Rutkowski M., Szpotowicz G., Prostak P., Otlewska A., Kozakiewicz M., Chrostek R., Styka L., Niewinska K. Hyperbaric Oxygen Therapy in Traumatology. Issue Rehabil. Orthop. Neurophysiol. Sport Promot. 2018; 25: xxx-xxx. DOI: 10.19271/IRONS-00083-2018-25

Zastosowanie tlenoterapii hiperbarycznej w traumatologii

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STRESZCZENIE

Wstęp

Zastosowania tlenoterapii hiperbarycznej w traumatologii są liczne. Na szczególną uwagę zasługują ostre niedokrwienia, zakażenia tkanek miękkich i kości, urazy zmiażdzeniowe i termiczne.

Cel

Celem pracy była analiza przebiegu leczenia pacjentów, u których prowadzono tlenoterapię hiperbaryczną z powodu urazów zmiażdżeniowych, termicznych, zakażeń ran pourazowych i ostrych zakażeń o charakterze ropowicy.

Materiały i metody

Grupę badaną stanowiło127 pacjentów Ośrodka Tlenoterapii Hiperbarycznej „Creator" (OTH) we Wrocławiu. Grupa składała się z 25 kobiet i 102 mężczyzn. Średni wiek pacjentów wynosił 44,3 lat.

Wyniki

W badanej grupie 11,81% pacjentów zostało skierowanych przed upływem 48 godzin od urazu lub przyjęcia do szpitala, 30,70% w ciągu 7 dni, a 26,77% po upływie miesiąca. Wśród 127 pacjentów 54,33% odbyło pełny cykl zleconych sprężeń, u 37% leczenie zostało przerwane z powodu pozytywnego efektu leczenia, 8,67% przerwało terapię z innych powodów. Znaleziono istotną korelację pomiędzy czasem, który upłynął od urazu do skierowania pacjenta do OTH, a wynikami leczenia. Prawie połowa (46,15%) skierowanych do 48 godzin i tylko jedna piąta skierowanych po upływie miesiąca mogła zakończyć terapię HBO wcześniej w związku z poprawą stanu (p=0,02).

Wnioski

Korzyści z zastosowania tlenoterapii hiperbarycznej w traumatologii są największe przy wczesnym zastosowaniu. Wczesna kwalifikacja pacjentów do tej terapii mogłaby skrócić czas hospitalizacji i zredukować koszty leczenia.

Słowa kluczowe: Tlenoterapia hiperbaryczna, Ropowica, Uraz zmiażdżeniowy

Data otrzymania: 9 luty 2018 *Data zaakceptowania: 18 marca 2018*

Autorzy nie zgłosili źródła finansowania.

Autorzy nie deklarowali konfliktu interesów.

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Hyperbaric Oxygen Therapy in Traumatology

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SUMMARY

Introduction

There are numerous applications of hyperbaric oxygen therapy in traumatology. Particular attention should be paid to acute ischemia, infections, crush and thermal injuries.

Aim

The aim of the study was the analysis of patients referred for HBO treatment with crush injury, thermal injuries and acute post traumatic infections and infections of phlegmon character.

Materials and methods

The study group consisted of 127 patients from the Hyperbaric Oxygen Therapy Centre "Creator" (OTH) in Wroclaw. The group consisted of 25 women and 102 men. The mean age of patients in the study group was 44,3 years.

Results

Within the studied group 11,81 % of patients were referred within 48 hours post injury or admission, 30,70% within 7 days and 26,77 % after a month or more. Out of 127 patients 54,33 % completed their design number of sessions, 37% were discharged earlier due to satisfactory results, 8,67% quit our treatment for other reasons. Signifact correlation was find between the time elapsed from initial injury to HBO referral and clinical improvement. Almost half of the patients (46,15%) who were referred up to 48 hours and only one fifth (20,69%) of those referred after a month qualified for earlier withdrawal from HBO treatment based on improvement (p=0,02).

Conclusions

Benefits of hyperbaric oxygen therapy in traumatology are most significant in early application. Early qualification of patients to HBO therapy could shorten hospitalization time and reduce costs of treatment.

