IWJ International Wound Journal

International Wound Journal ISSN 1742-4801

ORIGINAL ARTICLE

# Is hyperbaric oxygen therapy indispensable for saving mutilated hand injuries?

I-Han Chiang[1], Yuan-Sheng Tzeng[1] & Shun-Cheng Chang[2,3]

1 Division of Plastic and Reconstructive Surgery, Department of Surgery, Tri-Service General Hospital, National Defense Medical Center, Taipei, Taiwan Republic of China
2 Division of Plastic and Reconstructive Surgery, Department of Surgery, Hyperbaric Oxygen Therapy Center, Shuang-Ho Hospital, Taipei, Taiwan Republic of China
3 Department of Surgery, School of Medicine, College of Medicine, Taipei Medical University, Taipei, Taiwan Republic of China

**Key words**
Hyperbaric oxygen therapy; Mutilated hand; Crush hand injury

**Correspondence to**
Shun-Cheng Chang
Assistant Professor, Chief and Attending Physician
Division of Plastic Surgery, Department of Surgery, Hyperbaric Oxygen Therapy Center, Shuang-Ho Hospital
Department of Surgery, School of Medicine, College of Medicine, Taipei Medical University
No. 291, Zhongzheng Rd., Zhonghe Dist
New Taipei City 235
Taiwan
Republic of China
E-mail: csc901515@gmail.com

Chiang I-H, Tzeng Y-S, Chang S-C. Is hyperbaric oxygen therapy indispensable for saving mutilated hand injuries?. Int Wound J 2017; doi: 10.1111/iwj.12730

## Abstract

Mutilated hand injuries are a profound challenge to the plastic surgeon, and such injuries often lead to limb loss and severe functional impairment. Hyperbaric oxygen therapy (HBOT) appears to counteract tissue hypoxia and stimulate acute wound healing. This study was performed to evaluate the efficacy of HBOT as an adjunctive therapy in patients with a mutilated hand injury. Between January 2006 and December 2014, 45 patients with a mutilated hand injury were enrolled. After reconstruction or revascularisation, patients underwent 120 minutes of HBOT with oxygen at 2·5 atmospheres absolute while breathing 100% oxygen. Outcomes such as amputee survival and surgery-related complications were recorded. The patients were 38 men and 7 women with average age of 37·2 years (range 18–62). The mean defect area was 131·5 $cm^2$ (range 40–300). Most patients experienced a pure crush injury (53%). The average number of operations from the initial debridement to the first reconstruction was 3·8 (range 1–6). A total of 33 patients (73%) underwent replantation during the initial reconstruction. For flap coverage, most patients received a free flap using an anterolateral thigh flap (18 patients) or local flap using an abdomen/groin flap (nine patients). The average time from the first reconstruction or revascularisation to the first HBOT was 6·5 hours (range 2–12). The average number of HBOT sessions was 9·1 (range 6–14 sessions). The survival rate of the replanted fingers was 81%, and the survival rate of the palms was 100%. Most complications in the initial reconstruction involved partial loss of an avulsed flap, and most complications in the chronic stage (≥3 months) involved scar contracture. When combined with delicate microsurgery, early intervention using adjunctive HBOT was effective in preserving partially viable tissue and restoring hand function in patients with a mutilated hand injury.

## Introduction

Mutilated hand injuries can occur through a variety of mechanisms, including crush, avulsion, friction, burn injury, sharp trauma or some combination of these and can include the destruction of bones, tendons, muscles, nerves, blood vessels and skin. Such injuries pose a formidable reconstructive challenge and can severely compromise hand function (1).

The mainstay of the treatment of a mutilated hand injury includes irrigation, debridement of any devitalised tissue or contamination, stable bone fixation, nerve repair and vascular restoration under microsurgical assistance. In addition,

### Key Messages

- mutilated hand injuries are a profound challenge to the plastic surgeon, and such injuries often lead to limb loss and severe functional impairment
- hyperbaric oxygen therapy (HBOT) appears to counteract tissue hypoxia and stimulate acute wound healing
- this study was performed to evaluate the efficacy of HBOT as an adjunctive therapy in patients with mutilated hand injuries

 doi: 10.1111/iwj.12730 

- when combined with delicate microsurgery, early intervention using adjunctive HBOT was effective in preserving partially viable tissue and restoring hand function in patients with a mutilated hand injury

intravenous antibiotics are given in accordance with the results of wound culture. After the wound bed is cleaned, the loss of composite tissues usually requires a graft or flap to provide coverage and to restore hand function (1,2).

