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Role of Hyperbaric Oxygen Therapy in Salvage of Compromised Flaps

Smriti B, Karthick G, Raja T and Maneesh S*

Department of Plastic, Reconstructive and Burns Surgery, All India Institute of Medical Sciences, India

Abstract

Introduction: Flaps can experience ischemia or mechanical obstruction because of their inherent traits. Arterial insufficiency or venous congestion are common causes of flap compromise. Surgically correctable causes of flap compromise must be immediately reversed. However, in cases where no rectifiable etiology is found during surgical re-exploration, HBOT may improve flap survival. However, conclusive evidence of its efficacy in salvaging compromised flaps in humans is lacking.

Aims and Objectives: To assess the efficacy of hyperbaric oxygen therapy in patients with compromised flaps and to propose an institutional protocol for hyperbaric oxygen therapy for compromised flaps.

Materials and Methods: HBOT is given for flap compromise after addressing mechanical causes. Therapy was administered 6 days/week. Regular clinical assessments were performed to evaluate tissue viability, vascularity, and stability. Initially, ten treatment sessions were planned for each patient. The ischemic or congested portion of the flap's dimensions was recorded before starting HBOT. A senior resident who was not included in the study, assessed clinical observations before and after HBOT to avoid bias. We used the paired t-test to compare pre-HBOT parameters with post-HBOT parameters, and a p-value of <0.05 with 95% Confidence Interval was considered statistically significant. We performed statistical tests using Microsoft Excel software.

Conclusion: HBOT can salvage a portion of a compromised flap, but secondary procedures may still be necessary. The results are promising, but further investigation is needed to determine its efficacy.

Keywords: Hyperbaric Oxygen Therapy (HBOT); Compromised flaps salvage; Debridement; Flap necrosis

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Correspondence:
Raja Tiwari, Department of Plastic, Reconstructive and Burns Surgery, All India Institute of Medical Sciences (AIIMS), R. No. 219, Burn & Plastic Surgery Block, Ansari Nagar, New Delhi, Delhi-110029, India

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Introduction

Flaps are one of the most commonly used reconstructive operations. Despite, appropriate patient selection, proper preoperative planning, and intra-operative technique, flap failure can occur. Hyperbaric Oxygen Therapy (HBOT) is not indicated for the uncompromised wounds or flaps. It is only indicated in the treatment of compromised flaps where ischemia is present after the flap transfer and has been proven to improve the tissue survival [1]. To understand the factors that compromise the flap survival it is crucial to understand the mechanisms through which HBOT exerts its beneficial effects.

Flaps are prone to compromise because of their own set of traits. Random pattern flaps usually undergo ischemia distally i.e., at the area that is furthest from the source of blood supply, more often in cases where the flap dimensions exceed its vascular capabilities. Pedicle kinking and twisting can cause mechanical obstruction of blood flow. In free tissue transfer, using microsurgical anastomosis, the flap is transferred to a distant recipient site and is prone to ischemia-reperfusion injury. Arterial insufficiency or venous congestion may cause compromise of any of the described flaps. Surgically correctable cause of flap compromise must be reversed as soon as they are discovered. HBOT may improve the flap survival when the tissue damage persists, despite no rectifiable etiology being found during the surgical re-exploration. However, there are not many studies to conclusively prove the role of HBOT in salving compromised flaps in human subjects.

Methodology

This study was conducted at the Department of Plastic, Reconstructive & Burns Surgery, AIIMS, New Delhi, to investigate the effectiveness of Hyperbaric Oxygen Therapy (HBOT) as an

intervention for compromised flaps. The inclusion criteria for the study were patients diagnosed with compromised flaps in the head and neck, upper limb, trunk, and lower limb soft tissue defects, who had in-correctible signs of compromised vascularity or persistent compromise in spite of primary corrective measures. The age of the patients was required to be over 18 years. The exclusion criteria included untreated pneumothorax as an absolute exclusion, and several conditions as relative exclusions: Asthma, claustrophobia, congenital spherocytosis, COPD, Eustachian tube dysfunction, high fever, pacemakers or epidural pain pump, pregnancy, seizures, and upper respiratory tract infections. The study design was a prospective interventional study, with no control group.