Key words: Hyperbaric oxygen therapy, Crush injury, Soft tissue infection

Date received: 9th February 2018 *Date accepted: 13th March 2018*

INTRODUCTION

Due to wide range of benefits to underperfused and underoxygenated tissues, hyperbaric oxygen is more and more often used to support the treatment of chronic conditions, such as difficult to heal wounds, as well as emergency conditions, including: carbon monoxide poisoning, bacterial infections, decompression sickness or necrotizing fasciitis. Particular attention should be paid to the new indications and to initiation of hyperbaric therapy in traumatology, on which we focus in this work: acute ischemic conditions, infections, crush and thermal injuries.

Ischemia or hypoxia affects the metabolic activity of tissues and impairs wound healing by affecting fibroblast proliferation, collagen and epithelium synthesis. The normal level of oxygen in the tissues is at the level of about 40 mmHg. In infected wounds and damaged tissues, oxygen levels may fall below the level of 30 mmHg. Decrease in oxygen concentration reduces the normal metabolic activity of tissues. In hyperbaric oxygen therapy (HBOT) a chamber that allows oxygen to be delivered at the appropriate partial pressure to target tissues is used. The treatment lasts from 90 to 120 minutes, during this time the patient breathes with 100% oxygen, which is delivered to the tissues at the pressure of 1.9 to 2.5 atm. Procedures are performed once a day and should be repeated 5 to 6 times a week. High oxygen partial pressure is maintained from 2 to 4 hours after the end of hyperbaric oxygen therapy, thereby inducing synthesis of epithelial nitric oxide synthase and angiogenesis and enhancing fibroblasts and leukocytes activity. Despite vasoconstrictive effects on adjacent vessels, HBOT increases oxygen availability for ischemic and hypoxic tissues. Elevated oxygen partial pressure allows to fulfill the metabolic requirements of tissues, even at a low hemoglobin concentration level. Despite the benefits of HBOT therapy, it is a complementary therapy and it cannot replace surgical treatment. Assessment of the healing process should be performed after 15-20 procedures of HBOT treatments (Guerreiro *et al*., 2015).

In Wroclaw, the hyperbaric chambers have operated since 2000, initially as a part of the Department of Disasters and Emergency Medicine of Wroclaw Medical University, later as an independent healthcare facility CREATOR, operating at the University Hospital. In our work, we focused on patients treated with HBOT who had a crush, thermal injury and infected wounds.

Aim of the study

The aim of our study was the analysis of the lenght of treatment in patients with crush injuries, thermal injuries, infected wounds and acute infections of phlegmon character, who underwent hyperbaric oxygen therapy. A detailed analysis was made of the elapsed time from initial diagnosis and patient's admission to the hospital department until the implementation of hyperbaric oxygen therapy.

Material and methods

A retrospective analysis of the medical records of patients of the Hyperbaric Oxygen Therapy Centre "Creator" (OTH) in Wroclaw, who were treated at the facility in the period between 01.01.2011 - 31.01.2016, was carried out. We paid particular attention to time elapsing from initial injury to referral resulting in initiation of HBO treatment.

During this time 127 patients were treated in the Centre with acute tissue injury or post traumatic infection. The group consisted of 25 women and 102 men. The mean age of patients in the study group was 44.3 years.

The most common indications for treatment were post traumatic soft tissue

infections (33,07%), crush injury (29,13%) and post-operative infections (9,44%). Other conditions were thermal injuries, phlegmones, soft tissue necrosis, compromised skin grafts, animal bites and acute ischaemias (Table 1). The statistical analysis of the results was performed by using non-parametric Chi-square (χ^2) test.

Table 1. Patients admitted to OTH from 1.01.2011 to 31.01.2016.

DIAGNOSIS	NUMER OF PATIENTS	% OF PATIENTS
Post traumatic soft tissue infection	42	33,07
Crush injury	37	29,13
Postoperative soft tissue infection	12	9,44
Frost bite	9	7,08
Phlegmone	6	4,72
Burns	6	4,72
Soft tissue necrosis	5	3,93
Compromised skin grafts	4	3,14
Animal bites	4	3,14
Acute ischaemia	2	1,57
TOTAL	**127**	

RESULTS

The inclusion time for hyperbaric oxygen therapy from the admission to the department until the initiation of therapy varied significantly. Only 11,81% patients were referred within 48 hours post injury or admission, 30,70 % within 7 days (quick referral group) and 26,77% after a month or more post injury or diagnosis.

