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Monitoring of skeletal muscle oxygenation using near-infrared spectroscopy during abdominal aortic surgery

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Abstract
Purpose. To examine the utility of near-infrared spectroscopy (NIRS) in assessing lower-leg perfusion, NIRS was performed on the calf muscles of patients who underwent abdominal aortic surgery.
Methods. Thirty patients undergoing elective infrarenal abdominal aortic surgery for abdominal aortic aneurysm (AAA group; $n = 16$) and aorto-occlusive disease (AOD group; $n = 14$) were studied. Before induction of anesthesia, NIRS probes were placed over both calf muscles, and muscle oxygen saturation (S_{tO2}) was continuously monitored throughout the surgery.
Results. The preoperative S_{tO2} value was significantly lower in the AOD group (57.0 ± 11.2%) than in the AAA group (68.7 ± 7.0%). In both groups, S_{tO2} significantly decreased after aortic cross-clamping; the maximal ischemic value of S_{tO2} in the AAA group (17.8 ± 7.2%) was significantly lower than that in the AOD group (46.7 ± 17.1%). The time taken to reach maximal ischemia was significantly longer in the AAA group (30 ± 12 min) than in the AOD group (19 ± 12 min). After release of the aortic clamp, the decreased S_{tO2} returned to the preoperative level in the AAA group, whereas it increased above the preoperative value in the AOD group.
Conclusion. NIRS performed on the calf muscles is a useful method for assessing the changes in lower-leg perfusion during and after abdominal aortic surgery.

Key words Monitoring · Near-infrared spectroscopy · Oxygen saturation · Skeletal muscle · Aortic surgery

Introduction

Near-infrared spectroscopy (NIRS), a noninvasive method of monitoring tissue oxygen saturation, has been used to assess skeletal muscle oxygen delivery [1–4]. NIRS monitoring of skeletal muscle oxygenation is useful in detecting acute lower-extremity ischemia following vascular surgical procedures [5]. Previously, Eiberg et al. [6] found that NIRS performed on the dorsum of the foot was appropriate for perioperative monitoring during infrainguinal bypass surgery. The clinical significance of NIRS measurements, however, has not been fully evaluated during major vascular surgery. In this study, we applied NIRS technique to the calf muscle in surgical patients with vascular disease and examined the utility of this technique in monitoring the changes in lower-leg perfusion during reconstructive surgery.

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Materials and methods

After obtaining approval from the institutional Ethics Committee and informed consent from each patient, we studied 30 patients (ASA physical status 1 or 2) undergoing elective infrarenal abdominal aortic surgery for abdominal aortic aneurysm (AAA group; $n = 16$) and aorto-occlusive disease (AOD group; $n = 14$).

All patients were premedicated with midazolam 2–3 mg i.m. 30 min before induction of anesthesia. Lead 2 of the electrocardiogram, pulse oximetry, noninvasive blood pressure, and rectal temperature were monitored. A radial artery catheter was inserted for continuous monitoring of arterial pressure and blood sampling. NIRS measurements were made using a continuous light source, dual wave-length spectroscopy (INVOS 3100, Somanetics, MI, USA). The instrument includes a sensor and a central unit containing a display and a computer. The probe to be placed on the patient consists of two near-infrared diodes used as light sources (735 and 810 nm) and two silicon light detectors. The difference between light absorption at 735 and 810 nm is used to assess hemoglobin-myoglobin oxygen saturation [6]. Two NIRS probes were used for each patient; each probe was placed on the calf muscle 10–12 cm from the knee, and muscle oxygen saturation (S_{tO2}) was bilaterally measured before and during surgery.

Before induction of anesthesia, each patient received a thoracic epidural catheter through the T10–12 interspace; a test dose of 2ml of 1.5% lidocaine with 1:200000 epinephrine was followed by a bolus of 8–10ml of 1.5% lidocaine. General anesthesia was induced with $3\,mg\cdot kg^{-1}$ thiamylal and $0.1\,mg\cdot kg^{-1}$ vecuronium. After tracheal intubation, anesthesia was maintained with 1%–2% end-tidal sevoflurane, 67% nitrous oxide in oxygen, and intermittent epidural administration of 1.5% lidocaine. Systolic blood pressure elevation in excess of 20% of baseline was controlled with nitroglycerin infusion ($0.2–0.6\,\mu g\cdot kg^{-1}\cdot min^{-1}$).