The treatment goal is to restore maximum hand function. Several complications as a result of the inflicting injury are frequently encountered when treating mutilated hand injuries; these can include oedema, direct structural destruction and nerve palsy. Treatment-related complications during staged reconstructions can include scar contraction, fascial adhesions causing restricted tendon motion and impaired muscle function with time (3). The greater the extent of the injury, the greater the risk of compromise to hand function (4).

Hyperbaric oxygen therapy (HBOT) includes the intermittent administration of 100% oxygen at pressures >1 atmosphere absolute (ATA) in a pressure vessel (5). Adjunctive HBOT is a safe and effective modality used to increase tissue oxygenation to assist the healing of compromised acute wounds (5,6). There are a few studies of the use of HBOT for mutilated hand injuries, and we have found no comprehensive reviews or meta-analyses. The aim of this study was to evaluate the efficacy of HBOT as an adjunctive therapy after reconstruction or revascularisation in patients with mutilated hand injuries.

## Materials and methods

Between January 2006 and December 2014, 45 patients who were diagnosed with a mutilated hand injury in the Tri-Service General Hospital, Taipei, Taiwan and who had a resultant defect measuring >40 $cm^2$ participated in the study. All patients were older than 18 years. The patients' characteristics, including age, gender, smoking habits, medical disease, mechanism of injuries and lesion size and location, were recorded (Table 1).

All patients underwent an initial trauma evaluation to exclude more serious life-threatening injuries. After stabilisation and initial resuscitation, limb salvage and functional reconstruction were started. The principles of wound management included intravenous broad-spectrum antibiotics, irrigation, meticulous debridement, early restoration of vascularity, stable bone fixation and repair of specialised tissue such as nerve and tendon, followed by early definitive soft tissue coverage.

Early intervention with HBOT started within 24 hours after the initial revascularisation or replantation. Patients were placed in the hyperbaric chamber and received 120 minutes of oxygen at 2·5 ATA while breathing 100% oxygen inside the chamber. Patients were treated in the chamber 5 days per week except on the day of an operation or if their haemodynamic variables were unstable. HBOT was stopped when the wound stabilised or a clear demarcation of the wound could be identified. The number of HBOT sessions, time from the initial replantation or revascularisation to HBOT, complications and patient's satisfaction (scored 1–10) were recorded.

**Table 1** Patients' characteristics

| | Number of patients |
|---|---|
| Gender | |
| Men | 38 |
| Women | 7 |
| Average age (years) | 37·2 (18–62) |
| Smokers | 20 |
| Medical disease | |
| Hypertension | 6 |
| Diabetes mellitus | 2 |
| Tongue cancer | 1 |
| Hepatitis C | 1 |
| Atrial fibrillation | 1 |
| Liver cirrhosis | 1 |
| Gout | 1 |
| PSVT | 1 |
| GERD | 1 |
| Mechanism of hand injury | |
| Pure crush | 24 |
| Crush–deglove | 10 |
| Crush–burn | 7 |
| Segmental cutting | 1 |
| Explosion | 3 |
| Associated injuries | |
| Clavicle fracture | 2 |
| Lung insult and rib fracture | 3 |
| Pelvis fracture | 1 |
| Head injury | 3 |
| Hypovolemic shock | 2 |
| Lower limb fracture | 1 |
| Location | |
| Dominant hand | 27 |
| Non-dominant hand | 20 |
| Dorsal aspect of hand | 21 |
| Volar aspect of hand | 26 |
| Finger | |
| Thumb | 18 |
| Index | 24 |
| Third | 24 |
| Fourth | 24 |
| Fifth | 19 |
| Average defect area ($cm^2$) | 131·5 (40–300) |
| Average avulsed or degloved flap area ($cm^2$) | 70 (0–200) |

PSVT, paroxysmal supraventricular tachycardia; GERD, gastroesophageal reflux disease.

