

Original Article

Intraoperative partial pressure of oxygen measurement to predict flap survival

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ABSTRACT

Introduction: Flap monitoring using partial pressure of oxygen (pO_2) is a proven modality. Instruments needed are expensive and are not readily available to a clinician. Here, pO_2 of flap has been determined using readily available and cheap methods, and a cut-off value is calculated which helps in predicting flap outcome. **Methods and Results:** Total 235 points on 84 skin flaps were studied. Capillary blood was collected from flap and fingertip using 1-ml syringes after at least 30 min of flap inset, and pO_2 analysed using blood gas analyser. Fall/change of pO_2 (difference of mean of pO_2 [diff- pO_2]) was also calculated by subtracting the flap pO_2 from the finger pO_2 . Flap was monitored clinically in post-operative period and divided into two groups depending on its survival with Group 1 – dead points and Group 2 – alive points. pO_2 and diff- pO_2 amongst both the groups were compared and found to be statistically different ($P = 0.0001$). Cut-off value calculated for pO_2 was found to be <86.3 mmHg with a sensitivity of 100% and specificity of 89.05%. The difference of >68.503 mmHg of flap pO_2 compared from finger pO_2 was calculated as a cut-off with sensitivity of 94.12 and specificity of 79.60%. **Conclusions:** Flap areas having intra-operative pO_2 value <86.3 mmHG have higher chances (60.71%) of getting necrosis later. Similarly, if diff- pO_2 compared to fingertip is >68.5 mmHg, chances of those points getting necrosed in post-operative period are high.

KEY WORDS

Flap; flap monitoring; partial pressure of oxygen

INTRODUCTION


Flap monitoring is as important to a plastic surgeon as flaps are in reconstruction. Optimal blood supply to deliver oxygen is essential for any tissue

to survive, and compromised supply, if detected early, can help correct the causative factor and salvage a dying flap.

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Direct clinical observation is still the gold standard monitoring system but is not objective and requires an experienced/trained staff. Although various methods are available to objectively monitor flap survival, all have a common drawback of being highly expensive and not available routinely to a surgeon.

In this study, we have used simple syringes and blood gas analyser, routinely available in any hospital, to get partial pressure of oxygen (pO_2) in a flap and calculated a cut-off value to objectively predict the chances of flap survival in post-operative period.

These cut-off values can further be used with implantable microcatheter oxygen sensors, where no such cut-off values are present, because of small number of flaps studied in literature.

METHODS

This prospective observational study was carried out from November 2014 to April 2016 on 75 patients having total of 84 flaps. Approval by the local Institutional Ethics Committee was taken for the study.

Thirty-minute post-elevation and inset of skin flaps, capillary blood is collected from the bleeding edges in 1-ml heparinised insulin syringes after spraying 0.1 ml of heparin (5000 μ /ml) to minimise clotting, intraoperatively from the proximal, middle and distal third of the flap. The fraction of inspired oxygen (FiO_2) was kept constant at 0.5% or 50% to minimise the confounding due to changes in oxygen level, as dissolved oxygen increases with increase in FiO_2 . Samples were immediately analysed for pO_2 . At the same time, sample of capillary blood was collected in similar manner from the fingertip as control and to compare the difference in the tissue oxygen levels.[Figure 1] If the sample collected was clotted or insufficient, that point was excluded from the study.

These points were marked and closely monitored clinically in post-operative period for a week to note for viability of the flap by assessing the skin colour, capillary refill, oozing on pinprick and comparison of flap temperature with normal adjacent skin. These 235 points were divided into two groups depending on the post-operative viability at each point: Group 1 – points those were clinically ischemic in post-operative



Figure 1: Clinical pictures of sample collection. (a-c) From distal middle and proximal flap; (d) from fingertip. (e and f) Posterior interosseous artery flap appeared to be of questionable viability intraoperatively but had partial pressure of oxygen of 210 at distal tip, 212 at middle part and 190 at proximal part. Post-operative follow-up showing complete survival of the flap

period (34/235) and Group 2 – all points that remained healthy in post-operative period (201/235).

