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Original Article

Our Experiences with Hyperbaric Oxygen Therapy in Paediatric Orthopaedics

Çocuk Ortopedisinde Hiperbarik Oksijen Tedavisi Deneyimlerimiz

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ABSTRACT

Objective: The main uses of hyperbaric oxygen therapy (HBOT) in orthopaedics are acute traumatic ischemia such as crush injuries and compartment syndrome, reimplantations, chronic osteomyelitis, grafts and flaps with suspected involvement, gas gangrene, necrotizing soft tissue infections, avascular necrosis and delayed post-op wound healing. The aim of this study was to determine the most common orthopaedic indications for HBOT in pediatrics. We also aimed to share information about HBOT with pediatric orthopaedic surgeons.

Method: By reviewing our files and system records, we documented all pediatric patients who underwent HBOT between 01.01.2006 and 01.01.2016 with the indications of crush injury, compartment syndrome, chronic osteomyelitis and delayed wound healing. We recorded the demographic characteristics, indications, outcomes, problems encountered, complications and side effects of patients aged 0-18 years who received at least 15 sessions of HBOT.

Results: A total of 1029 HBOT sessions were performed in 31 patients. Treatment was completed as planned in 24 patients (77.4%). Cure was achieved in 19 patients (61.3%). Two patients (6.4%) had improvement with minor morbidity, and three (9.7%) had no improvement as a result of the treatment. Anxiety symptoms were observed in only six patients during the first session (0.6% patient sessions). The sessions did not result in any complications that required treatment to be discontinued.

Conclusion: HBOT in patients with orthopaedic indications was completed without complications. We believe that HBOT can be safely used in pediatric orthopaedics. However, larger patient series are needed.

Keywords: Hyperbaric oxygen therapy, pediatric, safety, side effects

ÖZ

Amaç: Hiperbarik oksijen tedavisi (HBOT) ortopedide başlıca crush yaralanmalar ve kompartman sendromu gibi akut travmatik iskemiler, reimplantasyonlar, kronik osteomyelit, tutması şüpheli greft ve flepler, gazlı gangren, nekrotizan yumuşak doku enfeksiyonları, avasküler nekrozlar ve post-op yara iyileşmesinin geciktiği durumlarda kullanılmaktadır. Bu çalışmanın amacı çocuklarda en çok hangi ortopedik endikasyonlarda HBOT uyguladığımızı belirlemektir. Ayrıca çocuk ortopedisi ile ilgilenen hekimlerle HBOT konusunda bilgi paylaşmayı amaçladık.

Yöntem: Dosya ve sistem kayıtlarımızı inceleyerek 01.01.2006 ile 01.01.2016 tarihleri arasında crush yaralanma, kompartaman sendromu, kronik osteomyelit ve gecikmiş yara iyileşmesi endikasyonlarıyla HBOT uyguladığımız tüm çocuk hastaları belgeledik. 0-18 yaş arasında ve yukarıda sayılan endikasyonlarda en az 15 seans HBOT gören hastaların demografik özellikleri, endikasyonları, tedavi sonuçları, karşılaştığımız sorunlar, komplikasyon ve yan etkileri kayıt altına aldık.

Bulgular: Otuz bir hastaya toplam 1029 seans HBOT uyguladık. Hastalardan 24'ünün tedavisi planlandığı şekilde tamamlandı (%77,4). Hastaların 19'unda (%61,3) şifa sağlandı. İki hastada (%6,4) tedavi sonucunda minor morbidite ile düzelme oldu, üç hastanın (%9,7) tedavi sonucunda ise herhangi bir düzelme olmadı. Altı hastada ilk seans sırasında anksiyete bulguları gözlendi (%0,6 hasta seansı). Seanslar sırasında tedavinin kesilmesini gerektirecek bir komplikasyona rastlanmadı.

Sonuç: Ortopedik endikasyonlarla tedaviye alınan hastaların HBOT'si herhangi bir komplikasyon olmadan tamamlanmıştır. HBOT'nin çocuk ortopedisinde güvenli bir şekilde kullanılabileceğini düşünmekteyiz. Ancak bu konuda daha geniş hasta serilerine ihtiyaç vardır.

