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Case Series

Hyperbaric oxygen therapy in low extremity trauma: A case series

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ABSTRACT

Introduction: Trauma to the extremities is a common major health problem that requires special attention because it can have a dangerous impact on both the viability of the limb and the patient's life. Hyperbaric oxygen therapy is an alternative therapy hypothesized to improve the prognosis in lower extremity trauma.
Case presentation: We present a series of 7 cases of lower extremity trauma treated with hyperbaric oxygen therapy: soft tissue loss, neglected chronic burn injury, high-voltage electrical burn, gas gangrene, crush injury, chemical burn, and excoriation with skin loss.
Discussion: Hyperbaric oxygen therapy involves giving 100% oxygen in a chamber at pressures above atmospheric pressure (2–3 atm absolute [ATA]). It can increase oxygen delivery to peripheral tissues with vascular compromise, cytogenic and vasogenic edema, and cellular hypoxia caused by limb trauma.
Conclusion: Hyperbaric oxygen therapy has many benefits in lower extremity trauma for wound recovery, preventing complications, and helping patients return to daily activities.

1. Introduction

Trauma to the extremities is a common major health problem that requires special attention because it can have a dangerous impact on both the viability of the limb and the patient's life [1]. Injuries to the extremities are often associated with trauma-related presentations to the emergency department and are also a source of disability. They can range from mild to severe and even life-threatening and may involve soft tissue, bone, and neurovascular structures [1,2]. Hyperbaric oxygen therapy is an alternative therapy that is believed to improve the prognosis of lower extremity trauma. We will present several cases of lower extremity trauma that used hyperbaric therapy (Table 1). This case series is reported in line with the Preferred Reporting of Case Series in Surgery (PROCESS) guidelines [3].

2. Case series

2.1. Patient 1

A 47-year-old man was treated in the emergency room with injuries to his right leg from a traffic accident. Local examination of the right leg found a wound with partial soft tissue loss, sized 25 × 12 cm, with irregular edges, no active bleeding, no crepitation, and normal distal neurovascular status (Fig. 1A and B). The wound was debrided in the operating room under a general anesthetic. The patient was then treated with normal saline solution, antibiotics, and intravenous analgesics. To

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Table 1
Demographic data of patients who underwent hyperbaric oxygen therapy (HBOT).

Patient	Age	Sex	Diagnosis	Surgical Intervention	HBOT Sessions
1	47	M	Soft tissue loss in lower leg region	STSG	9
2	20	M	Neglected chronic burn injury	Gastrocnemius muscle flap + STSG	9
3	28	M	High-voltage electrical burn on left foot	Radial forearm free flap	9
4	56	M	Gas gangrene in left lower leg	Debridement + fasciotomy + STSG	6
5	3	F	Crush injury on left foot	STSG	6
6	29	M	Chemical burn	Debridement	10
7	26	F	Excoriations and skin loss on right foot	Debridement	10

Note: F = female, M = male, STSG = split-thickness skin graft.

accelerate the granulation process, hyperbaric oxygen therapy was used 9 times in 2 weeks (Fig. 1C). Once the granulation tissue was adequate for reconstruction, skin grafts were performed by taking the donor skin from the anterolateral side of the patient's right thigh (Fig. 1D). The patient was then transferred to and observed in the ward. After the evaluation of the wound in the first week post reconstruction, no signs existed of infection or thrombosis. Vascularization of the graft and donor and around the operation site was adequate. Treatment was then resumed, and the patient was discharged after 5 weeks of treatment. Three months later, the patient came to the outpatient department for follow-up. We found that the graft was fully healed and the patient could function normally (Fig. 1E).