Treatment was initiated upon recognition of flap compromise and after mechanical causes have been addressed appropriately. Due to logistic issues such as the availability of the HBOT machine, therapy could only be given once a day for six days in a week. HBOT was administered at 2.0 to 2.5 ATA for 90 min to 120 min based on the recommendations of the Undersea and Hyperbaric Medical Society. Regular clinical assessments in terms of flap color, temperature, turgor and color of blood in pin prick were performed to assess tissues for improved viability, vascularity, and stability. Flap edema was diagnosed based on clinical examination. Decrease in flap turgor, size and presence of wrinkles indicated edema resolution. A total of ten treatment sessions were initially planned for each patient. If the flap didn't show any clinical improvement and underwent necrosis, HBOT was stopped and definitive procedure as per clinical condition was done. Flap dimensions were noted as per operative notes. The dimensions of the ischemic or congested portion of the flap were measured just before starting HBOT. In addition to this, other factors such as color, turgor and bleed on prick were examined and judged clinically on a daily basis till the completion of therapy. In case of free flaps number of perforators included, number of veins anastomosed, flap ischemia time, preexisting vascular disease was noted. Details like pre-existing vascular disease, diabetes, respiratory diseases and SpO_2 pre-op, intra-op and post-op was recorded. To avoid bias the clinical observations before and after HBOT was assessed by a senior resident who was not involved in the study. The clinical improvement of the compromised flap in the postoperative period was judged based on reduction of oedema and improvement in the discoloration.

Data was entered into Excel spreadsheets for this study. Descriptive analysis of the study population was done. Categorical data was represented in numbers and percentages, and continuous data was presented as mean and range (± standard deviation). Statistical significance was set at a p-value of <0.05 with 95% confidence using a paired t-test. All statistical analysis was performed using Microsoft Excel on Windows 10.

Results

A total of 14 patients were included in the study. Majority of the patients in the study were males (93%) and the mean age of the study population was 32.5 years (range: 19-52 years).

The indications for flap cover in all of the patients was post traumatic soft tissue defect. Location of the soft tissue defect was in upper limb in 4 (28.57%) patients and lower limb in 10 patients (71.4%). Free flaps were done in 7 patients (50%), among them six free flaps were done for lower limb defects and one for upper limb defect. Anterolateral thigh flap was done in all patients in free flap category. Pedicled flaps were done in 7 patients (50%), among them three pedicled flaps were done for upper limb defects (2 groin flaps & 1 first dorsal metacarpal artery flap), four for lower limb defects (reverse sural artery flap in 2 patients, posterior tibial artery perforator flap in 1 patient and superomedial genicular artery flap in 1 patient. The mean duration gap between the first detection of the flap compromise and initiation of HBOT was 1.7 days (range: 0-4 days). All of the patients had venous congestion at the time of detection of flap compromise. Two of the patients with total flap necrosis had venous compromise followed by arterial compromise. None of the patients had an isolated arterial compromise (Table 1).

Table 1: Showing nature of flap compromise.

Flap compromise	No of patients
Venous compromise	14
Venous and arterial compromise	2
Arterial compromise	0

Among free flap patients, only one out of seven patients underwent HBOT following re-exploration of the flap followed by thrombectomy and venous re-anastomosis. Rest of all the patients didn't require flap re-exploration, instead they had only partial flap compromise at the distal margins of the flaps. The mean number of sessions undertaken per patient in the study population was 6.35 (range: 1-10). HBOT was abandoned in 2 (14.28%) patients due to claustrophobia in one patient and otalgia in another patient. Complete ten sessions of HBOT were given for 5 patients (35.7%). For the rest of the patients either the flap necrosis was demarcated and or there was evolving infection which warranted debridement of the already established skin necrosis. Discontinuation of HBOT decision was made on case-to-case basis.

