in turn favors deep tissue infection (4). Any persistent infection affects and prolongs wound healing processes; in our study sample, the prolongation was 4.5 days on average. HBO applied immediately after the operation and continued for a period of time increases the extent of surviving tissue in an ischemic random flap that would otherwise become necrotic (19). In free flaps reconstruction, it seems that HBO protects the ischemic flap from ischemic-reperfusion injury (19).

Injuries associated with open fracture and segmental bone defects are a great treatment challenge even today (22). Comminuted war fractures of long bones are primarily best treated by external fixation (23,24). Classification of osteomyelitis by Cierny et al (25) can be used to determine the type of bone infection that may benefit from adjuvant HBO (25,26). The fact that oxygen enhances healing of the soft-tissue cover over the fracture justifies the administration of HBO therapy in fracture treatment (27). The wound becomes mature and formation of fibrous callus is improved, followed by bone callus formation (28). If refractory osteomyelitis occurs, HBO therapy should be applied preoperatively and postoperatively, as in case of any bone non-union (22).

Adjuvant HBO therapy has also been evaluated in the treatment of chronic wounds (29). The pooled data from controlled clinical trials of 4 chronic wound types (diabetic foot ulcers, venous leg ulcers, arterial leg ulcers, and pressure ulcers) showed a 70% reduction of the risk of major amputation in diabetic patients when HBO was used in conjunction with standard treatment (29).

The unique advantage of our study is that we had our own, internal control group of patients that were not treated with HBO but were still comparable to the study group. This was allowed by the cohort design of the study; thus, unlike in case-control studies that use external control groups, the sampling bias was negligible. The limitations of our study stem from its retrospective design. We could not verify that the data used in our study were correct. On the other hand, the number of patients was large and the medical records and operation protocols that served as data sources were complete. Although the number of patients receiving HBO treatment in each wound severity group was relatively small, it still allowed us to obtain reliable results. However, this is the first controlled study that analyzed the effects of adjuvant HBO treatment of war wounds and further research is needed to confirm the obtained results.

In conclusion, treatment of complex war injuries on extremities by combining surgical and adjuvant HBO therapy reduces the odds of deep soft tissue infection, osteomyelitis, skin graft lyses, and flap necrosis. Irrespective of the type of surgical strategy applied, the HBO therapy significantly reduced the time to wound stabilization and fresh granulation production. These beneficial effects were observed in all groups of severely wounded patients. Thus, adjuvant HBO therapy should become part of the treatment protocol for extremity war injuries associated with open bone fractures, blood vessel and nerve injuries, and large soft tissue defects.

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