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CLINICAL RESEARCH

Supplemental Postoperative Oxygen and Tissue Oxygen Tension in Morbidly Obese Patients

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Abstract
Background Subcutaneous tissue oxygen tension ($PsqO_2$) is a major predictor for wound healing and the occurrence of wound infections. Perioperative subcutaneous wound and tissue oxygen tension is significantly reduced in morbidly obese patients. Even during intraoperative supplemental oxygen administration, $PsqO_2$ remains low. Tissue hypoxia is pronounced during surgery and might explain the substantial increase in infection risk in obese patients. It remains unknown whether long-term supplemental postoperative oxygen augments tissue oxygen tension. Consequently, we tested the hypothesis that 80% inspired oxygen administration during 12–18 postoperative hours significantly increases $PsqO_2$ compared to 30% inspired oxygen fraction.
Methods After IRB approval and informed consent, 42 patients undergoing laparoscopic bariatric surgery were randomly assigned to receive either 80% inspired oxygen via a PULMANEX Hi-Ox™ Mask (Viasys MedSystems, Wheeling, IL) (10 L/min) or 30% oxygen via nasal cannula (2 L/min) after surgery until the next morning. $PsqO_2$ was measured with a temperature-corrected Clark-type electrode in the subcutaneous tissue of the upper arm and adjacent to the wound.
Results Postoperative subcutaneous tissue oxygen tension was significantly increased in the Hi-Ox group: 58 (47.7, 74.1) mmHg vs. 43 (38.7, 55.2) mmHg, $P=0.002$. Also, wound tissue oxygen tension was improved during supplemental oxygen administration: 75.2 (69.8, 95.5) mmHg vs. 52.4 (46.3, 66.1) mmHg, $P<0.001$.
Conclusion Subcutaneous tissue oxygen tension was significantly increased by supplemental postoperative oxygen administration. Whether there is an effect on the incidence of wound infection in morbidly obese patients is matter of further research.

Keywords Obesity · Supplemental oxygen · Tissue oxygen tension · Wound infection

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Introduction

Tissue perfusion in morbidly obese patients is impaired in the perioperative period [1]. This fact has been attributed to local conditions as well as systemic factors. Cardiac output, circulating blood volume, and resting oxygen consumption are all increased in obese individuals [2, 3]. However, fat tissue mass expands without a

concomitant increase in blood flow per cell, which results in relative hypoperfusion [4]. Consequently oxygen delivery to obese tissue might be critically reduced during certain conditions such as for example the perioperative period when surgical stress and relative hypovolemia impair tissue perfusion.

Impaired tissue perfusion with subsequent tissue hypoxemia might be one major reason for the increased number of surgical site infections in morbidly obese patients, contributing to high morbidity and mortality [5, 6]. Oxidative killing by neutrophils is the primary defense against surgical pathogen [7]. The risk of infection is thus inversely related to perioperative tissue oxygen partial pressure in a surrogate wound in the upper arm [8]. Factors that increase tissue oxygen tension thus reduce infection risk and also augment wound healing [9]. For example, perioperative supplemental oxygen administration, which doubles subcutaneous oxygen tension in normal-weight patients, decreases the incidence of infection in colon surgical patients [9, 10].

Intraoperative subcutaneous tissue oxygen tension ($PsqO_2$) is significantly reduced in obese patients compared to non-obese controls during normoxemia [11] as well as during a short period of supplemental oxygen administration [12]. Perioperative factors such as endocrine responses, hypovolemia and mechanical ventilation might contribute to the relatively low tissue oxygenation. This is further supported by the observation that obese, awake volunteers show similar $PsqO_2$ values compared to lean volunteers [13]. It remains unknown if prolonged supplemental oxygen administration in the postoperative period has a more pronounced effect than intraoperative oxygen administration. We thus tested the hypothesis that 80% inspired oxygen administration during 12–18 postoperative hours significantly increases subcutaneous arm ($PsqO_2$arm)—and wound oxygen tension ($PsqO_2$wound)—as the main region of interest compared to 30% inspired oxygen fraction in morbidly obese patients.

Methods

With approval of the Medical University of Vienna Institutional Review Board and with written informed consent, we recruited 42 patients aged 18–65 years with a body mass index (BMI) > 35 kg/m^2 scheduled for laparoscopic gastric bypass surgery. Exclusion criteria included documented coronary or peripheral artery disease, insulin-dependent diabetes mellitus and recent history of smoking. Furthermore, we did not include patients with polysomnography-defined obstructive sleep apnea syndrome requiring continuous positive airway pressure. We also excluded patients with preoperative systolic arterial blood pressure >170 mmHg or diastolic arterial blood pressure >90 mmHg.