The dominant implication for the use of hyperbaric oxygen therapy in the study group were post traumatic soft tissue infections and crush injury (62,2%). Patients were scheduled for HBO treatment according to Undersea and Hyperbaric Medical Society guidelines. The quick referral group in which HBO therapy was instituted early, were scheduled for 15 sessions, according to their initial diagnosis. The late referral patients were admitted to our facility after apparent signs of infection already occurred and those patients were scheduled for 30 sessions.

After initiation of HBO treatment sessions were run daily for 5 days/week. Therapy could be withdrawn at any time according to patient's underlying condition, bad tolerance of pressure or oxygen or on decision of a referring physician, based on patient's health improvement.

In our material 69 out of 127 patients completed their design number of sessions (54,33%), 47 were discharged earlier on decision of their referring physicians due to satisfactory results (37%), before completion of designed number of treatments. Eleven

patients (8,66%) quit our treatment for other reasons.

The analysis of treatments number vs referral time showed significant correlation. Seven of 15 (46,15%) patients who were referred for HBO treatment up to 48 hours post injury or initial diagnosis were discharged earlier on decision of referring physicians based on patient's health improvement (Figure 1), and 18 of 40 (44,12%) who were referred up to 7 days (Figure 2) were discharged prior to completing a designed number of sessions due to satisfactory results. Only 7 of 34 (20,69%) patients who started treatment more than 30 days post initial diagnosis qualified for earlier discharge (difference is statistically significant – Chi square=5.37, p=0.02) (Figure 3).

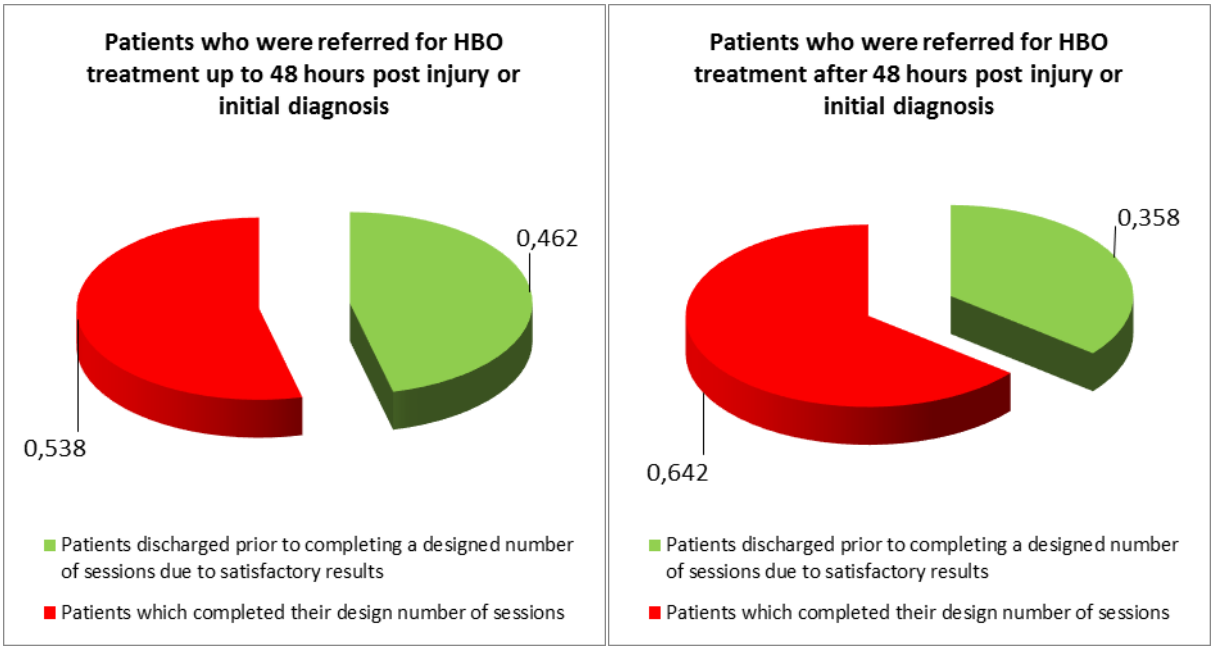

Figure 1. Percentage of patients discharged prior to completing a designed number of sessions due to satisfactory results among patients treated in OTH who were referred for HBO treatment up to or after 48 hours post injury or initial diagnosis.