The exclusion criteria for use of HBOT were pregnancy, pneumothorax, severe chronic obstructive pulmonary disease, recent chest surgery, psychiatric problems (especially claustrophobia), concussion or head injury, convulsions, epilepsy or heart disease (ejection fraction < 35).

The outcomes included finger and palm survival and mortality. Surgery-related complications after the initial reconstruction, such as infection, partial loss of the flap and compartment syndrome, were recorded. Surgical complications appearing 3 months or more after the operation (chronic stage), such as infection, stiffness of joints, malunion, bulky flap, tendon adhesion and neuropathy, were recorded.

**Table 2** Details of reconstructive strategies

| | Number of patients |
|---|---|
| Replantation | 33 |
| Initial amputation of finger(s) | 3 |
| Free flap | 29 |
| ALT | 18 |
| Radial forearm | 6 |
| Medial sural | 1 |
| Superficial temporal | 2 |
| AMT | 1 |
| Lateral arm | 1 |
| Local/regional flap | 19 |
| Abdomen/groin | 9 |
| Reverse radial forearm | 3 |
| FDMA | 1 |
| Advanced or rotation flap | 6 |
| Average number (range) of operations before the initial reconstruction | 3·8 (1–6) |

ALT, anterolateral thigh; AMT, anteromedial thigh; FDMA, first dorsal metacarpal artery.

## Results

A total of 45 patients (7 women, 38 men) were enrolled. The average age of the patients was 37·2 years (range 18–62 years), and the mean defect area was 131·5 $cm^2$ (range 40–300 $cm^2$). The mean size of the avulsed or degloved flap was 70 $cm^2$ (range 0–200 $cm^2$). Of the 45 patients, 20 (44%) had a history of smoking and were trying to quit after trauma. Several patients had some type of medical disease, including hypertension ($n = 6$), diabetes mellitus ($n = 2$), paroxysmal supraventricular tachycardia ($n = 1$), atrial fibrillation ($n = 1$), gout ($n = 1$), tongue cancer ($n = 1$), liver cirrhosis ($n = 1$), gastroesophageal reflux disease ($n = 1$) and hepatitis C ($n = 1$). The mechanisms of hand injury were pure crush (24 patients; 53%), crush–degloving (ten patients; 22%), crush–burn (seven patients; 16%), explosion (three patients; 7%) and segmental cutting (one patient; 2%). Three patients had a head injury, two patients had a clavicle fracture, three patients had lung insult and rib fracture, one patient had a lower limb fracture, and two patients experienced hypovolemic shock. The most frequent injury was to the dominant hand (27 patients) and the volar part of the hand (26 patients). Most injuries involved fingers 2– 4, followed by finger 5 and the thumb (Table 1).

The average number of operations from the initial debridement to the first reconstruction–replantation or insertion of a free flap or local flap coverage was 3·8 (range 1–6 times). A total of 33 patients underwent replantation, and three patients required an amputation at admission because of severe crush injury. The most frequently performed free-tissue transfer was a free anterolateral thigh flap (18 patients), followed by free radial forearm flap (six patients), free superficial temporal flap (two patients), free medial sural flap (one patient), free anteromedial thigh flap (one patient) and lateral arm flap (one patient). Of the 19 patients who received a local or regional flap, nine patients received an abdominal or groin flap, three patients a reverse radial forearm flap, one patient a first-dorsal metacarpal artery flap and six patients an advanced or rotation flap (Table 2).

**Table 3** Surgical and HBOT outcomes

| | |
|---|---|
| Number (percentage) of fingers that survived replantation | 89/110 (81%) |
| Palm survival rate | 100% |
| Survival of avulsed/degloved flap | 67% |
| Time from reconstruction to HBOT (range) | 6·5 hours (2–12) |
| Number of HBOT sessions (range) | 9·1 (6–14) |
| Number (percentage) of patients who returned to work | 39/45 (87%) |
| Mean time to return to work | 12·7 months (2–28) |
| Satisfaction with HBOT (1–10 scale) | 9·2 |

HBOT, hyperbaric oxygen therapy.