All patients with flap oedema had a portion of distal flap margin discoloration. Flap oedema was noted in eight patients (57.12%), among these two patients had total flap necrosis due to flap related issues. Hence, clinical response to HBOT in terms of reduction of flap oedema could be analyzed in 6 patients (42.8%). Out of these six patients there was resolution of oedema in 4 patients (66.6%). The mean of number of sessions required for complete resolution of flap oedema was 5.25 days (range: 4-6 days). Two patients had no reduction of edema. One of the patients had an abscess underneath the flap and the other patient had progressive necrosis of flap which was managed by partial flap debridement. Measurement of flap discoloration is the most important measure of the effectiveness of HBOT. In spite of HBOT, there was no improvement in the flap discoloration and the flap progressed to total loss in two patients. One patient had an extensive venous thrombosis in a free flap and another

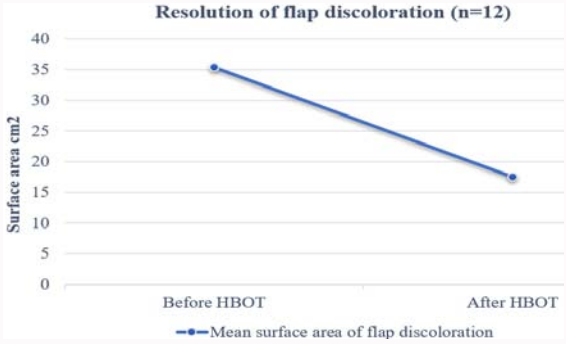

Figure 1: Resolution of flap discoloration with HBOT in the viable flaps.

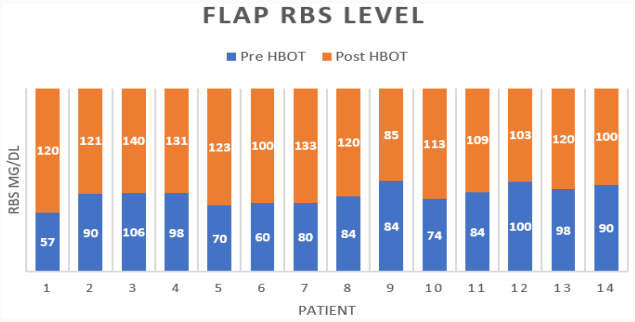

Figure 2: Change in Flap RBS with HBOT.

Table 2: Various flap characteristics pre and post HBOT.

	Pre HBOT	Post HBOT	P-value
Discolored Flap Surface Area (mean) (cm^2)	35.4	17.54	0.0504
Flap RBS (mean) (mg/dl)	83.9	115.5	**0.00002**
Capillary refill time	Brisk	Improved	-
Limb girth (upper limb) (mean)	26.3 cm	26.05 cm	-
Limb girth (lower limb) (mean)	43.2 cm	41.8 cm	

had progressive necrosis in a perforator flap. In the rest of the 12 patients the surface area measurement could be analyzed before and after HBOT. The mean surface area of flap discoloration before HBOT in the study population was 35.4 cm^2. The mean surface area of flap discoloration after HBOT was 17.54 cm^2. There was 49.5% reduction in the surface of flap discoloration following HBOT however, this was not statistically significant (t= -2.19, p=0.0504) (Figure 1).

Flap temperature was cold to touch at the compromised region in all patients. At the end of treatment temperature was normal in the salvaged portion of flap. Capillary refill was deranged in the compromised flap portion in all the patients. At the end of treatment capillary refill was normal in the salvaged portion of flap. Table 2 summarizes the changes in the flap characteristics following HBOT.

The mean flap RBS level post HBOT was 31.6 mg/dl more compared to pre HBOT levels and this improvement was statistically significant (t=6.42, p<0.00) (Figure 2).

None of the patients had a complete flap salvage. Two patients (14.28%) had total flap necrosis in spite of ongoing HBOT. Twelve patients (85.72%) had variable degrees of necrosis in the distal portion of the flap. A total of three patients (21.42%) required a second flap either due to total flap failure (n=2) or a partial flap failure leading to implant exposure (n=1). Debridement of the gangrenous portion of the flap and skin grafting was sufficient in seven patients (49.98%). One patient (7.14%) required debridement of the gangrenous flap and secondary skin suturing; wound was left for healing by secondary intention in another patient (Figure 3). All of these patients had healed wounds eventually.