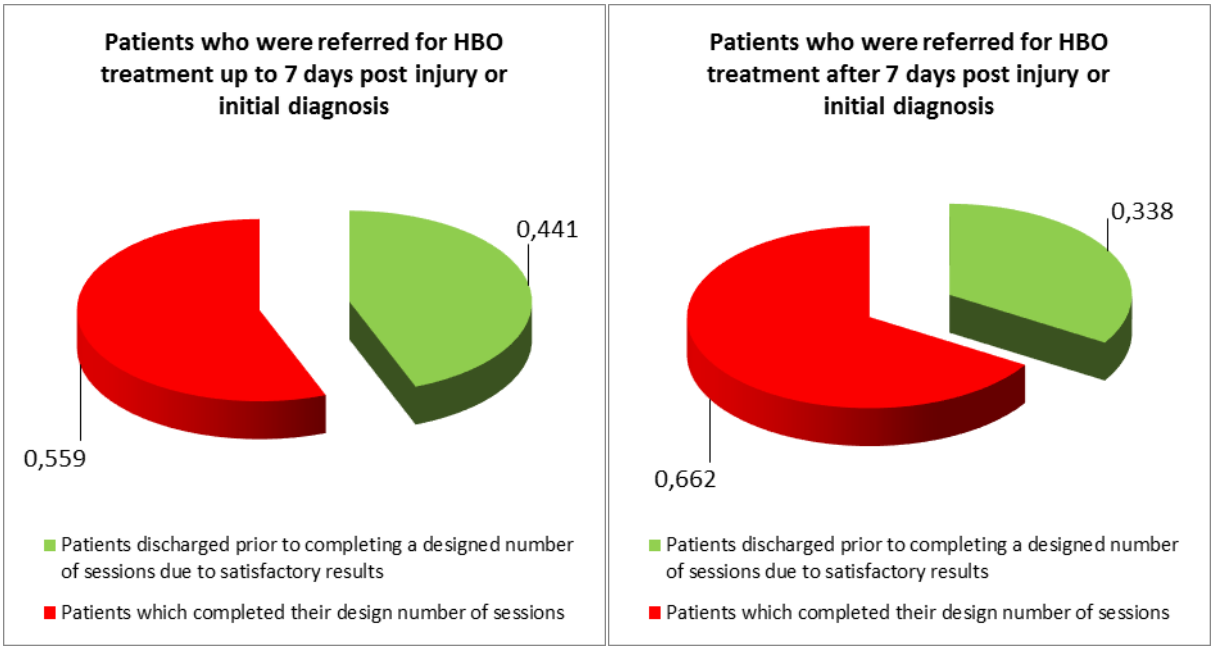

Figure 2. Percentage of patients discharged prior to completing a designed number of sessions due to satisfactory results among patients treated in OTH who were referred for HBO treatment up to or after 7 days post injury or initial diagnosis.