Values of the pO_2 in dead flap points and alive flap points were compared with their corresponding control (fingertips) to see for any significant difference in levels of pO_2 in two groups. Difference of mean of pO_2 ($\text{diff-}pO_2$) was calculated for each of these 235 points by subtracting pO_2 of fingertip of the same patient. This value showed the change in pO_2 levels in the flap compared to the body (fingertip).

We analysed the data for obtaining the prediction values of partial pressures which can determine the flap survival using receiver operating characteristic (ROC) analysis. [Figure 2].

RESULTS

Seven of 75 patients in study underwent two flaps while one had three skin flaps making 84 flaps in 75 patients. Table 1 shows the different types of surgically elevated flaps, along with their frequency. A total of 252 (84×3) flap points were there in 84 flaps from which blood was analysed of which 17 samples were inadequate and thus excluded.[Figure 3] Of these, 17 inadequate samples 7 were from distal, 6 from middle and 4 from proximal points of flap, thus leaving 77 distal, 78 middle and 80

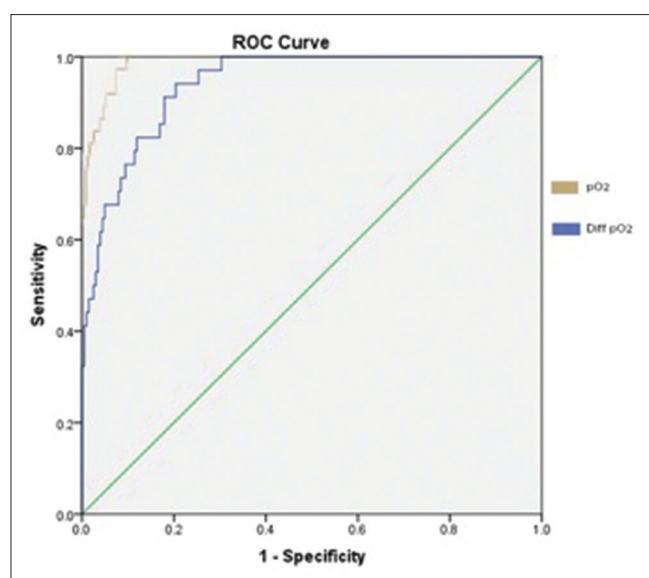


Figure 2: ROC curve of pO₂ and diff-pO₂. pO₂: Partial pressure of oxygen, diff-pO₂: Difference of mean of partial pressure of oxygen, ROC: Receiver operating characteristic

Table 1: Type of surgically elevated flaps

Flaps	Frequency
Abdominal	2
Cross leg	2
Gluteal rotation advancement	2
Reverse sural	12
Deltpectoral	5
Free flaps	2
Post-expander	10
Leg fasciocutaneous	4
Flag flap	1
Forehead flap	3
Musculocutaneous gastrocnemius	1
Groin	15
Hypogastric	1
Latissimus dorsi flap	2
Lateral calcaneal artery	1
Perforator	9
Paravertebral flap	1
Rotation flap back	2
Nasolabial flap	1
Preputial flap	1
Scalp rotation	2
Post-auricular flap	1
Tensor Fascia Lata flap	1
Pedicled tram	1
Tube flap for auricle	2
Total	84

proximal flap points to be evaluated making a total of 235 flap points. Mean (standard deviation [SD]) pO₂ of distal, middle and proximal points of flaps was 100.5 (45.59), 126.6 (47.22) and 143.1 (38.57) mmHg, respectively. Mean (SD) pO₂ from finger was 166.6 (29.96) mmHg.