Anahtar kelimeler: Hiperbarik oksijen tedavisi, çocuk, güvenlik, yan etkiler

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INTRODUCTION

Hyperbaric oxygen therapy (HBOT) is a medical treatment based on the inhalation of 100% oxygen at atmospheric pressures greater than 1 atmospheric absolute (ATA), with a minimum of 1.4 ATA for effectiveness. Treatment is administered in monoplace or multiplace HBOT chambers by delivering 100% oxygen via a mask, hood or endotracheal tube (Figure 1). The duration of treatment varies between 1.5 and 2 hours in routine HBOT sessions, and the treatment pressure varies between 2 and 2.8 ATA[1].

The effect of HBOT is achieved by two different mechanisms. The first mechanism is related to the effect caused by the increase in the atmospheric pressure which is used in the treatment of decompression sickness and arterial gas embolism. The second mechanism concerns with the effect of increasing the partial pressure of oxygen inhaled under high pressure. In this way, hypoxia is eliminated thanks to the increased partial oxygen dissolved in the tissues, which has antitoxic, antibacterial and anti-edema effects. In addition, wound healing processes are also supported by high partial oxygen levels[2-6].

Figure 1. Multiplace pressure chamber, a) interior view, b) exterior view (University of Health Sciences Turkey, İzmir Bozyaka Training and Research Hospital, Clinic of Underwater Medicine and Hyperbaric Medicine)

In 2001, the indications for HBOT according to the "Regulation on Private Health Institutions Applying HBOT" guideline published by the Turkish Ministry of Health are shown in Table 1[7]. Indications for HBOT have been specified by the Undersea and Hyperbaric Medical Society and the European Committee of Hyperbaric Medicine, and consensus reports with levels of evidence were published[1,8]. There are no randomised controlled trials in the literature on indications and treatment protocols in children. Indications and protocols in adults are being used for HBOT in children.

Indications for HBOT in pediatric orthopedics include crush injuries, compartment syndromes, avascular necrosis, necrotizing soft tissue infections, gas gangrene, chronic osteomyelitis, grafts and flaps suspected of being infected or impaired, and conditions where postoperative wound healing is delayed[9].

There are a limited number of studies in the literature on HBO treatment in children[10-14]. In addition, there are no case series on the use of HBOT in pediatric orthopedics. In this study, we reported the indications for HBOT in pediatric orthopedics, the treatment outcomes and the difficulties we encountered during treatment. We compared our data with those of other studies in the literature. We aimed to share this information with pediatric orthopedic surgeons in particular.

Table 1. Indications for hyperbaric oxygen therapy[7]
Decompression sickness
Air or gas embolism
Carbon monoxide, cyanide poisoning, acute smoke inhalation
Gas gangrene
Necrotizing infections of soft tissues (subcutaneous, muscle, fascia)
Crush injuries, compartment syndrome and other acute traumatic ischaemias
Delayed wound healing conditions (diabetic and non-diabetic)
Chronic refractory osteomyelitis
Excessive blood loss
Radiation necrosis
Skin flaps and grafts with suspected involvement
Thermal burns
Brain abscess
Anoxic encephalopathy
Sudden hearing loss
Retinal artery occlusion
Acute osteomyelitis of the skull, sternum and vertebrae