Protocol

On the morning of surgery, patients were orally premedicated with midazolam 7.5 mg. Five hundred milliliters of lactate-containing Ringer's solution was administered preoperatively. For all operations, patients were placed in the 25° reverse Trendelenburg position. Considering a preoxygenation period over 5 minutes with 18 L oxygen flow, general anesthesia was induced with fentanyl (1–1.5 $\mu g \cdot kg^{-1}$ total body weight), propofol (2 $mg \cdot kg^{-1}$ total body weight) and rocuronium (0.9 $mg \cdot kg^{-1}$ ideal body weight), and direct view laryngoscopy was performed. Following induction of anesthesia, a 20-g cannula was inserted into a radial artery.

To optimize tissue oxygen availability, all patients received 80% inspired oxygen fraction during the intraoperative period. Patients were mechanically ventilated with a tidal volume of 6–8 $mL \cdot kg^{-1}$ ideal body weight at a rate sufficient to maintain end-tidal pCO_2 near 40 mmHg. Positive end-expiratory pressure was set between 7 and 10 cm H_2O, and peak airway pressure was kept less than 30 cm H_2O. Subsequently, general anesthesia was maintained with sevoflurane in a carrier gas of inspired oxygen and air. Sevoflurane administration was adjusted to maintain mean arterial blood pressure within 20% of the preinduction value. A supplemental bolus dose of fentanyl (100 μg) was given when heart rate or arterial pressure exceeded 120% of the baseline value.

Hypovolemia decreases wound perfusion and oxygenation. Thus, we controlled intra- and postoperative fluid management. Specifically, we administered 10 $mL \cdot kg^{-1} \cdot h^{-1}$ of crystalloid throughout surgery, normalized to ideal body weight calculated according the following formula: men: ideal body weight (in kilograms) = 52 kg + 1.9 kg for each inch over 5 feet; women: ideal body weight (in kilograms) = 49 kg + 1.7 kg for each inch over 5 feet [14]. Additionally, blood loss was replaced with crystalloid at a 3:1 ratio or colloid at a 1:1 ratio to maintain normal intravascular volume throughout surgery. Upper-body forced air warming was used to keep patients normothermic, while local warming of the measurement site was strictly avoided.

Paracetamol 1000 mg was administered intravenously for postoperative analgesia before extubation.

At the end of surgery, wounds were dressed with standard surgical bandages that did not apply direct pressure to the wound. After complete reversal of neuromuscular blockade, all patients were extubated in the semirecumbent position following manual hyperinflation.

Extubated patients were randomly assigned to two equally sized groups. Randomization was based on

computer-generated codes that were maintained in sequentially numbered opaque envelopes. The designated treatments were supplemental oxygen administration at an inspiratory oxygen concentration of approximately 80% (Hi-Ox group) or standard oxygen administration reaching an inspiratory oxygen concentration of approximately 30% (Low-Ox group). Patients assigned to the Hi-Ox group received an oxygen flow rate of 10 L/min over a PULMANEX Hi-Ox™ Adult Oxygen Mask (Viasys MedSystems, Wheeling, IL). The standard group received 2 L/min oxygen flow via a nasal cannula. Oxygen flow was increased as necessary to maintain oxyhemoglobin saturation (as determined by pulse oximetry) ≥ 90%.

The designated oxygen treatment was maintained during the entire measurement period. Any changes in oxygen treatment were recorded. Patients were visited at regular intervals to ensure compliance with the oxygen treatment. Instructions for the nurses not to change the settings were placed.

Postoperative pain was treated with intravenous piritramid according to the patient's requirements by clinicians not involved in the study. During the postoperative investigation period, crystalloid was administered at a rate of 3.5 mg · kg^{-1} · h^{-1} normalized to ideal body weight. Supplemental fluid was given as necessary to maintain urine output greater than 0.5 mL · h^{-1} · kg^{-1} ideal body weight.

Measurements

Demographic data, American Society of Anesthesiologists (ASA) physical status, comorbidities, preoperative laboratory values, and type and duration of surgery were recorded. All routine anesthetic, respiratory, and hemodynamic variables were also recorded. Detailed records of intra- and postoperative fluid management, including urine output, were kept. Inspired oxygen, end-tidal sevoflurane and carbon dioxide concentrations were measured during surgery. Oxygen saturation was measured with pulse oximeters during the operative procedure and the postoperative measurement period. Intraoperative core temperature was measured in the distal esophagus (Mon-a-therm, Tyco-Mallinckrodt Anesthesiology Products, St. Louis, MO).

Arterial pressure was monitored continuously from the arterial catheter during surgery and in the postanesthesia care unit. Arterial blood gases were obtained hourly during surgery, at arrival in the postanesthesia care unit as well as at 4-hour intervals during the postoperative investigation period. More frequent blood gas analysis was performed according to clinical requirements.

Intra- and postoperative opioid requirements were recorded. Patients were asked to rate their pain on a 100-mm-long visual analog scale at 30-minute intervals for the first hour of recovery; later on, visual analog scores were recorded at 4-hour intervals during the measurement period.