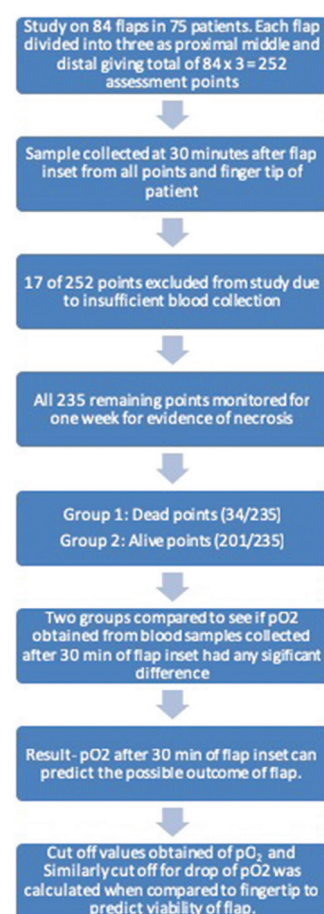


Figure 3: Consort flow chart of the study. pO₂: Partial pressure of oxygen

Sixty out of 84 flaps remained healthy while 24 developed variable degrees of necrosis. Two flaps showed necrosis of more than two-third of the flap; six showed one-third to two-third flap necrosis while 16 showed less than one-third flap necrosis.

Descriptive statistics of pO₂ from these fingertip samples is given in Table 2. Data were checked for distribution using Shapiro–Wilk test and were not found to be normally distributed, so pO₂ at fingertip in both groups was analysed using non-parametric independent samples Mann–Whitney U-test. We observed no difference between pO₂ of both the groups with mean (SD) finger pO₂ of 158.6 (30.06) mmHg in the dead and 167.9 (29.81) mmHg in the alive group [Figure 4] with ($P = 0.56$). Thus, both the groups were comparable, and there was no confounding based on the patient's oxygen levels, as assessed from the fingertip pO₂.

Oxygen levels

pO₂ in flap points (flap pO₂) half an hour after elevation was found to be lower in the dead/ischemic flaps points, compared to the flap points which remained healthy in

the post-operative period. Mean (SD) of flap pO₂ for the dead flap points was 49.4 mmHg (SD: 14.61) as compared to 134.9 mmHg (SD: 38.99) for the alive flap point group.

Independent samples *t*-test (normally distributed data for flap pO₂) showed that the two groups had significantly different pO₂ in the flap points when comparing the two groups with $P = 0.005$. ROC curve was plotted [Figure 2] and was used to find the sensitivity and specificity at different levels of pO₂ as shown in Table 3. Applying the Youden index, a cut-off value of pO₂ <86.3 mmHg was calculated with a sensitivity of 100% and specificity of 89.05%. Table 4 shows a 2 × 2 table taking cut-off value of pO₂ <86.3 mmHg. The positive predictive value at this level is 60.71 and the negative predictive value is 100%. We infer from the above that if capillary blood drawn from the flap points shows pO₂ <86.3 mmHg, it would mean that there is a 60.71% chance that the flap will show evidence of necrosis. If the value obtained is >86.3, there is a 100% chance that the flap points will be healthy as negative predictive value is 100%. From the various other cut-offs on ROC curve, as shown in Table 3, we can see that at a value of <49.78, there is a 100% chance of flap failure, as at this value, the specificity of the test is 100%.

Difference of oxygen level from fingertip (difference of mean of partial pressure of oxygen)

The difference/fall in pO₂ was calculated by subtracting flap pO₂ from finger pO₂. These values were found to be normally distributed and were compared statistically and *P* value was calculated to see for any statistical difference.

Diff-pO₂ was found to be higher in the Group 1 (dead/ischemic flap points) compared to Group 2 (alive/healthy flap points).

Mean (SD) value of diff-pO₂ from the dead flap points was 109.3 mmHg (SD: 28.03) compared to 33.1 mmHg (SD: 41.02) in the alive/healthy flap point group [Figure 4].

Independent samples *t*-test was used (normal distribution) to see for any difference which showed that the two groups were significantly different with $P = 0.000$.

