Intraoperative Colon Mucosal Oxygen Saturation During Aortic Surgery

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Background. Colonic ischemia after aortic reconstruction is a devastating complication with high mortality rates. This study evaluates whether Colon Mucosal Oxygen Saturation (CMOS) correlates with colon ischemia during aortic surgery.

Materials and methods. Aortic reconstruction was performed in 25 patients, using a spectrophotometer probe that was inserted in each patient's rectum before the surgical procedure. Continuous CMOS, buccal mucosal oxygen saturation, systemic mean arterial pressure, heart rate, pulse oximetry, and pivotal intraoperative events were collected.

Results. Endovascular aneurysm repair (EVAR) was performed in 20 and open repair in 5 patients with a mean age of 75 ± 10 (±SE) years. CMOS reliably decreased in EVAR from a baseline of 56% ± 8% to 26 ± 17% (P < 0.0001) during infrarenal aortic balloon occlusion and femoral arterial sheath placement. CMOS similarly decreased during open repair from 56% ± 9% to 15 ± 19% (P < 0.0001) when the infrarenal aorta and iliac arteries were clamped. When aortic circulation was restored in both EVAR and open surgery, CMOS returned to baseline values 56.5 ± 10% (P = 0.81). Mean recovery time in CMOS after an aortic intervention was 6.4 ± 3.3 min. Simultaneous buccal mucosal oxygen saturation was stable (82% ± 6%) during aortic manipulation but would fall significantly during active bleeding. There were no device related CMOS measurement complications.

Conclusions. Intra-operative CMOS is a sensitive measure of colon ischemia where intraoperative events correlated well with changes in mucosal oxygen saturation. Transient changes demonstrate no problem. However, persistently low CMOS suggests colon ischemia, thus providing an opportunity to revascularize the inferior mesenteric artery or hypogastric arteries to prevent colon infarction. © 2006 Elsevier Inc. All rights reserved.

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INTRODUCTION

Colon ischemia is a rare but devastating complication after aortic reconstruction. The reported cases range from 2 to 30% [1] after aortic reconstruction where patients after repair of a ruptured abdominal aortic aneurysm (AAA) and aortic reconstruction for aorto-iliac occlusive disease were most likely to have colon ischemia [2]. When ischemic colitis was diagnosed, bowel resection with fecal diversion occurred in 65% with an overall mortality of 54 to 89% [3]. To prevent colon ischemia, the need for in line flow of the internal iliac arteries as well as preservation of the inferior mesenteric artery has been described [4]. However, these principles have recently been challenged because of the more prevalent endovascular techniques in aortic reconstruction. Coil embolization of unilateral or bilateral internal iliac arteries along with covering the inferior mesenteric artery during endovascular aneurysm repair (EVAR) have been described as relatively safe [5–7]. The need for these procedures have evolved because 20% of AAAs have an associated common iliac artery aneurysm and the aortic stent graft not infrequently needs to
cover one or both internal iliac arteries and be extended into the external iliac artery to obtain adequate fixation [1].

Techniques described in the past to assess for colon and pelvic ischemia such as intravenous fluorescein [8], intraoperative tissue oximetry [9], and the assessment of distal stump pressures of the inferior mesenteric artery [10] are only useful during an open AAA repair and have limited utility during an EVAR procedure. The routine use of colonoscopy after high-risk aortic surgery has also been described to prevent colon ischemia in the perioperative period [11]. To date, a universal technique to measure colon ischemia during aortic reconstruction has not yet been accepted.

In this study, a visible light colon mucosal oxygen saturation probe was used to assess whether changes in colon perfusion correlated well with intra-operative surgical changes during aortic reconstruction.

MATERIALS AND METHODS

Visible Light Spectroscopy Oximeter

For this study, a visible light spectroscopy (VLS) oximeter was used [12] (T-Stat, model 303; Spectros Corp., Portola Valley, CA). Briefly, this oximeter emits white light from a probe placed on, in, or near tissue collecting any light returning the probe from the tissue. The collected light is separated by wavelength into 2,048 bins, measured simultaneously. For oximetry, the blue-to-yellow (476–584 nm) portion of the visible spectrum is used to solve for light scattering and for the concentration of each of the major forms of hemoglobin (deoxyhemoglobin, oxyhemoglobin) using first differential spectroscopy and least squares fitting to known hemoglobin spectra. Tissue hemoglobin is estimated as (deoxyhemoglobin + oxyhemoglobin), and the tissue hemoglobin oxygen saturation (StO₂) is determined as the (concentration of oxyhemoglobin)/(concentration of deoxyhemoglobin + concentration of oxyhemoglobin). The oximetry measurements are continuous, with each measurement typically requiring 5 to 50 ms, depending on the intensity of the reflected light. The data were continuously saved on an internal hard drive within the VLS oximeter (Fig. 1).
Probes

There were two probes used in this study: a clip-on surface probe for placement on the buccal mucosa and a flexible rectal probe (12 mm diameter × 20 cm) to measure colon mucosal oxygen saturations (Fig. 2).