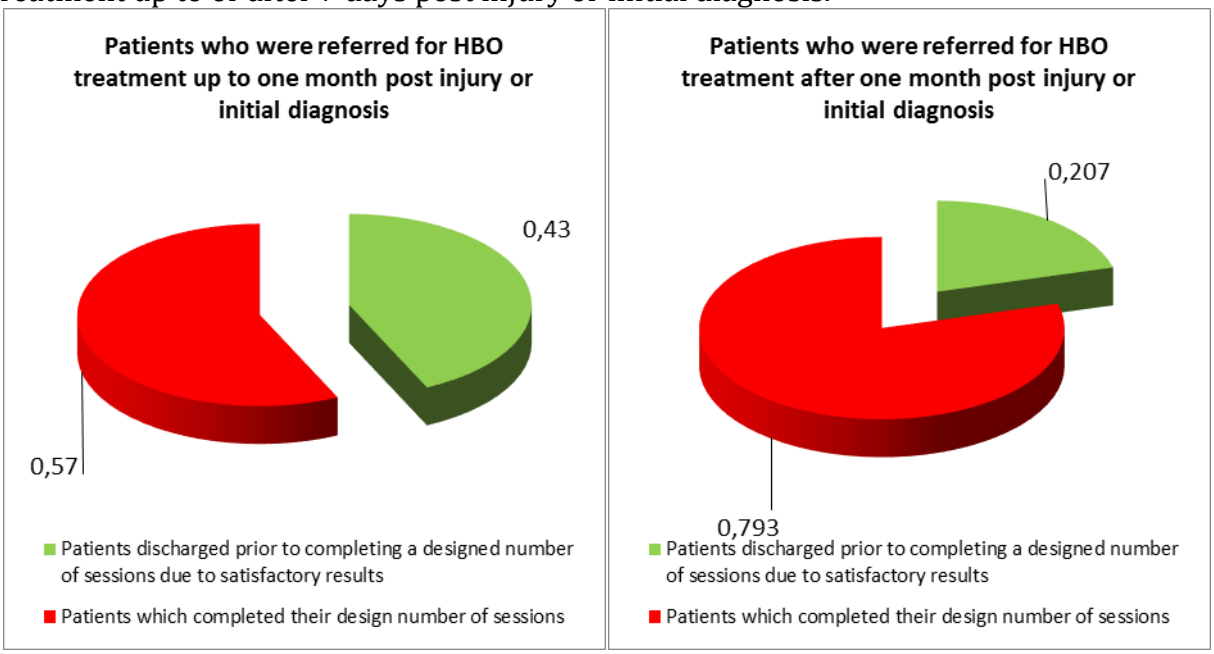

Figure 3. Percentage of patients discharged prior to completing a designed number of sessions due to satisfactory results among patients treated in OTH who were referred for HBO treatment up to or after one month post injury or initial diagnosis.

Patients in late referral group (> 30 days) completed a full designed number of treatments and earlier disruption was only due to personal decision of patients or bad tolerance of pressure or oxygen.

Discussion

In literature, a number of publications on the positive effects of HBOT in the treatment of crush injuries can be found. An example is the work of Strauss on the introduction of HBOT for the treatment of open fractures and crush injuries. The study was based on more than 700 cases with positive effects of treatment with hyperbaric oxygen, such as higher total recovery rate, faster wound healing and shorter hospitalization time (Strauss, 1981).

Another work that significantly demonstrates the effectiveness of HBOT in the treatment of crush injuries is the clinical trial conducted by Bouachour et al. in 1996. Severity of injury was assessed according to Gustilo scale, which is widely used in the classification of open fractures. Serious injuries (Gustilo IIIB, IIIC) were closely related to complications such as infections, nonunions, or amputation of the injured limb. A clinical trial showed complete recovery among 94% of patients treated with HBOT compared to 59% of patients from control group. 6% of HBOT patients required subsequent operations, while in the control group, 33% of patients required reoperation. Fracture healing among patients over 40 years of age has been significantly improved with HBOT. The results of Bouachour's clinical trial showed that treatment of crush injuries in combination with HBOT therapy increases the level of cured patients and reduces the level of complications. Gustilo III-B and III-C injuries are associated with the 50% risk of complications. Class II injuries are associated with the 10% risk of complications. For this

type of fracture, the Bouachour study showed an improvement in primary healing by 35% and a reduction in the need for additional surgical interventions by 27% in the HBOT treatment group (Bouachour *et al*., 1996).

The introduction of HBOT treatment has also proved to reduce the cost of treating patients after crush injuries. In 1977, Brighton et al. reported that in the United States, the mean cost of treatment of patients with fractures of crushing type, among whom primary healing failed, was $ 140,000 (Brighton *et al*., 1977).

Basing on the highest level of clinical evidence, there are objective indications for HBOT use in crush injuries. Hyperbaric chamber therapy fulfills the criteria for the first category according to American Heart Association. Both the Undersea and Hyperbaric Medical Society and the American social insurance system Medicare recommend the use of HBOT in crush injuries. Basing on clinical evidence and cost analysis, the inclusion of HBOT as a standard procedure in medical institutions dealing with the treatment of this type of injury is justified. The more programmes that take into account the use of HBOT are implemented, the more likely the emergency physicians are involved in the early inclusion of hyperbaric oxygen therapy as a part of the surgical treatment (Buettner *et al.,* 2007).