HBOT related complications were seen in two patients (14.28%). One patient had claustrophobia and another had otalgia. HBOT was abandoned and conventional treatment was provided.

Cases Reports

Case 1: A 25-year-old male patient developed flap compromise following a free flap. HBOT was started after 3 days of detection of flap compromise. A 10 cm × 12 cm region of the flap was compromised.

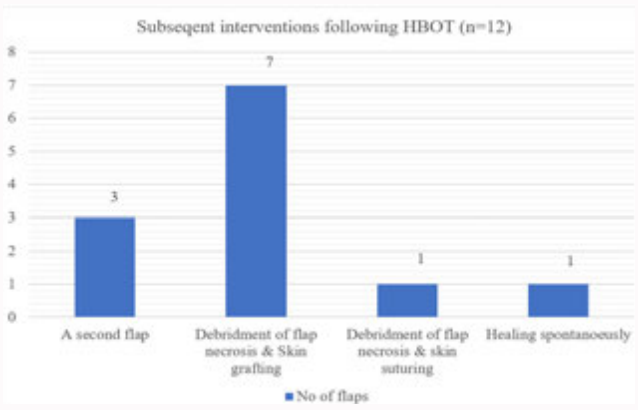

Figure 3: Subsequent interventions following HBOT in the study population.

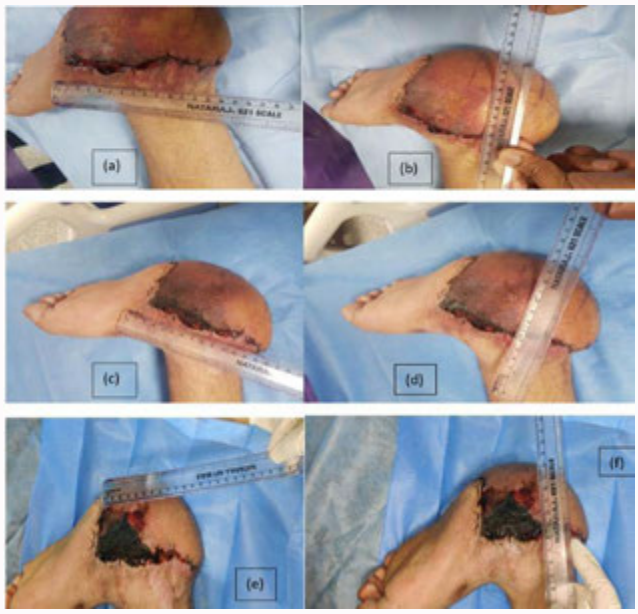

Figure 4: a, b) Showing flap compromise (HBOT day 0). c, d) Showing some improvement in flap discoloration (HBOT day 3). e, f) Showing demarcation of flap necrosis (HBOT day 10).

Following HBOT the discoloration was noted in 6 cm × 4 cm. The necrosed flap was debrided and skin grafting was performed (Figure 4).

Case 2: A 52-year-old male patient underwent ALT flap and had flap compromise on POD 0. Flap was re-explored and venous thrombus was removed. HBOT was administered from 4th POD due to uncontrolled blood sugar in the immediate postoperative period. There was improvement in the flap discoloration and oedema. However, the distal portion of the flap was gangrenous and skin graft was done later on (Figure 5).

Case 3: A 39-year-old man underwent reverse sural flap for exposure of implant over the tibia. On POD 3 flap compromise was noted. HBOT was started on the same day and partial flap salvage was achieved. Upon debridement of the flap the underlying implant got exposed and he underwent a free flap later on (Figure 4).