**Table 4** Surgical and HBOT complications

| | Number of patients |
|---|---|
| After the initial reconstruction | |
| Infection | 7 |
| Partial loss of replantation finger(s) | 4 |
| Partial loss of avulsed/degloved flap | 10 |
| Partial loss of free flap | 5 |
| Compartment syndrome | 2 |
| Middle-ear barotrauma during HBOT | 7 |
| Chronic stage (≥3 months) | |
| Infection | 6 |
| Joint stiffness | 10 |
| Scar contracture | 25 |
| Tension adhesions | 12 |
| Malunion | 1 |
| Bulky flap | 7 |
| Neuropathy | 2 |

HBOT, hyperbaric oxygen therapy.

In patients who underwent hand reconstruction with adjunctive HBOT, 89 of 110 replantation fingers survived, giving an 81% survival rate of the replanted fingers. The survival rate of the palm was 100%. The survival rate for an avulsed or degloved flap was 67%. All patients enrolled in the study completed HBOT. The mean time from the initial replantation or revascularisation to HBOT was 6·5 hours (2–12 hours). HBOT was delivered for a mean of 9·1 sessions (6–14) until the wound became stable or showed a clear wound demarcation. The mean of patients' satisfaction with HBOT was 9·2 out of 10. Of the 45 patients, 39 (87%) returned to work after an average of 12·7 months (2–28 months) (Table 3).

Surgery-related complications after the initial reconstruction mainly included partial loss of an avulsed or degloved flap (ten patients), followed by infection (seven patients), partial loss of a free flap (five patients), partial loss of replanted fingers (four patients) and compartment syndrome (two patients). Surgical complications in the chronic stage were revaluated and included scar contracture in 25 patients, followed by tendon adhesions in 12 patients, joint stiffness in ten patients, bulky flap in seven patients, infection in six patients, neuropathy in two patients and bone malunion in one patient. Seven patients (16%) experienced middle ear barotrauma during the first HBOT session and underwent tympanostomy to allow them to complete HBOT (Table 4).


**Figure 1** (A, B) A 40-year-old man who sustained a devastating injury to the right hand. (C) After debridement and irrigation, the injured hand was revascularised and reconstructed. (D, E) Partially viable tissue survived, and the wound was demarcated with the help of adjunctive hyperbaric oxygen therapy. (F) The final result shows stable coverage.

## Case reports

### Case 1

A 40-year-old man sustained a severe avulsion–crush injury to his right hand and a large avulsed flap circumferentially around his thumb and dorsal aspect of his hand. After fixing of the bones, the tendons and nerves were repaired, and the arteries were revascularised with vein grafts. HBOT was applied 4 hours after the initial reconstruction. Because of the severe crush injury mutilation to the hand, a compromised flap was noted gradually. After ten HBOT sessions, the wound was demarcated, and most of the flap survived except for a small defect in the mid-palm and right tip of the thumb. A regional groin flap was used, and the patient returned to work 1·2 years after the injury (Figure 1).

### Case 2

A 30-year-old man sustained a crushing injury to his right palm in a car accident. He experienced comminuted fractures of the metacarpal bones, severance of multiple tendons and a compromised palm flap. Open reduction and internal fixation of the bony fragments and repair of the tendons were performed. The arteries were anastomosed using microsurgery. HBOT was applied 6 hours after the initial revascularisation. After nine HBOT sessions, the palm flap had survived completely, and hand function was restored. The patient returned to work 9 months after the injury (Figure 2).

### Case 3

A 45-year-old man sustained a crush accident while operating a machine, which resulted in a huge avulsed flap on the palm and open fracture of the metacarpal bones. After debridement and internal fixation of the fractured bones, the avulsed flap was revascularised, and the flap was applied without tension. The exposed soft tissue was covered with a skin graft. The patient underwent 12 HBOT sessions 6 hours after revascularisation, and the viable palm flap healed gradually. The wound was stable and had ischaemic tissue only on the distal portion of the thumb. A groin flap was used for wound coverage. The patient returned to work after 1 year of rehabilitation (Figure 3).