However, in spite of the development of healing methods of chronic wounds with the use of HBOT, there is still a need to develop appropriate guidelines based on modern standards of evidence-based medicine (EBM).

Hyperbaric chamber has been used not only for the treatment of crush injuries, but also for burns and frostbite, although evaluation of the effectiveness of hyperbaric oxygen therapy in the treatment of frostbite is difficult. Thanks to the hyperbaric chamber, the oxygen pressure increases in the bloodstream, so this method of treatment can only be effective if the blood supply to the distal tissues is correct. In case of frostbite, this condition is not fulfilled. However, hyperbaric therapy is used due to other positive effects such as beneficial effects on the function of erythrocytes and a reduction in the risk of bacterial infection. Two studies (Von Heimburg *et al.,* 2001, Finderle *et al.,* 2002) shows good results of HBOT use for the treatment of frostbite. Various mechanisms of action are suggested, but the most important changes appear to occur in microcirculation. It is likely that HBOT increases the elasticity of erythrocytes, reduces the formation of edema in ischemic tissue, and has bacteriostatic effects. This can counteract platelet aggregation, embolism formation and increase in the number of leukocytes observed in the microcirculation of the frostbitten tissue. In their publication, Finderle and Cankar point out the successful use of HBOT among patients without significant loss of frostbitten tissue, who underwent 28 sessions in chambers for many people, at an oxygen pressure of 2.5 atm for 90 minutes per day. Treatment started 12 days after the injury. The role that HBOT plays in all phases of frostbite treatment and the fact that it is a relatively safe and inexpensive treatment justifies further conduction of research (Freer *et al*., 2001).

The use of HBOT as a treatment of burns also requires additional research. Despite considerable progress in the treatment of patients with severe burns, still a very high level of mortality is observed in this group of patients. Large scale burns can be a serious crisis for the public health system. Burns are very often a devastating event for the patient, both due to physical and mental injury. Broad, severe burns can lead to severe disability as well as death of the patient (Van Loey *et al.*, 2003).

Burns cause necrosis of the cellular elements of epidermis and dermis. There is also a dynamic systemic response after initial injury. Secondary emerging interstitial edema and dysfunction of internal organs caused by bacterial growth in the superficial part of burns (scab) may lead to systemic infection and sepsis. The depth of the injury is

closely related to the intensity and duration of the heat effect, so a preliminary assessment of the degree of injury is an important first step in the treatment of burns (Grunwald *et al*., 2008). Treatment of acute burns includes fluid therapy aimed at maintaining hemodynamic stability of the patient, escharotomy, adequate supply of nutrients, topical and systemic antibiotic therapy, proper dressing treatment with surgical debridement and transplantation of skin grafts, inclusive (Bezuhly *et al.*, 2012). Hyperbaric oxygen therapy significantly increases the availability of oxygen to burned areas. HBOT can stimulate wound healing, since enzymes involved in the fight against bacteria, collagen synthesis, angiogenesis, and the growth of new epidermis layers require oxygen levels above > 25 mm Hg in burned tissues (Schreml *et al.* 2010; Thom, 2011; Dauwe *et al*., 2014). However, the results of randomized trials have not been sufficient to confirm or exclude the efficacy of HBOT in the overall treatment of burns (Brannen *et al.*, 1997; Villanueva et al., 2004). An example of the effectiveness of oxygen therapy can be the treatment of patients who were injured after the explosion of a flammable starch-based powder that occurred in 2015 in the amusement park in New Taipei City (Taiwan). It was the most serious burn on a mass scale in Taiwan's history, with 499 wounded and 15 fatalities. 33 of them were treated at the Tri-Service General Hospital (a specialist center), where a study was conducted to evaluate the effect of HBOT on the course of their treatment. The aim of the study was to compare the number of days needed to normalize the level of procalcitonin in blood - a protein, the synthesis of which is strongly associated with an existing bacterial infection. The number of days that passed from trauma to normalization of procalcitonin level was significantly shorter (83.63 6.72 vs 136.25 23.01 days, p = 0.007) than among patients, who did not undergo HBOT (Chiang *et al*., 2017). It may also suggest that HBOT is helpful in treating patients after burns, increasing the level of control of potentially developing infections, shortening the duration of antibiotic therapy and skin grafts healing after transplantation (Perrins, 1967).