ROC curve was plotted for diff-pO₂ [Figure 2] and was used to calculate sensitivity and specificity at different levels of diff-pO₂ as shown in Table 3. Applying the Youden index, a cut-off value of >68.5 was calculated

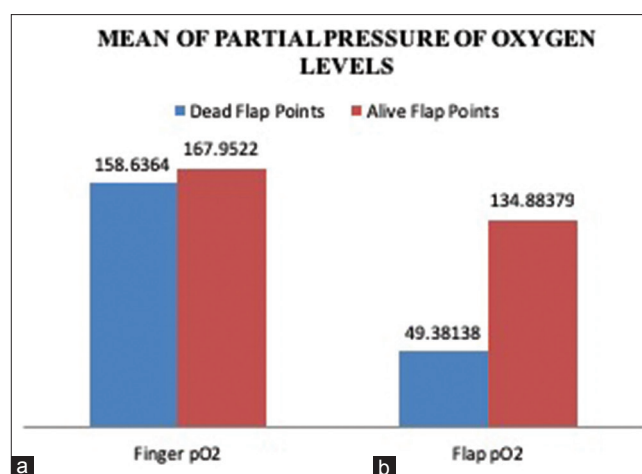


Figure 4: Similar values of mean pO₂ of finger but significantly different values of flap pO₂ when compared between dead and alive groups (a); diff-pO₂ between finger and flap is much higher if flap points necrose verses if it survives (b). Diff-pO₂: Difference of mean of partial pressure of oxygen, pO₂: Partial pressure of oxygen

Table 2: Descriptive statistics of partial pressure of oxygen from fingertip and flap points

pO ₂	n	Minimum	Maximum	Mean±SD
Finger pO ₂	235	66.90	232.49	166.60±29.97
Flap pO ₂	235	19.3	250.47	122.51±47.31

SD: Standard deviation, pO₂: Partial pressure of oxygen

with a sensitivity of 94.12% and a specificity of 79.60%. Table 4 shows a 2 × 2 table taking cut-off value of drop of oxygen >68.5 mmHg.

This implies that if diff-pO₂ is >68.5 mmHg, there is a 43.84% chance that the flap points will show evidence of necrosis, whereas if fall is ≤68.5 mmHg, it means that there is a 98.77% chance of healthy flap.

If the drop is ≤54.0 mmHg, then the chance of survival of flap is 100% as sensitivity and negative predictive value will be 100%, and for a drop of >127.6 mmHg, chance of flap ischemia is 100% as specificity and positive predictive value will be 100% as shown in Table 3.

DISCUSSION

pO₂ has been used in various studies to monitor the blood flow to a flap. Various methods such as Clark-type microcatheter,^[1] modified Clark electrode,^[2] transcutaneous polarographic measurements of oxygen developed by Huch and Lubbers,^[3] Licox catheter pO₂ micropore instrument,^[4] optochemical and oxygen-sensing electrode (oxygen optode inner space),^[5] dynamic phosphorescence imaging using luminescence lifetime imaging,^[6] and many more have been used in

Table 3: Sensitivity and specificity of partial pressure of oxygen and difference of mean of partial pressure of oxygen at different levels