Primary outcome measures were postoperative subcutaneous tissue oxygen tension measured in the upper arm ($PsqO_2$arm) and adjacent to the surgical incision ($PsqO_2$wound). After induction of anesthesia, a silastic tonometer was inserted into the left lateral upper arm for measurement of subcutaneous tissue oxygenation and temperature. At the end of surgery, a second tonometer was inserted 2–3 cm lateral and parallel to the greatest surgical incision. Each tonometer consisted of 15 cm of tubing filled with hypoxic saline; 10 cm of the tubing was tunneled subcutaneously. A Clark-type oxygen sensor and thermistor (Licox™, Gesellschaft für Medizinische Sondensysteme, GmBH, Kiel, Germany) were inserted into the subcutaneous portion of both tonometers, as previously described [15]. The disposable microprobes were connected to a digital bedside monitor (Licox™, Gesellschaft für Medizinische Sondensysteme, GmBH), which displayed tissue oxygen and temperature values directly. Furthermore, both sensors were interfaced with a laptop PC, allowing data to be recorded on a continuous basis and stored electronically. Values were then transferred into an Excel spreadsheet for analysis.

Recording of $PsqO_2$arm and $PsqO_2$wound started after an equilibration time of 30 minutes. The probes were removed form the patient before transfer to the surgical ward.

In vitro accuracy of the oxygen sensors is ±3 mmHg for the range from 0 to 100 mmHg and ±5% for 100 to 360 mmHg (in a water bath at 37°C). Temperature sensitivity is 0.25%/°C, and thermistors are incorporated into the probes and temperature compensation is included in the tissue oxygen tension ($PsqO_2$) calculations. Oxygen sensor calibration remains stable (within 8% of baseline value for room air) in vivo for at least 8 hours. The electrodes are individually factory-calibrated, but calibration was confirmed by exposing the electrode to room air (ambient PO_2 of 154 mmHg); in all cases, measurements in air were within 10% of 154 mmHg. To exclude a significant drift of the oxygen sensor, probes were again exposed to room air after each investigation; none differed by more than 10% from baseline values.

Data Analysis

The number of patients required for this trial was estimated as follows: previous studies evaluating the effect of postoperative supplemental oxygen on tissue oxygenation showed an increase of $PsqO_2$ of approximately 20 mmHg. Standard deviations of $PsqO_2$ values in postoperative patients range between 15 and 30 mmHg with an average of 23 mmHg [9, 12]. Therefore, accepting a type I error risk

of 5% and a type II error risk of 20% (power 80%), 21 patients would be required in each group to confirm our hypothesis.

Serial measurements of routine anesthetic parameters were recorded at 15-minute intervals. Data were first averaged within each patient and then averaged among the patients in each treatment group. Potential confounding factors and outcomes of the study were analyzed with two-sided unpaired Student's *t* test when the data were normally distributed; the Wilcoxon rank-sum test was used for data sets, which diverged from the normal distribution. For paired comparisons, a two-sided paired *t* test or a Wilcoxon signed-rank test was used, depending on the distribution of the data. Normal distribution was assessed with q-q-plot and Shapiro–Wilk test. Categorical data were analyzed using Fisher's exact test or the χ^2 test as appropriate.

Tissue oxygenation and temperature values displayed at 15-minute intervals during each measurement period were analyzed using summary measures and the groups were compared with Wilcoxon rank-sum test.

Spearman correlation coefficients were calculated to compare tissue oxygen measurements performed in the upper arm with values obtained adjacent to the surgical incision.

Data are expressed as mean ± SD or as median (25th percentile, 75th percentile) dependent on distribution. A *P* value of 0.05 was considered significant.

Analysis was conducted with SPSS software (Version 17.0.0; SPSS Inc., Chicago, IL).

Results

Age and BMI were similar in the two groups. Patients in both groups had comparable ASA scores and comorbidities such as arterial hypertension and type 2 non-insulin-dependent diabetes. Furthermore, duration of anesthesia and surgery did not differ between the groups. The majority of our patients were female; however, gender distribution was even (Table 1).

Intraoperative Period

Hemodynamic values, anesthetic management, core temperatures, fluid replacement therapy, urine output and intraoperative hemoglobin values were comparable in both groups. None of the patients required allogeneic blood transfusion. Respiratory rates were similar in the Hi-Ox- and Low-Ox groups (13±2 and 13±1 breaths per minute, respectively; P=0.132), as were tidal volumes (549±88 and 548±89 mL; P=0.959) and positive end-expiratory pressures (7±2 and 7±2 cmH_2O, P=0.932) and thus $paCO_2$ (Table 2).

Per protocol, all patients received an intraoperative inspiratory concentration of 80% oxygen in air, which resulted in similar arterial oxygen tensions (Table 2). Intraoperative subcutaneous oxygen partial pressure ($PsqO_2$arm) and tissue temperature (Tsqarm) did not differ either (Table 3).