Human Study Methods

A prospective evaluation of patients undergoing aortic reconstruction was performed under institutional review board approval at Stanford University Hospital, University of California, Davis Medical Center, and the Sacramento Veterans Affairs Medical Center.

After informed written consent was obtained, the patients underwent general anesthesia for planned aortic reconstruction. Systemic mean arterial pressure, heart rate, and pulse oximetry values were obtained throughout the operative procedure. After adequate general anesthesia was established a clip-on surface probe was placed on the buccal mucosa of the patient and a flexible rectal probe was placed 10 to 20 cm past the anal sphincter (Fig. 3). Pivotal intraoperative events were also recorded. Based on previous studies performed in human subjects during colonoscopy, colon ischemia was defined as a decrease of over 40% in CMOS [13].

Twenty-five patient CMOS levels and buccal mucosal oxygen saturation levels were obtained during aortic reconstruction: 20 patients underwent EVAR and five patients underwent open aortic reconstruction.

Statistics

CMOS during events such as balloon occlusion or aortic clamping were compared using a Student’s two-tailed t test. A difference was considered significant for a P value <0.05.

RESULTS

The average age of patients enrolled was 74.7 ± 10 years. Twenty-two patients were males and three were females. During aortic reconstruction, pivotal endovascular, and surgical maneuvers caused significant changes in the CMOS. For the EVAR patients, the baseline CMOS values were 55.8 ± 8.0%. The values fell quickly at times of diagnostic aortograms and when a proximal balloon was placed in the infrarenal aorta. The CMOS values dropped to 25.7 ± 17.4%, significantly different from baseline (P < 0.001) and when the balloon was deflated or at the completion of the aortogram, the CMOS values returned to baseline values of 56.5 ± 10.3% (p = NS) (Fig. 4). Similarly, during open aortic reconstruction, baseline values were 56.0 ± 9.2% that then would fall significantly to 14.8 ± 18.6 (P < 0.0001) and would return to baseline values 55.7 ± 5.7% (P = NS) (Fig. 5). Relative changes in CMOS values for each individual patient during surgical intervention, demonstrate appropriate changes during key surgical maneuvers (Fig. 6).

Buccal mucosal values were also obtained simultaneously to confirm CMOS were truly measuring local events in the aorta and pelvic circulation. The buccal mucosal values remained unchanged during all pivotal endovascular and surgical maneuvers at 82% ± 6%. However, on a few occasions (two patients) when there was hypotension and intraoperative bleeding, there was a detectable fall in the buccal mucosal values to 64% ± 5%.

Because the aortic balloon and aortic clamps were placed in the infrarenal location the CMOS values would slowly return to baseline values, presumable collateralization from the celiac and the superior mesenteric arterial system. The average time to recovery was 6.4 ± 3.3 min.

At the conclusion of the aortic reconstruction, 22 patients had a return to baseline values. No patient with return to baseline values had problems of colon ischemia postoperatively (no false negatives). Two other patients (EVAR) were identified to have a very slow return to baseline values and were subsequently

FIG. 2. (A) The clip-on surface probe for placement on the buccal mucosa. (B) The flexible rectal probe which was 12 mm in diameter and 20 cm in length for placement in the rectum. (Color version of figure is available online.)
identified to have atheroembolism from stent graft deployment. These patients were observed and no immediate or long term complications were identified.

One patient (EVAR) continued to have abnormally low values and intraoperative interventions were performed. The patient was undergoing an EVAR for aneurysmal disease and had a patent inferior mesenteric artery and a unilateral common iliac artery aneurysm. The baseline CMOS value for this patient was 57%. At the conclusion of the aortic stent graft deployment, the values remained low at 5%. Despite waiting several minutes, there was no return to baseline values. At this time, an external iliac artery to ipsilateral internal iliac artery bypass was performed and the CMOS values rose to 78% at the conclusion of the internal iliac artery revascularization (Fig. 7). This patient suffered no short or long term effects from the prolonged decrease in CMOS values.

**DISCUSSION**

Colon ischemia is a well described problem after aortic reconstruction and occurs more frequently after ruptured AAAs and for aorto-iliac occlusive disease [2]. Moore had first described this problem after abdominal aortic surgery in 1954 and has been confirmed by several retrospective and prospective reports [3, 4, 14, 15].

**FIG. 3.** On the left is the cartoon of the rectal probe within the patient’s body. (A) is the probe tip seen in the cartoon on the left and the probe seen on fluoroscopy. (B) are coils placed in this patient’s left internal iliac artery. (C) is a deployed aortic stent graft. (Color version of figure is available online.)

**FIG. 4.** A graphic demonstrated in real-time the colon mucosal oxygen saturation (CMOS) levels. The Y-axis is % saturation and the X-axis is time. (A) The CMOS levels are quite depressed after the deployment of the aortic stent graft. (B) is the final release of clamps after the construction of an ipsilateral external iliac artery to internal iliac artery bypass. Note the return to baseline levels.