Case 4: A 34-year-old male underwent free anterolateral thigh flap for open ankle dislocation. On the second POD there was discoloration of the flap and no obvious infection. Two days later

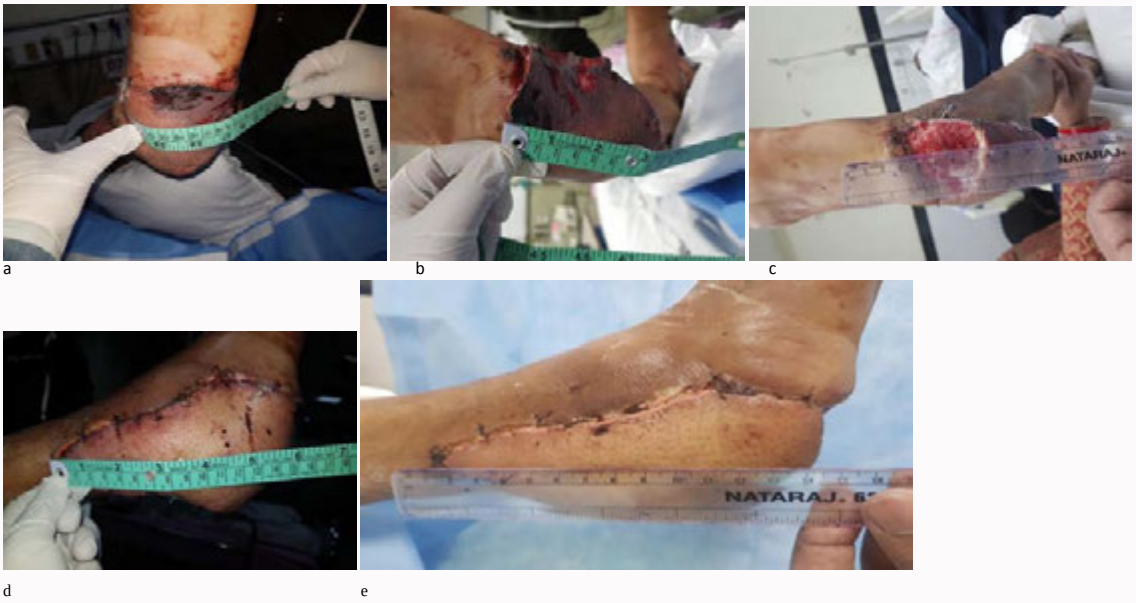

Figure 5: a, b) Showing flap compromise (HBOT- day 0). c) Showing defect following debridement of flap (HBOT- day 10). d) Showing flap edema (HBOT- day 0). e) Showing resolution of flap edema (HBOT- day 10).