Postoperative Period

All patients' tracheas were extubated immediately after surgery. None of the patients required positive pressure ventilation during the measurement period. The average postoperative measurement period was 13±4 hours in the Hi-Ox group vs. 13±3 hours in the Low-Ox group (P=0.670). While heart rate was comparable between the groups, we observed a significant higher arterial blood pressure in patients receiving supplemental oxygen. Fluid intake, urinary output, postoperative hemoglobin values and VAS pain scores did not differ between the groups. According to their randomized allocation, patients received either 10 L oxygen via a non-rebreathing face mask or 2±

Table 1 Demographics and morphometric characteristics

	Hi-Ox	Low-Ox	*P*
Number of patients	21	21	
Age (y)	41±11	38±14	0.538
Weight (kg)	127±22	136±26	0.238
Height (cm)	165 (160, 171)	170 (163, 173)	0.332
BMI (kg/m^2)	45±5	47±7	0.255
Gender (M/F)	4/17	4/17	1.000
ASA score (1/2/3)	1/17/3	2/16/3	0.834
NIDDM (yes/no)	4/17	2/19	0.663
Arterial hypertension (yes/no)	9/12	8/13	1.000
Preoperative hemoglobin (mg/dL)	13.6 (12.9, 14.9)	13.8 (12.4, 14.6)	0.485
Duration of anesthesia (minutes)	175 (162, 210)	160 (144, 162)	0.144
Duration of surgery (minutes)	125 (118, 165)	120 (103, 159)	0.295

Data are presented as means ± SDs, medians (25th percentile, 75th percentile) or as counts for the categorical outcomes. Means were compared with an unpaired two-sided *t* tests, medians with Wilcoxon rank-sum tests, and counts with χ^2 or Fisher's exact tests. Hi-Ox group is defined by 80% postoperative oxygen administration; Low-Ox group is defined by 30% postoperative oxygen administration

NIDDM non-insulin-dependent diabetes mellitus

Table 2 Intraoperative management

	Hi-Ox	Low-Ox	*P*
MAP (mmHg)	84 (77, 90)	81 (76, 96)	0.930
HR (b/min)	77±16	77±12	0.965
Core Temperature (°C)	36.2±0.4	36.4±0.4	0.545
End-tidal sevoflurane (%)	2.1±0.5	2.0±0.5	0.735
Fentanyl (μg)	494±160	515±231	0.329
Crystalloid (mL)	2000 (1500, 2450)	2000 (1000, 2000)	0.278
Colloid (mL)	0 (0, 375)	0 (0, 250)	0.671
Urine output (mL)	120 (100, 300)	200 (120, 500)	0.254
PaO_2 (mmHg)	230±96	253±84	0.785
$PaCO_2$ (mmHg)	44±5	43±5	0.683
Hemoglobin (mg/dL)	12.5 (12.2, 13.4)	11.9 (11.5, 13.8)	0.251

Data are presented as means ± SD or median (25th percentile, 75th percentile). Means were compared with unpaired, two-sided, *t* tests and medians with Wilcoxon rank-sum tests

1 L oxygen over a nasal cannula. Three patients assigned to low-oxygen administration required 4 L oxygen in order to maintain adequate saturation. This resulted in a significant difference in average arterial oxygen tension. Arterial CO_2 concentrations were also slightly but significantly higher in patients receiving higher supplemental oxygen concentration (Table 4).

Average $PsqO_2$ measured in the subcutaneous tissue of the upper arm [58 (47.7, 74.1) mmHg vs. 43 (38.7, 55.2) mmHg] and adjacent to the wound [75.2 (69.8, 95.5) mmHg vs. 52.4 (46.3, 66.1) mmHg] was significantly greater during administration of higher oxygen concentrations. Tissue temperatures in the upper arm and near the wound were nearly identical between the groups. Furthermore, $PsqO_2$wound and Tsqwound were significantly higher compared to values measured in the arm in both groups (Table 3, Figs. 1 and 2). The observed median difference between $PsqO_2$arm and $PsqO_2$wound was more pronounced in the Hi-Ox group compared to the Low-Ox group: 17.9 (15.5, 18.6) mmHg vs. 10.6 (7.4, 15.7) mmHg, P=0.015. Furthermore, the correlation of $PsqO_2$ in individual patients between both measurement sites was weak during supplemental oxygen administration (r_s=0.28) as well as in the standard treatment group (r_s=0.359).

It is evident from Fig. 3 that $PsqO_2$wound, which represents the actual region of interest, increased progressively during supplemental postoperative oxygen administration to reach a maximum difference near 40 mmHg compared to the standard treatment group after 13 postoperative hours (94 (77.1, 116.6) mmHg vs. 52.4 (38.6, 58.6) mmHg, P=0.005).