2.2. Patient 2

A 20-year-old man came to our emergency department with fourth-degree burns caused by prolonged contact with a motorcycle muffler in an accident. An open wound was present on the anterior upper third of the left tibia, along with another wound on the right knee and thigh. The wound had been left for 2 months and treated with herbal medicines. The wound had become infected and the left knee joint could not be completely straightened out due to contracture (Fig. 2A and B). The patient was very thin and weak (BMI = 16) and appeared to have disuse atrophy of both legs. He was unable to walk on his own. Debridement was performed under a general anesthetic in the operating room. The patient was treated for a week with gradual stretching of the knee joint. A back slab cast was installed after stretching to maintain the length of the limbs. Over the next 2 weeks, the patient was treated with hyperbaric oxygen therapy to maximize the granulation process. He ate high-calorie and high-protein food to improve his nutritional status. After 3 weeks, the granulation tissue appeared, and the patient was ready to undergo the final reconstructive procedure (Fig. 1C). A local flap was taken from the gastrocnemius muscle to cover the exposed upper tibia, followed by a split-thickness skin graft (STSG) taken from the

Fig. 1. *(A) Lateral view. (B) Front view. (C) Wound bed post–hyperbaric oxygen treatment with granulation process after 2 weeks. (D) STSG covering right leg wound. (E) Three months post operation.* ***Left:*** *Front view.* ***Right:*** *Lateral view.*

Fig. 2. (A) Contracture left knee. (B) Contracture right knee. (C) Wound bed after hyperbaric treatment with granulation process. (D) Right: STSG covering gastrocnemius muscle flap; middle: gastrocnemius muscle flap covering left leg wound; left: STSG covering gastrocnemius muscle flap on left leg.

anterolateral part of the thigh (Fig. 1D). Another STSG was also performed to cover defects in the opposite leg. The patient was then observed on the ward for another 2 weeks with the back slab still maintained before discharge. Three months later, the patient came to the outpatient department for follow-up. We found that the graft was fully healed and the patient could function normally (Fig. 1E).

2.3. Patient 3

A 28-year-old man came to our emergency department with a high-voltage electric burn on the lateral side of his mid-left foot. He had been repairing electrical wiring on a roof and accidently stepped on the wire (Fig. 3A). On physical examination, the vital signs and general examination were within normal range. The left plantar pedis region showed an electrical burn with an area of 15 × 10 cm. The edges of the wound were irregular, with the base showing tendon surrounded by necrotic tissue with no active bleeding. Debridement was performed under general anesthesia in the operating theatre, and the patient was treated with hyperbaric oxygen therapy 10 times with 2.0 atm absolute (ATA; Fig. 3B). The wound was then closed with a radial forearm free flap.

2.4. Patient 4

A 56-year-old woman came to the outpatient clinic of our Plastic Surgery Division with an open wound in the left lower leg for 1 week. While walking in a flooded house, she had accidently stepped on sharp glass. For 1 week she had only cared for her wound at home. She also felt fever, pain, and difficulty moving her leg. On examination of the left

Fig. 3. *(A) A 28-year-old male with electrical burns sustained while repairing a high-voltage electrical wiring network. (B) Post operation with defect closure with radial forearm free flap and hyperbaric oxygen therapy 2.*0 ATA *10x.*

lower leg region near the medial malleolus, we found an open wound of 5 × 2 cm with subcutaneous tissue as the wound bed, with abscess and skin crepitation indicating gas gangrene and lymphadenopathy ipsilateral to the wound (Fig. 4A). The patient underwent debridement and fasciotomy, then continued with hyperbaric oxygen therapy 6 times with 2.0 ATA. This was followed by a skin graft to cover to wound (Fig. 4B).

2.5. Patient 5

A 3-year-old boy was brought by his parents to the emergency department because his left foot was run over by a car. On physical examination, his vital signs were within normal range, and he was fully conscious. The head, neck, chest, and abdomen were within normal limits. In the left foot region, the wound looked dirty, with muscle and tendon exposed (Fig. 5A). The patient underwent debridement, hyperbaric oxygen therapy 6 times at 1.5 ATA, and wound closure with a skin graft (Fig. 5B). The young patient was accompanied by his mother during the hyperbaric oxygen therapy, with drinks brought inside and diapers used while in the chamber.

