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Determining intestinal viability by near infrared spectroscopy: A veterinary application

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Abstract

Near infrared spectroscopy (NIRS) is a convenient noninvasive method for measuring both tissue oxygenation and total hemoglobin. The utility of this method was investigated using a porcine model for detecting areas of ischemia and monitoring intestinal hemodynamics. Sections of the small intestine were isolated to study ischemia and reperfusion. The segments were divided into control and two arterial-venous occlusion treatment groups, which were monitored by NIRS. Oxygenation and total hemoglobin showed no significant change over the duration of the protocol in the control segments. Oxygenation of the treatment segments dropped promptly upon, and remained depressed during occlusion. This variable was promptly restored to pre-occlusion levels in the segments that were later reperfused. Total hemoglobin displayed an increase in treatment groups, which can be attributed to insufficient occlusion to the four segments. Spectroscopic measurement of oxygenation and total hemoglobin precisely tracked the hemodynamic manipulations performed on each segment of the jejunum. NIRS provides a rapid and reliable means of detecting and monitoring ischemic regions of the small intestine. The ability to measure tissue oxygenation and to track perfusion using total hemoglobin as an indicator of blood volume make NIRS an attractive tool for noninvasive assessment of regional hemodynamics of the small intestine.

Keywords: Near infrared; Tissue oxygenation; Tissue blood volume; Intestinal ischemia

1. Introduction

Intestinal ischemia or an insufficient supply of blood to the small intestine or colon can result from a variety of disorders that can range in severity from mild short-lived abdominal pain to a life threatening condition, acute mesenteric ischemia, requiring emergency surgery. In many instances intestinal ischemia arises when a blood vessel is blocked by a blood clot or an embolism, or when vessels become narrowed reducing the blood flow to the intestine. In both human and veterinary medicine rapid restoration of blood flow before intestinal damage is irreversible is the most important factor in improving patient survival. Surgery is usually relied upon to alleviate or bypass the vascular obstruction. The viability of the intestine is also evaluated at the time of surgery or laparoscopy with infarcted (death from lack of blood flow) segments of the intestines being removed. Deciding if the ischemic injury to the intestine is reversible is a major challenge for the surgeon.

In this manuscript the focus is on intestinal ischemia in large animals. Abnormal twisting of the intestine resulting in obstruction is the most frequent source of intestinal ischemia in horses [1]. When not treated promptly it can result in both serious illness and death. In horses, it accounts for one of every three death insurance claims [2]. Correct identification of dead or dying tissue at the time of surgery is important. In order to maximize the function of the intestine, care must be taken not to remove too much of the adjacent viable tissue. If too much intestine is removed a condition known as short

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bowel syndrome can result, leading to malnutrition and ultimately death. On the other hand, if dead tissue is overlooked, peritonitis (inflammation of the membrane that lines the internal organs) or adhesions can occur, also leading to death [3,4]. Clinically, defining the margins of viable intestine is difficult to do. Therefore, an objective tool that could distinguish dead or dying tissue from healthy tissue during the surgical exploration would be helpful.

The most common technique for intra-operative assessment employs the subjective evaluation of intestinal color, arterial pulsations, wall thickness, and peristalsis. This subjective evaluation is considered to be unreliable in horses, with estimates of accuracy ranging from 36 to 75% for nonviable intestine, and 53% for viable intestine [3,5,6]. Instrument based methods have been evaluated including the intravenous injection of dye (sodium fluorescein) [7], Doppler ultrasound [7], oximetry of the serosal surface [5,8,9], and thermography [10], however surgeons do not regard any as reliable or accurate methods [5,7–11].