As shown in Fig. 4, there was also a significant increase over time in postoperative subcutaneous tissue temperature of the upper arm (Tsqarm) and near the surgical incision (Tsqwound). Within the entire study period, Tsqarm increased similarly compared to baseline in the Hi-Ox group by 2.1±2°C and in the Low-Ox group by 2.2±1.7°C. A more pronounced increase was observed adjacent to the incision: 2.9±1.8°C (Hi-Ox group) and 3±1.8°C (Low-Ox group) (P<0.001 for all comparisons).

Discussion

Obesity constitutes a rising problem in the western world [16, 17] and is associated with enormous health care expenses. Especially surgical procedures in this patient population are associated with major postoperative compli-

Table 3 Intra- and postoperative subcutaneous tissue oxygen tension and temperature

	Hi-Ox	Low-Ox	*P*
Intraoperative $PsqO_2$ arm (mmHg)	59.1 (50.7, 92.4)	52.9 (47.3, 71.1)	0.163
Intraoperative Tsqarm (°C)	33.2±1.2	33.6±1.6	0.504
Postoperative $PsqO_2$ arm (mmHg)	58 (47.7, 74.1)	43 (38.7, 55.2)	0.002
Postoperative Tsqarm (°C)	35.6±1.2	35.7±1	0.826
Postoperative $PsqO_2$wound (mmHg)	75.2 (69.8, 95.5)[a]	52.4 (46.3, 66.1)[a]	< 0.001
Postoperative Tsqwound (°C)	36.9±0.7[a]	36.9±0.7[a]	0.849

Data are presented as means ± SDs or medians (25th percentile, 75th percentile). Means were compared with unpaired, two-sided, *t* tests and medians with Wilcoxon rank-sum tests. Arm–wound comparisons were analyzed with paired, two-sided, *t* tests or Wilcoxon signed-rank tests

[a] Significant different from arm

Table 4 Postanesthesia care unit management

	Hi-Ox	Low-Ox	*P*
MAP (mmHg)	101 (93,106)	93 (88, 99)	0.029
HR (b/min.)	79±14	81±12	0.550
Crystalloid (mL)	2900 (2125, 4250)	3500 (2287, 4000)	0.472
Urine output (mL)	1860 (1425, 2300)	2150 (1335, 2840)	0.352
Pain (VAS)	30±13	25±16	0.276
PaO_2 (mmHg)	206±77	92±15	< 0.001
$PaCO_2$ (mmHg)	43±5	40±3	0.038
Hemoglobin (mg/dL)	12.8 (11.2, 12.1)	12.2 (11.2, 13.7)	0.192

Data are presented as means ± SDs or medians (25th percentile, 75th percentile). Means were compared with unpaired, two-sided, *t* tests and medians with Wilcoxon rank-sum tests. VAS is a 100-mm visual analog scale with 0 mm as no pain and 100 mm as the worst imaginable pain

cations leading to increased morbidity and prolonged hospitalization [6]. Obesity has been identified as a risk factor for infectious and wound complications after a wide variety of surgical procedures [18]. This increased risk has been variously attributed to immune impairment, ischemia along suture lines, greater wound areas, deficiencies in collagen synthesis and technical difficulties resulting in contamination and prolonged surgery [6, 19, 20]. At any rate, decreased tissue oxygen tension in relatively avascular adipose tissue might play a central role [4, 12].

The primary defense against surgical pathogens is oxidative killing by neutrophils, which critically depends on tissue oxygen tension [7]. Thus, subcutaneous tissue oxygen tension represents a major and powerful predictor for wound healing complications. Beyond that, the incidence of surgical wound infection is directly related to tissue perfusion and oxygenation [8]. Wound repair and resistance to infection both depend on tissue oxygen tension and can potentially be improved by increasing arterial oxygen tension even of fully saturated blood [9, 10].

Tissue perfusion and oxygenation is critically impaired in morbidly obese patients during open and laparoscopic surgery as well as in the immediate postoperative period [11, 12]. Even supplemental oxygen administration failed to increase subcutaneous tissue oxygen tension adequately. An intraoperative short-time oxygen challenge aimed to reach an arterial oxygen tension of 300 mmHg improved subcutaneous tissue oxygen tension only by 10 mmHg in obese patients compared to 25 mmHg in the non-obese control group. Absolute values remained in the range of 45–50 mmHg, which might be associated with an increased infection rate. It was thus concluded that obesity constitutes a major determinant for perioperative tissue oxygen availability [12]. Interestingly, tissue oxygen tension in awake, obese volunteers is similar as compared to lean volunteers. Furthermore, supplemental oxygen increases tissue oxygenation substantially in healthy volunteers providing further evidence that critical tissue hypoxia constitutes mainly an intraoperative event [13]. Correspondingly, tissue oxygen tensions were comparable in obese and non-obese patients on the first postoperative day and also short-time supplemental oxygen administration was considerably more effective in regards to subcutaneous tissue oxygenation at that point in time [12].