MATERIALS and METHODS

Approval for this retrospective study was obtained from the Ethics Committee of the University of Health Sciences Turkey, İzmir Bozyaka Training and Research Hospital on 17.05.2021 with the decision number 2021/05-16. We recorded demographic data, indications, HBOT protocol and number of sessions, problems encountered during treatment, complications and outcomes. Chest radiographs were taken before treatment and the lesions that could cause air trapping were assessed. Consent for treatment was obtained from the children's families. A hyperbaric nurse was present during treatment sessions. However, children who did not want to enter the hyperbaric chamber and showed signs of anxiety were allowed to be accompanied by a family member. Ear equalization manoeuvres were explained and demonstrated to the children. Young children were induced to perform ear equalization manoeuvres in the hyperbaric chamber by playing yawning games. HBOT sessions were performed in a multi-place hyperbaric chamber (Barotech-Istanbul) at 2-3 ATA pressures for 2 hours. Oxygen was administered by mask and hood in children too young to adapt to the mask. Toys that did not pose a fire risk were allowed in the hyperbaric chamber as a distraction for young children. During treatment sessions, the hyperbaric chamber was monitored and recorded by external cameras, and verbal communication was provided by an intercom system. Because of the risk of fire, electrical appliances and flammable objects were not allowed in the hyperbaric chamber. In addition, the oxygen level in the chamber was strictly controlled by oxygen sensors.

Statistical Analysis

Data were entered into a Microsoft Excel (Microsoft, US) spreadsheet under the categories of complete recovery, healing with minor morbidity (minor amputation, skin graft or surgical debridement), no recovery, withdrawal from treatment, and complications related to HBOT. These data were statistically analyzed with Microsoft 365 Excel 2021 software program.

Patients

A total of 31 pediatric patients aged 5-18 years (median 12 years) referred from orthopedic clinics were treated over a 10-year period. Patient demographics by indications and number of sessions performed are shown in Table 2. A total of 1029 HBOT sessions were delivered (mean ± standard deviation number of therapy sessions per patient: 33.2±16.4).

Eighteen patients received HBOT for delayed wound healing. Nine of these patients underwent surgery after trauma and developed infection or necrosis in the surgical field. Nine patients who presented with ulcers due to foot deformity with sequelae of meningomyelocele were school-aged and mobile patients. Eight patients were treated with a diagnosis of chronic osteomyelitis. Patients had femural osteomyelitis (n=1), humeral osteomyelitis (n=1), and tibial-fibular osteomyelitis (n=6). Five patients were treated with the diagnosis of crush injury and compartment syndrome, due to traffic accidents (n=3) and compression between objects (n=2).

RESULTS

Over a 10-year period, we treated a total of 31 patients aged 5-18 years with five different indications. Treatment outcomes are shown in Table 3. Cure was achieved in 19 patients (61.3%) (Figures 2, 3). Two (6.4%) patients had a minor morbidity, and three (9.7%) patients did not recover despite treatment.

None of the patients refused treatment because of claustrophobia. Anxiety was observed in only six out of 1029 sessions (0.6%). Anxiety symptoms disappeared when a family member entered the hyperbaric chamber with his/her children. No barotrauma or oxygen toxicity that would interrupt or terminate treatment was observed during HBO sessions.

DISCUSSION

Indications and levels of evidence for HBOT have been defined by international organizations[1,8]. In the absence of specific HBOT guidelines for children,

Table 2. Indication, demographics and number of sessions

Indication	n	Mean (SD) Age	Sex (F:M)	Median (SD) Session
Delayed wound healing	18			
Operation wounds	9	9.7 (4.0)	4:5	32.9 (13.3)
MMC	9	12 (4.7)	7:2	35.6 (18.8)
Chronic osteomyelitis	8	14.1 (4.0)	3:5	33.4 (21)
Crush injury, compartment syndrome	5	11.8 (4.8)	1:4	31 (12.5)
Total	31	12.2 (4.5)	15:16	33.2 (16.4)

F: Female, M: Male, SD: Standard deviation, MMC: Meningomyelocele

Table 3. Treatments outcomes					
Indication	**n**	**Complete recovery**	**Recovery with minor morbidity**	**No recovery**	**Withdrawal from treatment**
Delayed wound healing	18				
Operation wounds	9	5	1	1	2
MMC squealae	9	6	0	0	3
Chronic osteomyelitis	8	4	0	2	2
Crush injury, compartment syndrome	5	4	1	0	0
n (%)	31	19 (61.3)	2 (6.45)	3 (9.68)	7 (22.6)
MMC: Meningomyelocele					

Figure 2. Sixteen year-old female patient, foot deformity due to meningomyelocele, before HBOT

HBOT: Hyperbaric oxygen therapy

Figure 3. After 60 sessions of HBOT

HBOT: Hyperbaric oxygen therapy

current indications for adults were also used in our study for pediatric patients.