### Case 4

A 50-year-old woman sustained a mutilating injury to her right hand involving near amputation of her right thumb and open


**Figure 2** (A, B, C) A 30-year-old man sustained a devastating injury of the right palm in a motor vehicle accident. (D) The palm flap was revascularised, and the soft tissue defect was covered with a skin graft. (E) After adjunctive hyperbaric oxygen therapy use, the compromised flap survived completely, and (F) hand function was restored.

fracture with partial soft tissue loss of her palm. The bones were fixed, and the tendons and nerves were repaired. A free adipofascial flap of the anterolateral thigh was applied until all devitalised tissue was debrided. The artery of the flap was anastomosed to the radial artery. HBOT was started 8 hours after the free flap reconstruction. Because of tissue swelling and injury to the recipient artery caused by the initial trauma, the free flap was compromised. After completion of ten adjunctive HBOT sessions, most of the flap had survived, and only a small skin defect over the dorsal and volar aspects of the hand was noticed. A skin graft was performed, and the patient returned to daily activity after 1 year (Figure 4).

## Discussion

Mutilated hand injuries may result in extensive tissue loss, few available recipient vessels, disfigurement and significant functional impairment. Trauma causes tissue mortality, and oedema can contribute to ischaemia of the partially viable tissue. Oedema compounds the problems caused by ischaemia and hypoxia by increasing the diffusion distance from the capillaries to cells. With hypoxia, the tissues lose their ability to resist infection and to regenerate (7). Greater tissue loss in severe injuries is associated with a high rate of functional impairment of the affected extremity. The Mangled Extremity Severity Score is a simple rating scale for extremity trauma based on skeletal/soft tissue damage, limb ischaemia, shock and age. A value greater than or equal to 7 predicts a high amputation rate (8). The goals of management for mutilated hand injuries are preservation of hand length, improvement of appearance and restoration of function. Soft tissue coverage can ensue once the wound is adequate debrided, bone fixation is complete, and the vital structures are repaired or reconstructed (1,4).

The object of HBOT is to counteract the effects of ischaemia, to improve the survival of partially viable tissue and to identify the injury demarcation (7). A review by Thom showed that HBOT elevates tissue oxygenation, stimulates leukocyte function, decreases peripheral oedema and improves skin viability, neovascularisation, and penetration of concomitant antibiotic therapy (9). A systemic review by Eskes *et al.* and Dauwe *et al.* provided evidence that, when combined with standard wound management principles, HBOT can augment healing in complicated acute wounds such as burns, skin graft and severely crushed legs (6,10).

Perrins randomised 48 burn patients to undergo standard excision and grafting versus adjuvant HBOT in addition to

 


**Figure 3** (A) A 45-year-old man sustained a mutilating injury and a large avulsed flap over his right hand. (B) The hand was revascularised and reconstructed. (C, D) After combination adjuvant hyperbaric oxygen therapy, most of the compromised flap survived. (E) The distal phalange of the right thumb was covered with a groin flap. (F) The functional outcome of the injured hand is shown.

standard burn care. Adjuvant HBOT had a significant beneficial effect on the survival of skin grafts (11). Hart *et al.* prospectively evaluated HBOT in 16 burn patients who sustained burns over 10–50% of their total body surface area. The mean time to healing was significantly less in the HBOT group (12). Hammarlund *et al.* performed a prospective, controlled study to evaluate the use of HBOT for ultraviolet radiation-induced dermal burn injuries. They concluded that HBOT has beneficial effects on wound healing at the superficial dermal level by decreasing oedema and wound exudate (13). In a randomised, prospective, double-blinded study of lower-extremity crush injuries, Bouachour *et al.* found a higher rate of complete healing in patients older than 40 years with Gustilo grade III injuries who were given HBOT (14). A prospective controlled study by Stong and Jacono found that adjunctive HBOT reduced facial ecchymosis and hastened recovery in patients undergoing facelift surgery (15).

Baynosa and Zamboni's review (16) concluded that HBOT provides a useful adjunct in the salvage of compromised flaps and grafts, including the hypoxic wound bed, an excessively large harvested graft, avulsed or degloved ischaemic flap, venous or arterial insufficiency and ischaemia–reperfusion injury. Although there are hyperoxemia-induced local vasoconstriction effects, HBOT has a greater effect by increasing oxygen concentration in the plasma and by maintaining perfusion and high oxygen partial pressure in hypoxic tissue (17,18). For mutilated hand injuries, although the initially damaged tissue cannot be restored and should be debrided immediately, HBOT can help to maximise the viability of the compromised tissue while perfusion is being restored.