**FIG. 5.** The colon mucosal oxygen saturation levels at baseline, aortic balloon occlusion, and completion during EVAR. ($P < 0.001$) from baseline and aortic balloon occlusion.
Depending on the series, the risk for colon ischemia can range from 2 to 30% and once diagnosed, the mortality rate ranges from 50 to 90% [11].

From the 1980s to the 1990s quite a bit of interest was paid to preventing this devastating complication. In 1988, Ouriel and associates described a photoplethysmographic technique in 30 consecutive patients undergoing abdominal aortic reconstruction and was able to identify the loss of photoplethysmographic pulsatility with an immeasurable transcolonic oxygen saturation as suggestive of inadequate post-reconstructive colonic perfusion [16]. Sheridan and associates reported a technique using intraoperative oxygen tension measurement [9]. In 1992, the Mayo Clinic group described the selective use of intravenous fluorescein and Wood’s lamp illumination to identify whether there were areas of bowel viability after aortic reconstruction [8].

Ultimately, the most common denominators in patients with ischemic colitis after aortic surgery appear to be the ligation of a patent inferior mesenteric artery along with an occlusion or stenosis of one or both internal iliac arteries [2]. Based on this tenet, Ernst described the technique of using inferior mesenteric artery stump pressures of greater than 40 mm Hg as predictive of colon viability and performing selective ligation [10]. Seeger and associates described the routine re-implantation of a patent mesenteric artery to limit colon infarction after aortic surgery [17].

However, the essential surgical principles of preserving internal iliac arteries and inferior mesenteric artery circulation have been challenged with the increasing use of the endovascular aneurysm repair (EVAR) technique that was first introduced by Parodi and associates [18] in 1991. Several studies from independent institutions began to describe the “relatively innocuous” procedure of performing an EVAR concomitant with unilateral and bilateral hypogastric interruption [1, 5, 6]. Although preservation of both internal iliac arteries and inferior mesenteric arteries are warranted, other pelvic collateral flow should also be considered important. The preservation of the profunda femoris artery is a crucial vessel in maintaining adequate pelvic circulation after such endovascular procedures [5].

To date, many of the techniques described to assess colonic viability require laparotomy which is not feasible when EVAR is being performed. Routine colonoscopy [11] or flexible sigmoidoscopy has been suggested to make an early diagnosis after aortic reconstruction to minimize mortality and morbidity [19]. Similarly, Bjorck and associates describe a technique for pH monitoring of the sigmoid colon during and after aortic surgery (repair of ruptured AAA). However, the Bjorck group required the use of the pH monitoring for 48 h after surgery [20].

These techniques can only provide information after the aortic reconstruction has been performed but provides little information pre-emptively. We propose a technique that can predict in real time whether colon ischemia will develop.

The advantage of the visible light spectroscopy for EVAR, e.g., is that the probe can be placed in the patient’s rectum and decisions be made before endograft stent deployment or closing the abdomen. If there is a drop in values without a return to baseline values from
other collateral vessels within a 6 min time frame, then EVAR can be considered contra-indicated in patients considered high risk for colon ischemia after EVAR (patent inferior mesenteric artery with an associated common iliac artery aneurysm). The visible light spectroscopy clinical tissue oximetry is only recently coming to the forefront. The VLS relies on locally absorbed, shallow-penetrating visible light 475 to 625 nm for monitoring microvascular (capillaries) hemoglobin oxygen saturation. This, unlike pulse oximetry, is sensitive to the inadequacies of local blood flow, such as ischemia, where pulse oximetry measures hemoglobin oxygen saturation in the arterial system [12, 21]. Near infrared spectroscopy (NIRS) has also been used in other clinical applications such as the brain and leg muscle beds. The disadvantage of NIRS in the colon is that NIRS relies on large volume deeply penetrating emitted and detected using widely spaced sensors to reach internal tissues [12].

The need for a more feasible, reliable, and inexpensive method to detect pelvic ischemia is crucial to the better care of the vascular patient. With recent prospective data reporting lower immediate morbidity and mortality rates of EVAR compared with the open AAA repair [22], some investigators are suggesting that the trigger for aneurysm repair should be reduced from 5.0 to 5.5 cm for EVAR to smaller AAAs of 4.0 to 5.5 cm [23]. At present, a multicentered randomized trial is under way to evaluate whether smaller aneurysms should indeed be repaired with an aortic endograft (the Positive Impact of EndoVascular Options for Treating Aneurysms EarLy trial).

In summary, colon ischemia as well as other markers of pelvic ischemia such as erectile dysfunction, hip and buttock claudication are becoming more important factors in the decision to treat a patient with EVAR. The utilization of EVAR appears to be on the rise as the technology continues to improve and surgeons become more aggressive in coil embolizing the internal iliac artery making prospective monitoring, such as colon mucosal oxygen saturations a more important component in the overall treatment in patients with aortic disease.

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