pO₂			Diff-pO₂		
Levels of pO₂	Corresponding sensitivity	Corresponding specificity	Levels of diff-pO₂	Corresponding sensitivity	Corresponding specificity
<19.3	0.00	100.00	≥-127.1	100.00	0.00
≤49.78	61.76	100.00	>54.011	100.00	69.65
≤49.8	61.76	99.50	>54.666	97.06	69.65
≤50.47	64.71	99.50	>60.2	97.06	74.63
≤50.7	64.71	99.00	>60.5	94.12	74.63
≤54.64	73.53	99.00	>68.503	94.12	79.60
≤54.9	73.53	98.51	>68.9	91.18	79.60
≤54.91	76.47	98.51	>73.3	91.18	82.09
≤55.9	76.47	98.01	>75.667	85.29	82.09
≤56.37	79.41	98.01	>76.8	85.29	83.08
≤56.5	79.41	97.01	>78.3	82.35	83.08
≤58.3	82.35	97.01	>85.013	82.35	88.06
≤63.1	82.35	95.52	>85.149	79.41	88.06
≤63.307	85.29	95.52	>86.5	79.41	88.56
≤64.9	85.29	94.53	>86.513	76.47	88.56
≤67.341	88.24	94.53	>87.509	76.47	90.55
≤67.691	88.24	94.03	>88.369	73.53	90.55
≤68.494	91.18	94.03	>91.6	73.53	91.54
≤76.922	91.18	91.54	>91.889	70.59	91.54
≤79.8	97.06	91.54	>92.2	70.59	92.04
≤86.253	97.06	89.05	>92.7	67.65	92.04
≤86.3	100.00	89.05	>95.841	67.65	95.02
≤250.465	100.00	0.00	>96.484	64.71	95.02
			>97.195	64.71	95.52
			>98.2	61.76	95.52
			>100.25	61.76	96.02
			>100.746	58.82	96.02
			>103.79	58.82	96.52
			>107.7	52.94	96.52
			>107.95	52.94	97.01
			>108.8	50.00	97.01
			>110.7	50.00	97.51
			>111.217	47.06	97.51
			>112.7	47.06	98.51
			>113.612	44.12	98.51
			>113.8	44.12	99.00
			>114.2	41.18	99.00
			>114.6	41.18	99.50
			>119.199	32.35	99.50
			>127.6	32.35	100.00
			>180.116	0.00	100.00

Values highlighted in yellow are the recommended cut-off values. Diff-pO₂: Difference of mean of partial pressure of oxygen, pO₂: Partial pressure of oxygen

different studies to assess tissue oxygen levels. All of these methods were able to identify compromise of any perfusion, earlier than the clinical changes appeared.^[7] In this study, we have used commonly available 1-ml syringes and blood gas analyser to find the pO₂ of a flap. We calculated a cut-off value of flap pO₂ with high sensitivity and specificity, which allows us to predict the outcome of the flap. This study is unique in many ways; it can predict the outcome intraoperatively and

thus allows a surgeon to take measures to revise their flap, if needed. It is much cheaper and readily available to a clinician compared to other machines using pO₂ to monitor flap postoperatively. To the best of our knowledge, no study has been done using this method to assess pO₂ and predict flap survival.

Using the pO₂ values obtained in the flaps that survived and underwent necrosis, a cut-off of pO₂ was calculated.

Table 4: Results at cut-off value of partial pressure of oxygen of <86.3 mmHg and difference of partial pressure of oxygen at cut-off of >68.5 mmHg

Details	Flap point necrosed		Flap points healthy	Total
pO ₂ <86.3 mmHg	34		22	56
pO ₂ >86.3 mmHg	0		179	179
Total	34		201	
Diff pO ₂ >68.5	32		41	73
Diff pO ₂ <68.5	2		160	162
Total	34		201	
Details	pO ₂ <86.3 mmHg (%)		Diff pO ₂ >68.5 (%)	
Sensitivity	100	89.72-100	94	80.32-99.28
Specificity	89.05	83.90-93.01	79.60	73.36-84.95
AUC	0.95	0.91-0.97	0.87	0.82-0.91
Positive likelihood ratio	9.14	6.16-13.55	4.61	3.47-6.14
Negative likelihood ratio	0		0.07	0.02-0.28
Disease prevalence	14.47	10.23-19.63	14.47	10.23-19.63
Positive predictive value	60.71	46.75-73.50	43.84	32.24-55.95
Negative predictive value	100.00	97.96-100.00	98.77	95.61-99.85

AUC: Area under the curve, Diff-pO₂: Difference of mean of partial pressure of oxygen, pO₂: Partial pressure of oxygen

Comparing with other studies, values obtained by our study show that mean (SD) pO₂ of the group comprising healthy flaps is 134.9 (38.99) mmHg, whereas mean (SD) pO₂ of the group of flaps that did not survive is 49.3 (14.61) mmHg. A study by Geis *et al.* on nine free flaps showed the mean pO₂ of surviving flap, 4 h postoperatively to be 53 ± 0.7 mmHg. One flap was re-explored to improve flap perfusion, which had pO₂ below 10 mmHg.^[6] Another study by Schrey *et al.* assessed tissue oxygen levels of flaps which remained healthy and found a mean of 46.8 mmHg (SD: 17.0).^[8]