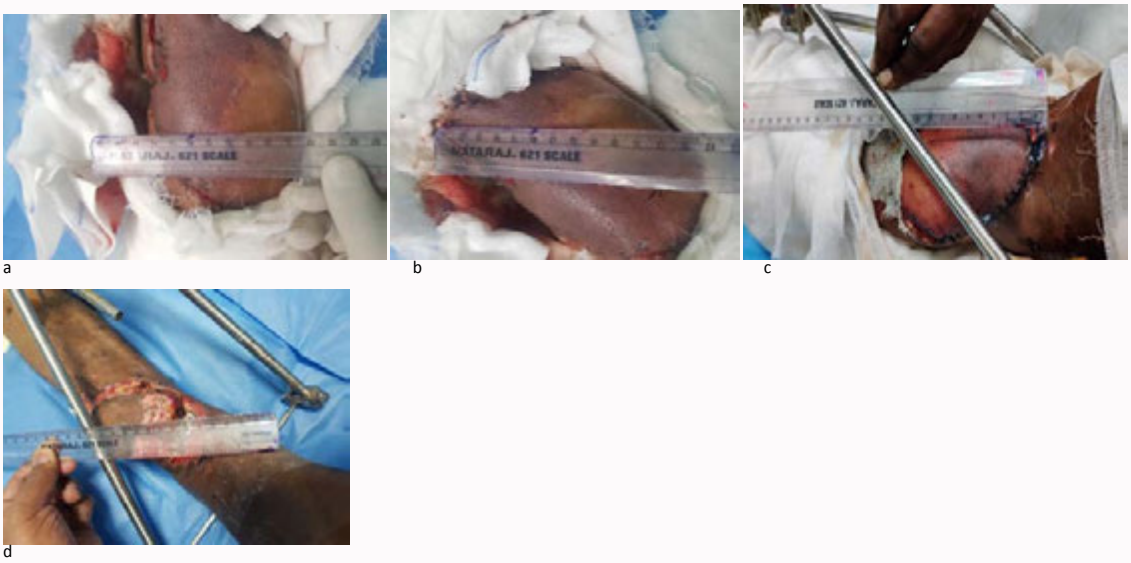

Figure 6: a, b) Showing flap compromise (HBOT- day 0), c) Showing improvement in the flap discoloration (HBOT- day 5). d) Showing condition of flap following debridement of demarcated flap necrosis. (HBOT- day 10).

HBOT was initiated. During the course of HBOT the abscess was formed underneath the flap. Hence HBOT was abandoned and wound was debrided and the abscess drained (Figure 6).

Discussion

HBOT (Hyperbaric Oxygen Therapy) is an effective treatment for CO poisoning, gas gangrene, mandible osteoradionecrosis, and diabetic foot ulcers [2,3]. However, the effectiveness of HBOT for managing ischemic flaps is less clear, and the additional cost and risk to patients raises questions. Most studies on this topic come from animal studies, so animal data is included in the discussion. Axial pattern flaps with a distal ischemic portion can be considered as a random flap because the ischemic portion is actually a random part of the flap. There have been numerous studies described in the literature. Experimental studies were conducted to evaluate the efficacy of HBOT on random flap survival [4-6], duration of therapy [7], and optimum pressure during HBOT [8]. It was concluded that most of the experimental studies in animals showed small but significant improvement in the salvage of an ischemic flap. However, if this was transposed in the clinical setting, only a few centimeters of the flap could be expected to survive beyond the well-perfused area. Similar findings were noted in our series. When it comes to clinical studies, there are no prospective randomized control trials in the literature. Ueda et al. [9] reported on 26 patients who developed flap ischemia immediately after surgery, with most of the flaps located in the head and neck region. The number of treatments varied for each patient, and the average day of initiation of HBOT was 2.6 days. Eleven patients had 100% flap recovery, five had 95% recovery, and

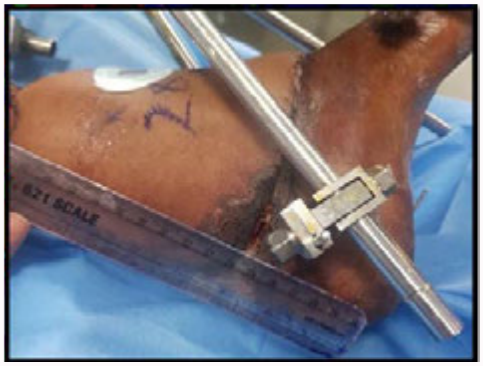

Figure 7a: Image showing flap compromise (HBOT- day 0).

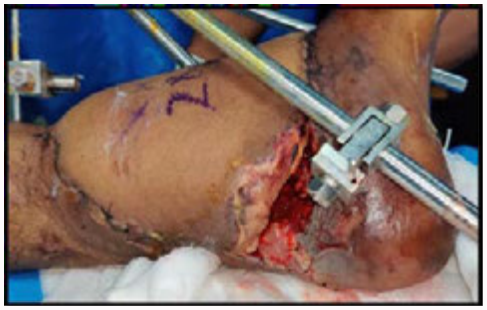

Figure 7b: Image showing flap after debridement (HBOT- day 4).

partial necrosis was seen in the remaining patients. There is only a single animal study by Bayati et al. [10] in which he demonstrated that HBOT improved the vascularity of the pre-fabricated flaps. The only clinical study looking at distant flaps was done by Ueda et al. [9] where he studied Abbe flaps, and as there was no control group, the flaps would have survived even without HBOT. In our study, a pedicled flap was done in seven patients. The distant flaps performed in our series were groin flap (n=2), and reverse sural flap (n=2). One of the patients with groin flap had otalgia, and HBOT was abandoned, but in the rest of the three patients, there was an average of 56.66% percentage improvement in the flap discoloration. There is no clinical study to compare this result.