2.6. Patient 6

A 29-year-old male foreign sea vessel worker was brought to the hospital with chemical burns on his lower leg (Fig. 6A), fever, and functional loss due to the inability to stand or walk on his own. His chemical burns were neglected for 10 days due to COVID-19 pandemic isolation and only treated by oral antibiotics. On physical examination, the vital signs and general examination were within normal range. Locally, we found a chemical burn with minimal necrotic tissue in the anterior crural region. We also found ipsilateral lymphadenopathy. The patient was treated with meropenem for 7 days, followed by hyperbaric oxygen therapy 10 times with 2 ATA (Fig. 6B).

2.7. Patient 7

A 26-year-old woman was brought to the hospital presenting with excoriations and skin loss on her right foot due to a motorcycle accident (Fig. 7A). She also had a mandibular chip fracture and wide excoriation of her face and hands. The patient was treated only with hyperbaric oxygen therapy 10 times with 2 ATA for 1 year (Fig. 7B). Currently, at 9 months follow-up, the wound is closed.

3. Discussion

The lower extremities are the most common site of injury due to their use. In 2007, a survey by National Hospital Ambulatory Medical Care in the United States found that 14.6% of cases of lower extremity injury came from approximately 117 million visits to the emergency department. The most common area of injury was the lower trunk (28%), followed by the ankle (20%), knee (16%), foot (15%), lower leg (11%), toe (7%), and upper leg (4%) [4]. We present 7 cases of lower extremity trauma treated with hyperbaric oxygen therapy: soft tissue loss (patient 1), neglected chronic burn injury (patient 2), high-voltage electrical burn (patient 3), gas gangrene (patient 4), crush injury (patient 5), chemical burn (patient 6), and excoriation with skin loss (patient 7).

The patient with soft tissue loss (patient 1) was a management challenge because of the operation timing, most suitable type of tissue, and decision to cover the defect [5]. Soft tissue injury can be accompanied by extensive damage to the deep structure of the limb and is also related to the risk of complications such as hematoma formation and wound infection; later, phlegmon can lead to sepsis [6]. Wound infections are associated with healing disorders caused by the ischemic wound. In another case, a patient had gas gangrene (patient 4) caused by gram-positive anaerobic bacilli of the species *Clostridium*, notably *C. perfringens*, which also contributes to tissue hypoxia. The bacteria produce α-toxin, which causes tissue necrosis. Appropriate surgical management with antibiotic therapy should constitute the first line of management [7]. In our case, the first management of these cases was debridement and infection control with appropriate antibiotics. In patient 4, we also performed a fasciotomy to release the compartment pressure.

Among our cases were two patients with burn injuries of the lower extremity. Patient 2 had a fourth-degree burn injury on the anterior upper third of the left tibia and another wound on the right knee and thigh. This was a neglected chronic wound that has been left for 2 months and treated herbally, and contracture of the left knee joint was present. Patient 3 had a high-voltage electrical burn on the lateral side of the mid-left foot. Burn is a complex injury that causes activation of platelets and white blood cells, microvascular damage by coagulation or thrombosis, and accumulation of edema. The goals of burn treatment are minimizing the edema, keeping tissue viable in the stasis zone of the burn, protecting the microvasculature, and enhancing host defenses to stave off infection. In fourth-degree burn injury, which may involve the underlying soft tissue and muscle or bone [8], it can also take longer than 2 weeks to heal and predictably produce scarring and contractures [9]. One of our patients was a 3-year-old boy with a crush injury to his left foot. Crush injury is defined as a destructive injury to the extremities

Fig. 4. (A) The patient was exposed to pieces of zinc during flooding, with pain and swelling of the left leg accompanied by ipsilateral lymphadenitis. (B) Post debridement as well as hyperbaric oxygen therapy 6x and skin graft.