Thus, perfusion in obese patients might be worsened during anesthesia and surgery. Especially surgical stress response, fluid shifts and alterations of the cardiovascular performance due to anesthetic medication, mechanical ventilation and surgical interventions such as positioning and pneumoperitoneum might contribute [21–23]. Besides

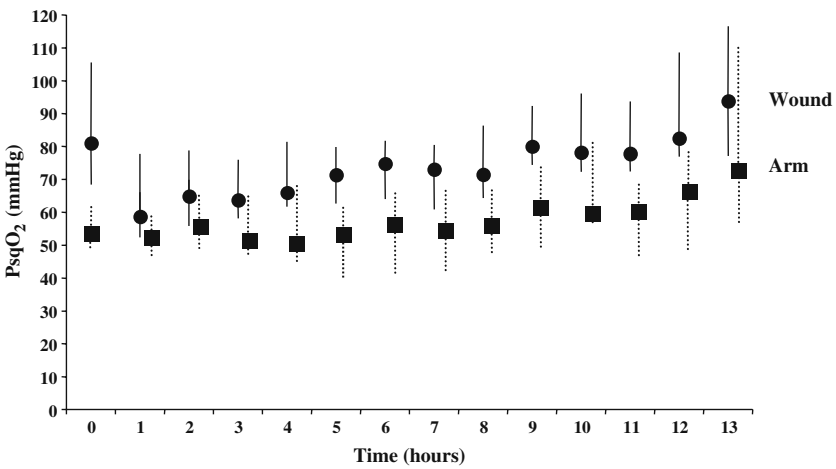

Fig. 1 Plot of $PsqO_2$arm and $PsqO_2$wound over time for 21 patients receiving 80% postoperative inspiratory oxygen concentration. *Squares* represent measurements at the arm; *circles* represent measurements near the surgical incision. Data are presented as medians (25th percentile, 75th percentile)

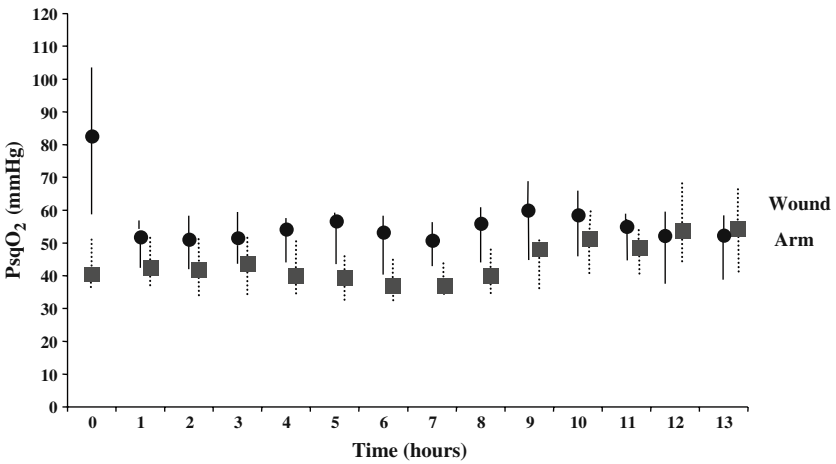

Fig. 2 Plot of $PsqO_2$arm and $PsqO_2$wound over time for 21 patients receiving 30% postoperative inspiratory oxygen concentration. *Squares* represent measurements at the arm; *circles* represent measurements near the surgical incision. Data are presented as medians (25th percentile, 75th percentile)

arterial oxygen partial pressure, cardiac output and peripheral perfusion are the major determinants of peripheral oxygen availability [24]. Thus intraoperative supplemental oxygen administration, especially in the morbidly obese, might be of limited benefit.

Wound infections usually are established in the perioperative period, the so-called decisive period [25]. For example, prophylactic antibiotic therapy is ineffective when administered after surgical incision. So far, the exact duration of the decisive period for supplemental oxygen therapy remains unknown. Former randomized studies predominantly focused on the intraoperative and immediate postoperative period. However, observational experimental and clinical studies give strong evidence that supplemental oxygen might have effects even several hours after surgery [8, 26]. The effect of exclusive postoperative oxygen administration on wound tissue oxygenation and wound healing complications has never been studied in a normal-weight patient population. Thus, it remains unknown if and to which extent postoperative supplemental oxygen is equally or even more efficient compared to immediate perioperative administration. Despite the fact that the "decisive" period for the development of wound infections is mainly the intraoperative and immediate postoperative period, the inflammatory response to surgical stress most certainly continues on much longer [27]. Thus, supplemental oxygen administration for an extended postoperative period might be beneficial.