In our review of the literature, we found a lack of papers about the use of adjuvant HBOT in the treatment of mutilated hand injuries. Our series is important for establishing the efficacy of HBOT in the treatment of such injuries. Once meticulous microsurgical revascularisation or free flap transfer is performed in the initial reconstruction to provide tissue perfusion, timely adjunctive HBOT reduces tissue oedema, counteracts the vicious cycle of hypoxia, controls wound infection and increases the chance of survival of the compromised flap. Therefore, the greater the degree of hand trauma, the more important the role of HBOT.

The patients in our study were mainly middle-aged, male labourers who had a steady income. The dominant hand and second to fourth fingers were the most frequently injured. Therefore, these men had a high functional demand of the hands and a high expectation to return to work. The average


**Figure 4** (A, B) A 50-year-old woman sustained a mutilating injury of her right hand. (C, D) A free adipofascial flap of the anterolateral thigh was used to provide appropriate wound coverage (E) The flap was compromised, and a large area of unviable tissue was found. (F) Adjunctive hyperbaric oxygen therapy enhanced tissue survival. (G) Most hand function was preserved with a satisfactory cosmetic result.

number of operations once the wound was clean after the initial debridement to the first reconstruction was 3·8. After the microsurgical revascularisation or replantation followed by early soft tissue coverage, the early intervention with adjunctive HBOT helped to increase tissue survival in the viable zone and to restore function. In our patients, HBOT was started an average of 6·5 hours after perfusion was established, and HBOT was delivered for an average of 9·1 sessions until the wounds were stable or showed clear wound demarcation. With the use of adjuvant HBOT and microsurgery, we found high survival rates for the replanted fingers, palm and compromised flaps. Most patients returned to work after about 1 year of rehabilitation.

There is no consensus on ideal treatment parameters for complicated wounds. Hyperbaric chambers are safe and are used routinely for treating even critically ill patients. Complications of HBOT include barotrauma to otic, sinus or pulmonary structures; claustrophobia; reversible myopia; and seizures, but these are rare and are usually self-limiting. Irreversible nuclear cataracts have been described if HBOT exceeds 150–200 hours (6,19). Although a high oxygen concentration can increase the production of reactive species, studies show that antioxidant defences are adequate, and the production of reactive species is reversible for clinical HBOT protocols, which are brief and often include air breaks (9,20). In our studies, only seven patients experienced middle-ear barotrauma, but they were able to complete HBOT after receiving a tympanostomy. The complication rate of HBOT was low (16%; 7/45 patients) with high patient satisfaction.

Mutilated hand injuries often require further surgeries to resolve issues of stiffness, contractures, adhesions and nonunion, and the procedures are designed to restore function during the chronic stage. Early aggressive rehabilitation is needed to prevent recurrence (1,4). Although complications and the need for secondary procedures are common in patients with a mutilated hand injury, reconstruction is functionally more advantageous than upper-extremity prosthesis (1). In our study, the HBOT increased the survival of the compromised flaps and preserved hand function, which reduced the number of complications during the chronic stage to lower contracture scars, tendon adhesions and joint stiffness. However, we acknowledge that a longer follow-up period is needed.

The limitations of this series include the small sample size and varying degrees and patterns of injury, which make it difficult to compare the outcomes of this study with those of other studies. This can largely be attributed to the rarity of mutilated hand injuries in our country because of improvements in

 

public safety. Further prospective randomised controlled trials, including larger cohorts, are required to confirm these results.

## Conclusion

When combined with meticulous microsurgical revascularisation or replantation, early intervention with adjunctive HBOT can improve the survival of mutilated hands and preserve hand function as much as possible. HBOT is safe and effective and requires few sessions. This study provides evidence and shows that HBOT is effective and beneficial.

## Acknowledgement

The authors thank the Civilian Administration Division of Tri-Service General Hospital, National Defense Medical Center, Taipei, Taiwan. The authors declare no conflicts of interest and no source of funding.