In our study, most commonly patients with delayed wound healing (n=18) received HBOT. Nine of these patients had chronic ulcers occurring in the deformed foot as a result of meningomyelocele. These patients were school-aged children with no activity limitations. Treatment regimens included HBOT, wound care and off-loading. The remaining nine patients were admitted for failure of the surgical site to heal after surgery for various reasons.

In addition to HBO treatment, wound care, appropriate antibiotherapy based on tissue culture results, and minor debridement of ulcers were performed. Traffic accidents were the most common cause of chronic osteomyelitis in eight cases. One of the four crush injury cases required a minor amputation. In the remaining cases, treatment achieved healing of wounds. One case of compartment syndrome was treated with HBO. This patient's treatment resulted in complete healing at the end of the 15th session of HBO without need for surgical intervention.

In the patient series of Frawley et al.[10] and Frawley and Fock[12], cases of delayed wound healing were treated with HBO. In a series of 112 patients, 13 patients were treated with a diagnosis of chronic osteomyelitis. Complete recovery was reported in 10 and recovery with minor sequelae in 3 cases[10]. In a series of 139 patients by Waisman et al.,[11] five cases of chronic osteomyelitis were treated and cured without the need for surgical intervention after an average of 32 sessions of HBOT. Another series of patients reported two cases of chronic osteomyelitis without any mention of the outcomes of the cases[12]. A total of 27 cases including 14 cases with crush injuries and 13 cases with compartment syndromes were reported. Three of these patients recovered with major disability and 15 with minor disability. The average number of 7.2 HBO sessions were used in these patients[10]. In the study by Waissman et al.,[11] 13 cases with acute traumatic and crush injuries were reported. Two patients recovered completely and five patients partially. Six patients did not benefit from the treatment.

The most common side effect of HBOT is ear and sinus barotrauma[15-18]. Side effects of HBOT have not been investigated in studies performed on pediatric patients.

However, the incidence of barotrauma in the general population has been reported to be 1.9-3% in various studies[16,17].

Complications requiring discontinuation of HBOT were not observed in our study. Anxiety was observed in only six (0.6%) sessions and these symptoms disappeared when the parents entered the hyperbaric chamber with their children. The rates of anxiety in the study by Frawley and Fock[12] were reported to vary between 2, and 3.2%. In the study by Plafki et al.[16] the rate of anxiety in the general population, was reported to be 4.3%, and in 1.3% of the cases treatment was discontinued because of anxiety. We believe that if a family member accompanies his/her child during therapy sessions, anxiety of these children will be relieved, and the treatment process will not be interrupted or discontinued.

Study Limitations

This study has some limitations. The main limitations are its retrospective nature, and the small number of patients included in the study population. We also did not have information on the outcomes of seven patients whose treatment was discontinued at the request of their families. The other limitation is the lack of a control group which prevents intergroup comparison of treatment outcomes.

CONCLUSION

HBOT is an adjunctive treatment modality that can be used for several indications in pediatric orthopedics. We believe that HBOT can be safely used in pediatric patients for the same indications as in adults. Large patient series are needed to provide more detailed information on the efficacy and side effects of HBOT in pediatric orthopedics.

Ethics

Ethics Committee Approval: Approval for this retrospective study was obtained from the Ethics Committee of the University of Health Sciences Turkey, İzmir Bozyaka Training and Research Hospital on 17.05.2021 with the decision number 2021/05-16.

Informed Consent: Retrospective study.

Author Contributions

Surgical and Medical Practices: F.A., M.İ., Concept: F.A., Design: F.A., Data Collection or Processing: F.A., Analysis or Interpretation: F.A., M.İ., Literature Search: F.A., M.İ., Writing: F.A.

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