The application of HBOT to free flaps has been applied by several authors. Gehmert et al. [11] studied the effect of HBOT in increasing the tissue oxygenation in free flaps with topical oxygen sensors. He concluded that there was an increase in the oxygenation of the entire flap. He included six patients. In this study, there were no flap compromises, and the intention of administering HBOT was not for the salvage of flaps. Vishwanath [12] conducted a randomized control trial to ascertain the prophylactic use of HBOT for free flap patients. HBOT was provided for seven days, and the flaps were followed for 14 days. He found no significant difference in the HBOT group and control group in terms of flap survival, venous congestion, and healing of the flap site. In our study, we provided HBOT only noticing flap compromise.

Our study is compared with other studies in Table 3. There is a gross discrepancy between all studies. Few authors used HBOT prophylactically in all patients. Like us, other authors provided HBOT only after noticing flap compromise. There was also no uniformity in the methodology and outcome measurements. Administration of HBOT within 24 h of flap ischemia had improved results [12,13].

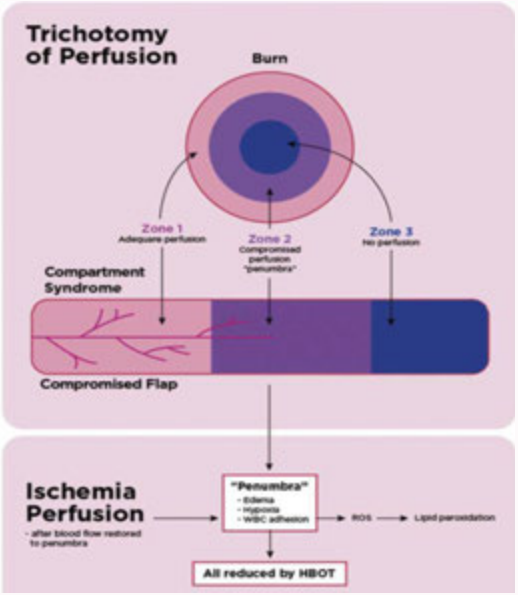

Figure 8: Image showing the trichotomy concept of flap perfusion.

The mean time gap between detection of flap compromise and administration of HBOT was 1.7 days. The delay was due to logistics issues in the availability of HBOT machine. Due to a low sample size, we couldn't analyze if the delay in initiation of HBOT affects the final outcome. The number of sessions differed amongst the authors. Francis et al. [14] provided HBOT for 20 days for compromised flap patients. In our opinion, a fixed number of sessions is not required. Once the flap necrosis was demarcated, and oedema in the flap has subsided, we discontinued HBOT. Thus, the mean number of sessions of HBOT in our study was 6.35.

Larson et al. [15] noted 68.3% improvement in the flap surface area. In our study, we noted it to be 49.5%. Vishwanath [12] noted no difference between the HBOT and control group with respect to flap edema. In our study, we have noted that there was a reduction in flap edema in 66.6% of patients, and 14.28% didn't show a reduction in edema until surgical debridement of the necrosed flap portion.

An interesting finding noticed in our series was significant increase in the flap RBS levels immediately after the administration of HBOT. There has been no previous study which has documented effects of HBOT on flap RBS levels. However, few studies mention improvement in glucose tolerance and insulin sensitivity and thereby reduced blood glucose levels in patients following HBOT(*). We may hypothesize that the increase in flap RBS levels may be due to improved flap circulation following HBOT. HBOT decreases edema, which may contribute to improved venous drainage and thereby improving microcirculation. However, since the RBS samples were only taken from the flaps and not from the patient's fingertips, it is difficult to corroborate this finding.