The variation obtained compared to these studies can be explained from the following points:

1. Fraction of FiO₂ in our patients was much higher (50%) which alters the oxygen level at tissue. It was observed that an increase in FiO₂ causes an increase in saturation, as well as in pO₂. This explains the reason for the higher values of pO₂ obtained in our study, compared to various other studies in which the measurements were done at room air (FiO₂ of 21%)
2. In our study, samples were collected earlier (after 30 min of flap inset), than other studies, where sampling was done later in post-operative periods, sometimes up to 2–3 days. A study by Kamolz *et al.* shows how the level of pO₂ changes with time. Decrease of the ptiO₂ levels was noted in all the patients during the 1st few min, until a more or less stable level was reached. At the time of weaning off, the ptiO₂ values decreased once again. After approximately 30 min, an almost stable but reduced ptiO₂ level was re-established (34.6 ± 10.9 mmHg). During the next days, Kamolz *et al.* observed a more

or less constant but reduced level. These values from the 2nd-day onwards were lower than the mean values of the 1st day. The mean value for all flaps was 23.1 ± 6.5 mmHg.^[9] It is the maximum initially and then drops to obtain a plateau by days 2–3. In another study by Geis *et al.* during the first 4 h, almost constant transcutaneous oxygen partial pressure (ptcO₂) values were detected (53 ± 0.7 mmHg). During the following time intervals, ptcO₂ values decreased and reached a more or less constant level after approximately 12 h. The mean ptcO₂ decreased from 53 ± 0.7 mmHg to 39 ± 1.0 mmHg.^[6]

3. Most studies in literature are on free flaps whereas bulk of our samples was pedicled flaps. In free flaps, due to complete absence of blood flow, the pO₂ is found to be much lower compared to pedicled, as in later, there is only a decreased flow and very rarely a complete absence of blood flow. It was seen in a study that the value of oxygen gradually decreased from base to periphery of a pedicled flap.^[10] This can be a reason for higher mean value obtained in our study of the necrosed flaps which might be having low blood flow initially at 30 min postoperatively, instead of absent blood flow seen in other studies with free flaps.^[6,8] This explains the difference of values obtained, as in our study, sample was taken intraoperatively after 30 min of flap elevation itself.

In this study, we also took sample from the fingertip as control. We calculated the difference or drop of oxygen level in capillary blood of flap by subtracting flap pO₂ value from the fingertip pO₂ value. Using this, we have also calculated a cut-off value for drop of flap pO₂ level as

compared to the fingertip, i.e. diff-pO₂, which will predict the flap survival/failure. In this way, we were able to reduce the error due to mixing of oxygen from air in the samples. These values were also found to be significantly different statistically in the two groups, i.e. the dead and the alive flap groups.

While most of the studies have evaluated trends of pO₂ to monitor flaps, but we have tried to predict the outcome by intraoperatively analysing single value of pO₂. We tested flap's inherent blood supply or factors affecting it at time of elevation or during movement and not the factors that affect flap survival in post-operative period. Using this study as a guideline, a clinician can take the sample from the edge of a flap intraoperatively after 30 min of flap inset, as shown in materials and methods. It is important to keep the FiO₂ at 50% while collecting samples, otherwise values will change as explained above. Similar samples should be taken from the fingertip of the same patient at the same time while flap sample is being collected to act as control and to calculate diff-pO₂. The sample should be assessed using a normally available blood gas analyser used in hospitals to obtain arterial blood gases.

The results can be interpreted as discussed above. With this, the surgeon can predict the survival of that part of the flap on the table. Surgeon can take remedial actions if flap pO₂ is ≤ 86.3 mmHg or diff-pO₂ is >68.5 mmHg as chances of failure are very high beyond these levels.