All data are expressed as means ± SD. Differences between the groups were tested by using one-way analysis of variance (ANOVA) with post hoc analysis by Fisher's protected least significant difference (PLSD) test and the chi-square test. Within-group comparison of S_{tO2} was made by using a repeated-measures ANOVA with post hoc analysis by Fisher's PLSD test. *P* values <0.05 were considered to indicate a significant difference.

Results

The demographic and procedural data of the patients in both groups are shown in Table 1. The two groups were comparable with regard to sex, age, weight, and height. The duration of aortic cross-clamping was significantly longer in the AAA group than in the AOD group.

Changes in S_{tO2} are shown in Fig. 1. The preoperative S_{tO2} value in the AOD group (57.0 ± 11.2%) was significantly lower than that in the AAA group (68.7 ± 7.0%). Neither epidural nor general anesthesia affected the S_{tO2} values throughout the study period. In both groups, S_{tO2} significantly decreased after aortic cross-clamping; the maximal ischemic value of S_{tO2} in the AAA group (17.8 ± 7.2%) was significantly lower than that in the AOD group (46.7 ± 17.1%). The time taken to reach maximal ischemia was significantly longer in the AAA group (30 ± 12min) than in the AOD group (19 ± 12min). Five minutes after aortic clamp release, the decreased S_{tO2} returned to the preoperative level in both the AAA (68.0 ± 9.0%) and the AOD (60.1 ± 12.2%) group. At the end of surgery, S_{tO2} remained at baseline level in the AAA group (65.5 ± 10.7%), whereas it significantly increased above the preoperative value in the AOD group (68.7 ± 11.2%). The postoperative course was uneventful, and no serious complications were found in either group.

Table 1. Patient demographic data[a]

Characteristic	AAA group	AOD group
Sex (M/F)	12/4	12/2
Age (yr)	72 ± 10	68 ± 9
Height (cm)	159 ± 4	157 ± 8
Weight (kg)	64 ± 4	68 ± 9
Aortic cross-clamp time (min)	88 ± 33	58 ± 29*

[a] Plus-minus values are means ± SD. AAA, Abdominal aortic aneurysm; AOD, aorto-occlusive disease
* $P < 0.05$ vs AAA group

Discussion

We found that aortic cross-clamping produced a greater reduction in S_{tO2} in the AAA group than in the AOD group. The decreased S_{tO2} in both groups returned to the preoperative level during the reperfusion period. The AOD group showed a significant increase in S_{tO2} above the preoperative value after surgery, reflecting the success of revascularization. Thus, the calf muscle oxygen saturation monitored by NIRS correlated well with lower-leg perfusion changes resulting from surgical procedures.

NIRS has been used to estimate changes in tissue oxygenation of human skeletal muscles in a variety of clinical conditions, such as heart failure [2], peripheral vascular disease [3,4], and lithotomy position [7]. Recently, the technique has been shown to be useful in