Two patients had total flap necrosis (14.28%). Both flaps were explored for possible salvage prior to initiation of the HBOT. Eventually flaps were totally necrosed and had to be debrided. Thus, HBOT was found to be ineffective in critically damaged flaps in which there is a persistent flap related issue. This has been observed by several other authors who reported flap necrosis in 15% [16] and 26.7% [15] of the flaps.

Transcutaneous Oximetry (TCOM) or laser doppler studies

Table 3: Comparison of various studies on the effect of HBOT on flap salvage.

Author	Sample size	Type of flap	Indication for HBOT	HBOT Started after	Outcome measurements		
					Flap necrosis	Flap area improvement	Flap survival rate
Zhou et al. [16]	957 (HBOT) 583 (Control)	Flaps and graft	Prophylactic*	Day 0	-	-	62.5-100 (HBOT group) 35-86.5% (Control group)
Roje Z et al. [17]	163 (flaps)	-	Prophylactic	Day 0	Flap necrosis 15% (HBOT group) 51% (Control group)	-	-
Larson JV [15]	15	Flap	Failing or threatened flaps	-	26.70%	68.30%	-
Bowersox et al. [18]	105	grafts or flaps	Ischemia	-	-	-	90%
Vishwanath G [12]	10 (HBOT 10 (Control)	Free flap	Prophylactic	Day 0	Nil (Both groups)	100% (Both groups)	100% (Both groups)
Our study	14	Pedicled & free flaps	Compromised flaps	1.7 days (mean)	14.28%	49.50%	85.72%

are very useful adjunctive modality to assess the tissue oxygenation during HBOT treatment [19]. This would be a more objective way of assessment. In our series we have monitored the response with clinical examination. Whenever a flap compromise was recognized, we ruled out correctible causes. In addition to HBOT we have removed few sutures to relieve the tension and improvement in flap perfusion. Without a randomized control study, we can't prove if the improvement in the flap is either due to HBOT or suture removal or it is flap's natural course of survival.

In our series we noted that none of the flaps were salvaged completely. This is based on the fact that the distal most portion of the compromised flap was always damaged beyond salvage in all cases. This can be corelated to the concept of trichotomy of perfusion [20] (Figure 7). As shown in the Figure 8 each compromised flap can be divided in to 3 zones. With HBOT we noticed we could salvage the zone 2 (compromised perfusion) region. In zone 3 (no perfusion) region we noticed there was always flap necrosis.

Is HBOT reducing the requirement of secondary surgeries? In one of our patients even though there was improvement in significant surface area of the flap, the distal most portion of the flap couldn't be salvaged. Upon debridement the implant was exposed and the patient required a second flap. In spite of the fact that almost 90% subjects in our study needed a second procedure, majority of the flaps did get partially salvaged and exhibited improved signs of vascularization. However, in absence of a control group, it still remains to be answered if HBOT has a role in reducing secondary procedures.

Limitations of the Study

- The sample size in our study is very low and there is no control group to make a comparison and prove findings statistically.
- The clinical improvement noted in the flaps in our study may be due to HBOT and the adjunctive measures like relieving tension sutures in the flap. Practically both measures have an impact on the flap survival. This could be proven only by a randomized control study design.
- The role of other confounding variables cannot be eliminated in absence of control group.

Conclusion

HBOT has shown to be useful in saving a significant portion of a compromised flap. However, there may still be a need for secondary procedures, such as a secondary suturing, skin graft, second flap procedure or other minor procedures, despite HBOT treatment. A definitive assessment of the efficacy of HBOT in patients with compromised flaps cannot be determined due to incomplete recruitment and requires a higher number of study subjects. It has been found to significantly and relatively rapidly reduce flap edema. However, if persistent edema occurs, re-evaluation of the flap is necessary to rule out other contributing factors. Established skin necrosis cannot be resolved with HBOT. Based on the experience gained from this study, we recommend a minimal trial of at least one HBOT session per day for six days to revive compromised flaps. If flap necrosis is demarcated and edema subsides, HBOT treatment may be discontinued. In spite of promising results, a definitive conclusion about the efficacy of HBOT couldn't be ascertained in this study. Therefore, the present study remains a hypothesis warranting further investigation.

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