The purpose of our study was to evaluate the effect of long-term postoperative oxygen administration on tissue oxygenation. Thus, all patients received 80% oxygen intraoperatively and were randomly assigned to 30% or 80% inspiratory oxygen fraction in the postoperative period. Comparable to our previous study, intraoperative tissue oxygen tension values obtained during 80% inspiratory oxygen concentration and an average PaO_2 near 250 mmHg remained low between 50 and 60 mmHg. These values are similar to those patients of normal weight receiving 30% inspiratory oxygen concentration and thus reaching a PaO_2 of 120 mmHg [9].

In our study, postoperative 80% oxygen administration via a non-re-breathing facial mask doubled PaO_2 compared to a standard management of 2 L /min oxygen via nasal cannula. Average postoperative tissue oxygen tension in the

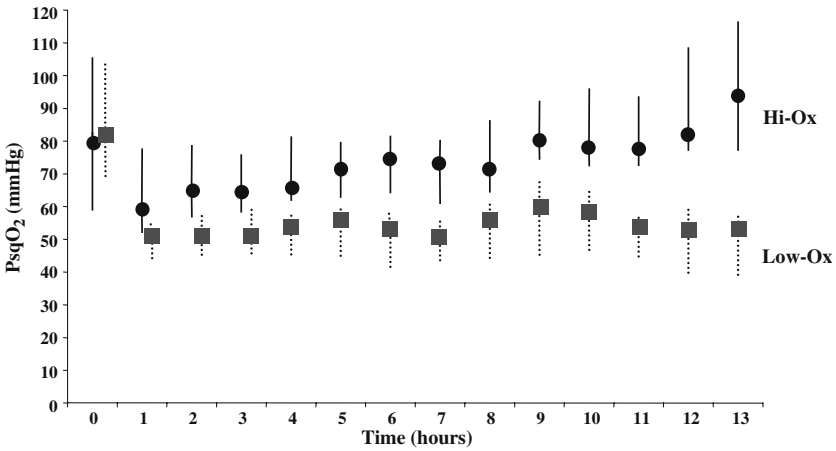

Fig. 3 Plot of $PsqO_2$wound over time during 30% and 80% postoperative inspiratory oxygen concentration. *Squares* represent measurements during low oxygen conditions; *circles* represent measurements during supplemental oxygen administration. Data are presented as medians (25th percentile, 75th percentile)

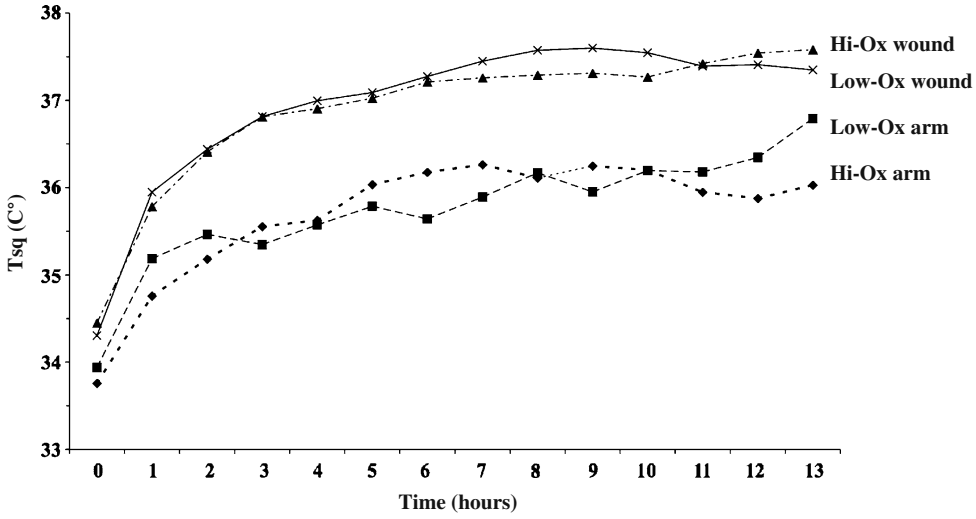

Fig. 4 Plot of Tsqarm and Tsqwound during 80% and 30% postoperative inspiratory oxygen concentration. *Squares* represent measurements at the arm during low oxygen conditions; *rhombi* represent measurements at the arm during supplemental oxygen administration; *crosses* represent measurement near the surgical incision during low oxygen conditions; *triangles* represent measurements near the surgical incision during supplemental oxygen administration. Data are presented as medians

upper arm was 58 mmHg during 80% oxygen administration, which is similar to intraoperative values. In contrast, tissue oxygenation decreased to 43 mmHg with 30% oxygen. Near the surgical incision, tissue oxygen tension was improved by roughly 25 mmHg and reached maximum values around 100 mmHg. These values might be sufficiently high to markedly diminish wound infection rate. Specifically, it has been shown that values around 90 mmHg reduce infection risk to almost zero, whereas values around 40 mmHg are associated with an infection rate up to 40% [8]. Tissue temperature also increased significantly over time at both measurements sites in all patients (Fig. 4). As subcutaneous tissue temperature serves as a marker for tissue perfusion in normothermic individuals, [15] this observation indicates postoperative restoration of sufficient tissue perfusion. Diminished sympathetic responses in the postoperative period as well as optimized fluid and pain management might have contributed to the gradual improvement of peripheral perfusion.