## Author Contribution

I-Han Chiang contributed to the literature search, data collection, data analysis, data interpretation, writing and figure collection and formatting. Yuan-Sheng Tzeng contributed to the literature search, data collection and critical revision. Shun-Cheng Chang contributed to the study design, data analysis, data interpretation, writing and editing.

## References

1. Hegge T, Neumeister MW. Mutilated hand injuries. *Clin Plast Surg* 2011;**38**:543–50.
2. Neumeister MW, Brown RE. Mutilating hand injuries: principles and management. *Hand Clin* 2003;**19**:1–15.
3. Lin CH, Nguyen A. Avoiding unfavorable results in microsurgical reconstruction in upper-extremity trauma. *Semin Plast Surg* 2010;**24**:67–76.
4. Neumeister M, Hegge T, Amalfi A, Sauerbier M. The reconstruction of the mutilated hand. *Semin Plast Surg* 2010;**24**:77–102.
5. Eskes A, Vermeulen H, Lucas C, Ubbink DT. Hyperbaric oxygen therapy for treating acute surgical and traumatic wounds. *Cochrane Database Syst Rev* 2013;**12**:CD008059.
6. Dauwe PB, Pulikkottil BJ, Lavery L, Stuzin JM, Rohrich RJ. Does hyperbaric oxygen therapy work in facilitating acute wound healing: a systematic review. *Plast Reconstr Surg* 2014;**133**:208e–15.
7. Strauss MB. The effect of hyperbaric oxygen in crush injuries and skeletal muscle-compartment syndromes. *Undersea Hyperb Med* 2012;**39**:847–55.
8. Johansen K, Daines M, Howey T, Helfet D, Hansen ST Jr. Objective criteria accurately predict amputation following lower extremity trauma. *J Trauma* 1990;**30**:568–72; discussion, 572–73.
9. Thom SR. Hyperbaric oxygen: its mechanisms and efficacy. *Plast Reconstr Surg* 2011;**127**(1 Suppl):131S–41.
10. Eskes AM, Ubbink DT, Lubbers MJ, Lucas C, Vermeulen H. Hyperbaric oxygen therapy: solution for difficult to heal acute wounds? Systematic review. *World J Surg* 2011;**35**:535–42.
11. Perrins DJ. Influence of hyperbaric oxygen on the survival of split skin grafts. *Lancet* 1967;**1**:868–71.
12. Hart GB, O'Reilly RR, Broussard ND, Cave RH, Goodman DB, Yanda RL. Treatment of burns with hyperbaric oxygen. *Surg Gynecol Obstet* 1974;**139**:693–6.
13. Hammarlund C, Svedman C, Svedman P. Hyperbaric oxygen treatment of healthy volunteers with u.v.-irradiated blister wounds. *Burns* 1991;**17**:296–301.
14. Bouachour G, Cronier P, Gouello JP, Toulemonde JL, Talha A, Alquier P. Hyperbaric oxygen therapy in the management of crush injuries: a randomized double-blind placebo-controlled clinical trial. *J Trauma* 1996;**41**:333–9.
15. Stong BC, Jacono AA. Effect of perioperative hyperbaric oxygen on bruising in face-lifts. *Arch Facial Plast Surg* 2010;**12**:356–8.
16. Baynosa RC, Zamboni WA. The effect of hyperbaric oxygen on compromised grafts and flaps. *Undersea Hyperb Med* 2012;**39**:857–65.
17. Sjoberg F, Singer M. The medical use of oxygen: a time for critical reappraisal. *J Intern Med* 2013;**274**:505–28.
18. Schreml S, Szeimies RM, Prantl L, Karrer S, Landthaler M, Babilas P. Oxygen in acute and chronic wound healing. *Br J Dermatol* 2010;**163**:257–68.
19. Palmquist BM, Philipson B, Barr PO. Nuclear cataract and myopia during hyperbaric oxygen therapy. *Br J Ophthalmol* 1984;**68**:113–7.
20. Narkowicz CK, Vial JH, McCartney PW. Hyperbaric oxygen therapy increases free radical levels in the blood of humans. *Free Radic Res Commun* 1993;**19**:71–80.