The next study by Hart et al. (1974) reports that the mean duration of treatment of patients with burns and their mean need for fluids is significantly lower among patients, who undergo HBOT therapy. Cianci et al. (1990) retrospectively analysed the effect of HBOT in the supported treatment of burns - it was found that the HBOT group was characterized by a shorter hospital stay, fewer surgical procedures and, consequently, lower cost of treatment. Holistic approach, which includes many different methods of treatment, including HBOT, can improve the outcome of the of treatment of burns. However, these findings should be confirmed by a study, which should include a larger number of patients. Further studies are needed to clarify the role of HBOT in the treatment of thermal burns, the results of current work are promising.

Another issue is the patients with the infection of a wound, which leads to phlegmon. Phlegmon is a purulent inflammation developing in the spaces between the tissues. It is most often caused by a traumatic event, pinprick with a dirty object or bite/sting. Local symptoms of inflammation are more or less of diffused character and are accompanied by systemic symptoms of infection, fever. In the first step, surgical debridement with pus evacuation, rinsing and draining and empirical antibiotic therapy are used (Stasiak *et al.,* 2012). Patients with phlegmon need urgent surgical intervention and procedures often need to be repeated. Wilkinson et al., in a prospective work on necrotizing fasciitis done on a group of 44 patients, showed that this therapy increases the chance of survival, reduces limb amputation frequency and increases long- term survival rate. This work shows that hyperbaric oxygen therapy has the strongest relationship to the survival (Wilkinson *et al.,* 2004). Non-specific stimulating effect of hyperbaric oxygen therapy is characterized as an acceleration of wound healing by

stimulating fibroblasts and vascular endothelial cells proliferation. Increased tissue oxygenation improves the effect of some antibiotics (e. g. oxygen-dependent pump, which transports aminoglycosides to the inside of the bacterial cell). Hyperbaric oxygen therapy also has an immunomodulating effect and decreases the production of proinflammatory cytokines by neutrophils. Hyperbaric oxygen therapy also modulates the interaction between neutrophils and vascular endothelial cells (Stasiak et al., 2012).

As every treatment, HBOT carries the risk of complications. Hadanna et al. retrospectively analysed the medical records of 2334 patients. The major side effects associated with HBOT were pressure injuries among 9.2% of patients. Other side effects, as described in literature, include hypoglycaemia, oxygen toxicity, dizziness, anxiety, dyspnea, chest pain, which occurred among 0.5-1.5% of patients. HBOT complications are rare and usually resolve spontaneously (Hadanny *et al.,* 2016).

Results of our study show direct relationship between early referral for HBO therapy and better results of treatment. Patients from early referral group were able to be discharged from our Center earlier than estimated date due to satisfactory results. In this group the number of sessions was reduced, therefore costs of treatment were lower.

CONCLUSIONS

The potential benefits of hyperbaric oxygen therapy in traumatology increase with early application of this method of treatment. We can assume that patients with crush injury, burn injury, open wounds, infected wounds, phlegmons could benefit most from hyperbaric oxygen, would they be referred to HBO facility within hours or days post injury or diagnosis.

Based on a literature review, we find that the inclusion of HBOT into complementary patient care in the early days after injury is important. Our results confirm the benefit of early referral. The mean inclusion time of hyperbaric oxygen therapy from admission to the ward to initiation of therapy at our Center was 32.8 days**,** which is a very long time, considering the potential benefits that HBO treatment can offer the patient. Pre-qualification of patients for admission to HBO unit, already performed in ER, could minimize patient's waiting period for hyperbaric oxygenation therapy inclusion. Such treatment can be expected to shorten the average patient hospitalization time and thus reduce the cost of treatment.

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Authors reported no source of funding.
Authors declared no conflict of interest.

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