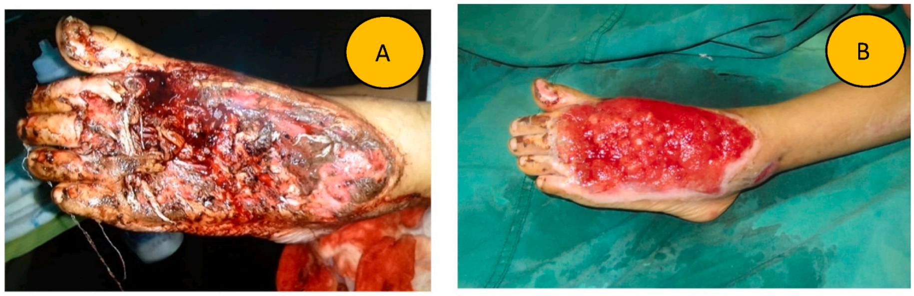

Fig. 5. (*A) A 3-year-old child with left foot run over by a car. (B) Post skin graft and hyperbaric oxygen therapy 6x, 1*.5 ATA.

Fig. 6. (*A) Patient with chemical burn on his right foot. (B) Post debridement and 10x hyperbaric oxygen therapy sessions.*

or other parts due to direct contact with the body. Such injuries can result in serious damage to the affected tissues, including the skin and subcutaneous soft tissues, blood vessels, nerves, tendons, fascia, joints, and bones [10].

All of our cases involved one or more surgical procedures such as debridement, STSG (patients 1, 2, 3, and 4), gastrocnemius muscle flap (patient 2), radial forearm free flap (patient 3), and fasciotomy (patient 4). The primary goal of debridement is to remove all the devitalized tissue from the wound bed to promote wound healing [11]. In our cases, all patients came to our emergency department with an infected wound. Therefore, the initial management was removing all necrotic or devitalized tissue and controlling the infection. The next procedure was to close the defect, such as with STSG, gastrocnemius muscle flap, or radial forearm free flap. The definition of STSG is a graft that contains the epidermis and a portion of the dermis. These are otherwise indicated in acute skin loss (burn wounds, traumatic wounds, infection), chronic skin loss (leg ulcers), and as adjuncts to other procedures (to cover a muscle flap) [12]. A gastrocnemius muscle flap is always used to repair the defect after severe trauma with extended soft tissue loss over the anterior aspect of the upper and middle third of the leg. The advantage of a gastrocnemius myocutaneous flap is that the flap can successfully cover the defect up to the middle third of the leg without any complications [13]. Another procedure used in our cases was a radial forearm free flap. The relative harvesting ease, pliable tissue, and reliable anatomy make these flaps the most common reconstructive workhorses for hypopharyngeal, oral cavity, total pharynx, and scalp defects [14].

The Undersea and Hyperbaric Medical Society defines hyperbaric oxygen as an intervention in which an individual breathes near 100% oxygen intermittently while inside a hyperbaric chamber that is pressurized to greater than sea level pressure (1 ATA) [15–17]. Hyperbaric oxygen therapy can increase the amount of reactive oxygen and nitrogen species, which represent important signaling molecules in the

Fig. 7. (*A) Excoriation and skin loss on right foot. (B) Post wound debridement and 10x hyperbaric oxygen therapy sessions. (C)* 9 months *follow-up.*