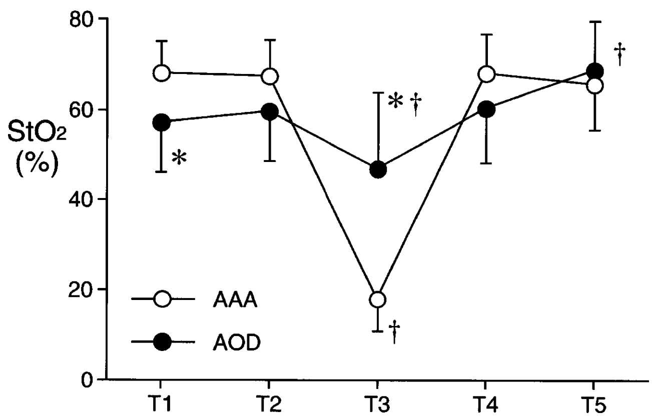

Fig. 1. Changes in calf muscle oxygen saturation measured by near-infrared spectroscopy during abdominal aortic surgery. *AAA*, Abdominal aortic aneurysm; *AOD*, aorto-occlusive disease; *StO_2* (%), calf muscle oxygen saturation; *T1*, before induction of anesthesia; *T2*, 5min before aortic cross-clamping; *T3*, maximal ischemic point after aortic cross-clamping (30 ± 12min in the AAA group; 19 ± 12min in the AOD group); *T4*, 5min after aortic cross-clamp release; *T5*, end of surgery. Values are means ± SD. *$P < 0.05$ versus AAA group; †$P < 0.05$ versus values before induction of anesthesia

monitoring lower extremity perfusion of trauma patients with compartment syndrome [8,9]. Giannotti et al. [9] found that decreased NIRS-derived tissue oxygen saturation in the leg compartment was usually normalized after fasciotomy.

The changes in S_{tO2} observed in this study are similar to those reported by Eiberg et al. [6]. They performed NIRS on the dorsum of the foot in patients who underwent infrainguinal bypass surgery, and found a correlation between tissue saturation and hemodynamic events such as proximal clamping and reperfusion. In their study, the same type of instrument as that used in this study was applied. Recently, we detected intraoperative acute lower-extremity ischemia by unexpected calf muscle oxygen desaturation monitored by NIRS during abdominal vascular surgery [5]. These findings indicate that NIRS is a useful tool for assessing the effect of surgical procedures on muscle perfusion.

Aortic cross-clamping was associated with a greater reduction in S_{tO2} in the AAA group compared than the AOD group in this study. Although we did not assess the degree of collateral vascularization preoperatively, this finding can be attributed to the difference in the extent of periaortic vascular collateralization between the two groups [10,11]. The collateral circulation associated with AOD may permit continuous lower-extremity perfusion during the cross-clamping period. Our results suggest that total or nearly total ischemia may develop in AAA patients with no or little collateral circulation within about 30 min after aortic cross-clamping. The mechanism of the difference between the two groups in the time taken to reach maximal ischemia is unclear.

The preoperative decreased S_{tO2} in the AOD group as compared with that in the AAA group may be due to chronic lower-extremity ischemia. In the AOD group, the success of revascularization was detected by an immediate postoperative increase in S_{tO2} above the preoperative value. NIRS showed a rapid response to perfusion changes resulting from surgical procedures in both groups.

NIRS has been shown to be a valuable indicator of oxygen delivery and utilization in healthy muscle. Hampson and Piantadosi [1] demonstrated that the technique was significantly more sensitive than transcutaneous oximetry in indicating tissue oxygen availability. Recently, NIRS was used to monitor oxygen consumption in the calf muscles, showing a reduced oxygen consumption in patients with peripheral vascular disease [3].

When transcutaneous NIRS is used to quantify muscular oxyhemoglobin and deoxyhemoglobin, the assumption must be made that skin and subcutaneous fat contribute a negligible amount to the signal. Piantadosi et al. [12] showed that double-thickness skin folds contributed less than 5% to the NIRS signal of transilluminated human forearm. A second assumption has been that myoglobin has identical absorption spectra to hemoglobin, and that the two species cannot be separated by NIRS [12]. Seiyama et al. [13], however, found that myoglobin contributed less than 10% to the NIRS signal in skeletal muscle. Thus, the resultant error from these assumptions is likely to be minimal.

The instrument used has two major advantages: the simplicity of the sensor application and the feasibility of recording tissue saturation without additional calculations. These two features are suitable for clinical use of NIRS in routine perioperative patient monitoring.

In summary, we monitored calf muscle oxygen saturation using NIRS in patients who underwent abdominal aortic surgery. A correlation was found between the changes in tissue oxygen saturation and the surgical procedures. The results indicate that NIRS monitoring of skeletal muscle can be applied to assess the efficacy of surgical treatment of major vascular disease.

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