Limitations of this study include only two free flaps. FiO₂ needs to be fixed at 50% to use this cut-off value, which is difficult in patients of regional anaesthesia. In such cases, venturi mask can be used to deliver FiO₂ of nearly 50%. Role of heparin spray is not well established and reference based we are using it by our own experience. Points with insufficient sample from the flap could not be analysed and were excluded from the study. These are points that are most likely to necrose but were excluded from study. Demographic data of coexisting illnesses such as lung disease and smoking were not noted which can be a confounding factor in the study. Further studies are required to get cut-off values at lower FiO₂. Method of collection of blood sample needs to further improvise to decrease the erroneous readings. In this study, instead of a whole flap, points are considered as individual reading, whereas in reality, we need the values for a flap, not points, especially in cases of free flaps. In case of

pedicled flaps, as in our study, points from where the values are below cut-off might be the areas that might necrose, whereas the places where the pO₂ is higher than cut-off most likely will survive.

CONCLUSIONS

From this study, we can conclude that pO₂, measured using capillary blood gas analysis in skin flaps, is helpful in predicting the skin flap viability. Similarly, the difference in pO₂ measured using capillary blood gas analysis between skin flaps and fingertip can be used to predict the chances of skin flap failure.

The cut-off value calculated in this study can be useful for a surgeon to take actions intraoperatively; in case, the values obtained for flap pO₂ are lower than calculated cut-off of <86.3 mmHg or diff-pO₂ is >68.5 mmHg.

We thus suggest that, in case any point on flap shows values <86.3 mmHg, measures should be taken immediately to revise the flap as otherwise it has high chances (60.71%) of failure. Similarly, if the difference from fingertip is >68.5 mmHg, measures to improve flap supply need to be taken to save the flap.

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Nil.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Driemel O, Oberfahrenheit I, Hakim SG, Kosmehl H, Pistner H. Intra- and postoperative monitoring of transplanted flaps. Measurement of the partial pressure of oxygen in tissue. *Mund Kiefer Gesichtschir* 2004;8:361-8.
2. Arricivita I. Transcutaneous measurement of arterial pO₂ and local perfusion using a modified Clark electrode. *Rev Enferm* 1982;5:67-9.
3. Knotte G, Bohmert H. Determination of the viability of skin regions in danger of necrosis by means of transcutaneous polarographic measurement of oxygen pressure. *Fortschr Med* 1977;95:640-4.
4. Kamolz LP, Giovanoli P, Haslik W, Koller R, Frey M. Continuous free-flap monitoring with tissue-oxygen measurements: Three-year experience. *J Reconstr Microsurg* 2002;18:487-91.
5. Golde AR, Mahoney JL. The oxygen optode: An improved

- method of assessing flap blood flow and viability. *J Otolaryngol* 1994;23:138-44.
6. Geis S, Schreml S, Lamby P, Obed A, Jung EM, Nerlich M, *et al.* Postoperative assessment of free skin flap viability by transcutaneous pO₂ measurement using dynamic phosphorescence imaging. *Clin Hemorheol Microcirc* 2009;43:11-8.
 7. Vikhriev BS, Kichemasov SK, Kochish AI, Matveenko AV, Skvortsov IR, Sokolov VA, *et al.* Changes in oxygen and carbon dioxide tension in skin capillaries as an indicator of the status of blood supply of compound skin flaps. *Vestn Khir Im I I Grek* 1989;142:54-9.
 8. Schrey AR, Kinnunen IA, Grénman RA, Minn HR, Aitasalo KM. Monitoring microvascular free flaps with tissue oxygen measurement and PET. *Eur Arch Otorhinolaryngol* 2008;265 Suppl 1:S105-13.
 9. Kamolz LP, Schrögenderfer KF, Giovanoli P, Koller R, Frey M. Continuous free-flap monitoring with tissue-oxygen measurements: Experiences of the last years. *Handchir Mikrochir Plast Chir* 2002;34:195-200.
 10. Wolff KD, Marks C, Uekermann B, Specht M, Frank KH. Monitoring of flaps by measurement of intracapillary haemoglobin oxygenation with EMPHO II: Experimental and clinical study. *Br J Oral Maxillofac Surg* 1996;34:524-9.