Our study is the first one administering supplemental oxygen during an extended period of time, i.e. till the first postoperative morning. Measurements were performed within an average period of 13 postoperative hours. This time frame seemed reasonable; as this was the average interval, patients stayed in our postoperative care unit specifically for the purpose of the study. Data were recorded continuously during the measurement period under stable conditions without any disruption due to discharge of patients. It also seems to be feasible to establish supplemental oxygen therapy via a non-rebreathing face mask as standard of care during a similar period of time even if patients are on a normal ward. Whether oxygen administration for an even longer period of time might be beneficial in high-risk patient populations such as for example the morbidly obese remains unknown. It might however be impractical as patient compliance decreases over time especially with administration of high oxygen flows.

During supplemental postoperative oxygen therapy, mean arterial blood pressure increased significantly by 9 mmHg. This is in accordance with early observations that hyperoxia increases systemic vascular resistance and mean arterial blood pressure in volunteers [28]. However, the clinical impact of this slight increase seems to be negligible. Exposure to hyperoxia might effect respiratory drive and ventilation–perfusion mismatch and thus increase $paCO_2$ in patients with chronic obstructive pulmonary disease [29]. Spontaneous breathing of high inspiratory oxygen concentrations might otherwise lead to hyperventilation and decreased $paCO_2$ in healthy subjects [30]. In our morbidly obese study population, average arterial carbon dioxide levels were statistically significant higher in the Hi-Ox group by 3 mmHg. This observed increase is well within a range, which is unlikely to have any clinical implication. However, patients with a history of pulmonary disease or diagnosed obstructive sleep apnea were excluded from our data collection. Thus, our result might not be transferable to a general obese patient population with more severe comorbidities.

Interestingly, wound tissue oxygen tension was significantly higher in both groups compared to the arm. This differs to previous results, which either showed similar or slightly decreased values [12, 31]. However, all our patients underwent laparoscopy, which is in contrast to former data obtained after open procedures. Thus, direct comparisons between the studies are not feasible and it might very well be that decreased values reflect more severe tissue injury and disruption of vessels after open surgery. Tissue temperature was also significantly higher near the abdominal incision. Postoperative wound hyperemia and thus

improved perfusion might contribute to this finding, which is similar to previous data comparing subcutaneous and wound tissue temperature in obese and non-obese patients [12]. Given the fact that the effectiveness of supplemental oxygen administration depends on adequate tissue perfusion, [24] it is reasonable that the observed difference in $PsqO_2$ between both measurement sites was more pronounced in the Hi-Ox group (Figs. 1 and 2).

Our recent data suggest that under the specific conditions of our study, in obese patients after laparoscopic procedures, arm tissue oxygenation does not reflect wound tissue oxygenation. This is also supported by the fact that there was no correlation between arm and wound measurements in both groups.

We did not specifically evaluate postoperative atelectasis or lung function. It has been previously shown that 80% inspiratory oxygen administration during and 2 hours after colon resection did not worsen pulmonary function and led to similar atelectasis formation compared to 30% inspiratory oxygen concentration [32]. Also, our morbidly obese patients showed appropriate oxygenation and had no clinical relevant symptoms of respiratory impairment. Thus, we do not assume that supplemental postoperative oxygen administration until the first postoperative morning causes clinically significant atelectasis. Nevertheless, this matter should be addressed in further studies.

One further limitation of our study is that we studied exclusively patients undergoing laparoscopic procedures. Most bariatric surgery is performed laparoscopically. Also, laparoscopic colorectal surgery gains more and more popularity, especially in high-risk patients, such as the obese. However, the majority of obese patients undergo all types of surgery. As a consequence, it might be difficult to transfer our data to a general obese surgical patient population.

In summary, postoperative wound oxygen tension was roughly 25 mmHg greater during supplemental oxygen and reached values which likely are associated with decreased infection risk. It is thus obvious that the impact of this simple, inexpensive treatment on wound infection rate needs to be evaluated in a large randomized outcome trial. With reference to our data, we recommend the administration of 80% inspired oxygen for a time period of 12–18 postoperative hours in obese patients. It has been shown that administration of 10-L oxygen per minute via a non-rebreathing face mask is able to double arterial oxygen tension and to increase wound tissue oxygen tension. This treatment proved to be safe and well tolerated and might be of benefit in this high-risk patient population.

Conflict of Interest The authors declare that they have no conflict of interest.

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