generation pathway of a variety of growth factors, cytokines, and hormones [18,19]. Through these mechanisms and alterations of heme oxygenase-1, hypoxia-inducing factor-1, heat shock proteins, and integrin, a reduction of inflammation is triggered and vascular endothelial growth factor is synthesized, inducing neovascularization [18]. The mechanism of hyperbaric oxygen therapy works according to Henry's law of physics, whereby the increase in the atmospheric pressure amplifies the amount of oxygen dissolved in plasma. Oxygen is crucial in the wound healing process because it increases intracellular aerobic metabolism and promotes fibroblast proliferation, collagen synthesis, neoepithelialization, and hence, granulation [20]. Among our cases, a patient with soft tissue loss (patient 1) and gas gangrene of the lower leg (patient 4) treated with hyperbaric oxygen therapy showed good granulation growth of the wound. Given that hyperbaric oxygen therapy can promote neovascularization, stimulating the recruitment and differentiation of circulating stem/progenitor cells to form vessels, patients with gas gangrene can be treated with hyperbaric oxygen therapy in combination with antibiotics and surgical removal of dead tissue. The literature has shown the use of hyperbaric oxygen therapy in soft tissue infection reduces the mortality rate [7,21].

Hyperbaric therapy in cases of burns has shown effectiveness in edema reduction, restoration, and preservation of microcirculation and angiogenesis. Simultaneously, its multi-layered induction of wound healing promotes fibroplasia and re-epithelialization [18]. Moreover, this therapy can reduce complications of burn injury [22]. Pain is a postoperative side effect. Analgesic therapy was administered by injection to all patients: ketorolac at a dose of 30 mg every 8 h in adult patients (patients 1, 2, 3, 4, 6, and 7) and paracetamol at 15 mg/kg/dose every 6 h in the pediatric patient (patient 5). However, the analgesic was only used for 2 days after surgery because hyperbaric therapy had been carried out. We thus hypothesized that hyperbaric therapy could help reduce postoperative wound pain. This is supported by the emergence of hyperoxia, triggering the emergence of vasoconstriction to reduce the formation of tissue edema [10,23].

Previous studies [7,10,21–23] have shown an acceleration of healing in chronic wounds, burns, and crush injuries of patients with large-scale antibiotic resistance. Therefore, the principle of using hyperbaric oxygen therapy is expected to be recommended as an adjunct therapy for wounds with long-term healing.

Six of the 7 patients in this study were followed up 3 months after discharge, with the remaining 1 patient (Patient 7) followed up 9 months after discharge due to distance and transportation constraints. At the follow-up, we assessed the wound healing process in each patient, especially the effectiveness of hyperbaric oxygen therapy in treating wounds. Our patients with burn injury (patients 2, 3, and 6) treated with hyperbaric oxygen therapy showed a significant improvement in wound recovery. Additionally, hyperbaric oxygen therapy can maintain graft survival.

4. Conclusion

Hyperbaric oxygen therapy has many benefits in lower extremity trauma for wound recovery, preventing complications, and helping patients return to daily activities.

Provenance and peer review

Not commissioned, externally peer-reviewed.

Ethical approval

The study is exempt from ethical approval in our institution.

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Conflicts of interest

The authors declare that they have no conflict of interests.

Author contribution

Mendy Hatibie Oley, Maximillian Christian Oley, Albertus Djarot Noersasongko, Andi Asadul Islam, Marcella Tirsa Tulong, and Melfrits Siwabessy researched the literature and wrote the manuscript. Mendy Hatibie Oley, Maximillian Christian Oley, Albertus Djarot Noersasongko, Melfrits Siwabessy, and Dicky Panduwinata performed the treatment, operated the patient and also had the idea for this case series. Mendy Hatibie Oley, Maximillian Christian Oley, Andi Asadul Islam, Marcella Tirsa Tulong, and Muhammad Faruk checked the manuscript and made corrections. Mendy Hatibie Oley and Maximillian Christian Oley provided the overall guidance and support. All authors read and approved the final manuscript.

Registration of research studies

None.

Consent

Written informed consent was obtained from the patient for publication of this case series and accompanying images. A copy of the written consent is available for review by the Editor-in-Chief of this journal on request.

Guarantor

Mendy Hatibie Oley and Maximillian Christian Oley.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.amsu.2022.103896.

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