Using a porcine model, near infrared point spectroscopy and imaging was used to detect intestinal ischemia and diagnose the viability of the jejunum (the middle part of the small intestine). Arterial-venous occlusion was used to induce intestinal ischemia in selected segments of the intestine. The cornerstone of the methodology involves monitoring tissue blood volume and blood oxygenation noninvasively using near infrared (NIR) reflectance spectroscopy. NIRS in this case is used to provide a rapid and noninvasive means to determine the relative concentrations of hemoglobin (Hb) and oxyhemoglobin (HbO_2) in tissue. Hemoglobin is the dominant oxygen carrier in blood and therefore can be used as an indicator of the oxygenation of tissue. Tissue perfusion or blood volume can be calculated by the sum of the relative concentrations of both Hb and HbO_2. Both oxygenation and tissue perfusion can be used to detect intestinal ischemia and assess intestinal viability.

2. Materials and methods

2.1. Animal model

All experiments conformed to the guidelines set out by the Canadian Council on Animal Care regarding the care and use of experimental animals and were approved by the local Animal Care Committee of the National Research Council of Canada.

The animals were fasted for 12 h prior to surgery. Prior to induction of anesthesia, each pig was weighed and sedated with midazolam (0.33 mg/kg IM), atropine (0.05 mg/kg IM) and ketamine hydrochloride (22 mg/kg IM). Each pig was placed in dorsal recumbency, and anesthesia induced with isoflurane (3–4% in oxygen at a flow rate of 2 L/min) delivered via a mask. The pig was then intubated, and anesthesia was maintained with isoflurane (1.5–2.0%) in 100% oxygen. An indwelling arterial catheter was placed in the carotid artery and arterial blood was sampled at 30 min intervals to ensure maintenance of $P_a(O_2) > 100$ mmHg. Mean arterial blood pressure was continuously monitored and Lactated Ringer's solution was administered through a catheterized marginal ear vein at 5–10 ml/kg/h to maintain blood pressure above 70 mmHg. Heart rate and systemic arterial oxygen saturation were continuously monitored at the ear using an Ohmeda 5250RGM pulse oximeter.

A 20 cm midline incision was made through the skin and linea alba into the abdominal cavity. Nine 20 cm sections of distal jejunum were identified and isolated commencing at the ileal artery and moving orad. Segments 1 and 6 were designated as controls, while segments 2–5 were designated as those that would undergo treatment. The remaining three segments were used as spacers and were interposed between each of the experimental segments to minimize confounding results between the various hemodynamic manipulations imposed on the segments included in the study. Treatment segments were divided into two groups: segments subjected solely to arteriovenous occlusion (AVO) and segments that underwent arteriovenous occlusion followed by reperfusion (AVOR). The division of the intestine into control, AVO, and AVOR groups is depicted in Fig. 1.

Once the segments were identified, tying the inner space of the intestine (the lumen) off at the beginning and end of each segment created what is known as mural occlusion. Mural occlusion in this case refers to the interruption of blood flow within the intestinal wall itself, so that blood cannot pass from one segment to the next. Each segment, therefore, is supported only by a system of arteries and veins that runs from within the abdominal cavity to the intestine itself, without any ''cross-talk'' between segments. The digital photograph in Fig. 2 shows one such segment.

The next step in the study was to occlude the arteries and veins that supply each treatment segment (AVO and AVOR groups) with blood. For the AVO group (segments 2 and 4), the veins and arteries were cut with a surgical stapling

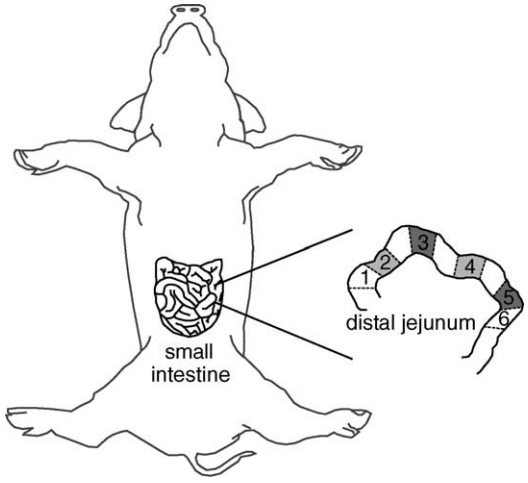

Fig. 1. Schematic of the small intestine and its division into control (segments 1 and 6), AVO (segments 2 and 4), and AVOR (segments 3 and 5) groups.