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ORIGINAL ARTICLE

Intra-operative acute isovolemic hemodilution is safe and effective in eliminating allogeneic blood transfusions during right hepatic lobectomy: Comparison of living donor versus non-donors

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Abstract
Background. Multiple studies have shown acute isovolemic hemodilution (AIH) to be safe and effective during liver resection to limit the use of banked blood. However, no studies to date have studied AIH in living donor right hepatectomy. Conventional right hepatectomies for living donors is not identical to non-donor right hepatectomies. Since division of the parenchyma is often performed without devascularization of the right lobe, blood loss may be significantly higher. *Methods.* Ten consecutive patients undergoing living donor right hepatectomies (LDRH) and ten consecutive patients undergoing non-donor right hepatectomies (NDRH) were compared using AIH. *Results.* There was no mortality or morbidity related to the use of AIH. No allogeneic blood transfusions were required in either group, intra-operatively or post-operatively. There was no significant difference in post-operative hematocrit, average estimated blood loss, and average fluid replacement. Average hospital length of stay and operating room time were longer for the LDRH. *Conclusion.* AIH can be performed safely and effectively in both LDRH and NDRH without subjecting patients to unnecessary risks of allogeneic blood transfusions.

Key Words: *Acute isovolemic hemodilution, allogeneic blood transfusion, liver resection, living liver donors*

Introduction

The use of autologous blood donation has become a popular alternative for patients likely to receive transfusions during surgery. Autotransfusion is an approach to reinfuse a patient's own blood and decrease the need for allogeneic transfusion. The popularity and use of autologous transfusion increased dramatically during the 1980s, due in part to the fear of transfusion-transmitted viruses, especially HIV. In recent years, testing for transfusion-transmitted viruses has improved to the point that the allogeneic blood supply is considered by most to be safe; however, autologous transfusion remains the safest alternative.

Liver resection is a major operation for which, even with the improvements in surgical and anesthetic techniques, the risk of major intra-operative blood loss and resultant blood transfusion remains. In several liver resection series, the reported rate of allogeneic blood transfusion has been rarely below 40% [2,3], with about 60% of the transfused patients requiring 1–2 units of blood [4]. Further, the incidence of postoperative complications was significantly higher following liver resection accompanied by allogeneic blood transfusion in cirrhotic and non-cirrhotic patients [5]. We have previously reported a decreased incidence of allogeneic transfusions with acute isovolemic hemodilution (AIH) in major liver resections [6].

There are essentially four types of autologous transfusion techniques used today: preoperative blood donation, intraoperative blood salvage, postoperative blood salvage, and AIH. Multiple studies have shown that AIH is safe and effective [5,6]. However, no studies to date have looked at AIH in living donor right hepatectomy (LDRH). Since vessels cannot be ligated prior to parenchymal dissection in living donors, blood loss may be significantly higher than in patients undergoing non-donor right hepatectomies for benign or malignant lesions. This case series reviews the use of AIH in LDRH versus non-donor related right hepatectomy (NDRH).

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Table I. Indications for non-donor right hepatectomies

	Number of patients
Metastatic colon cancer	3
Hepatocellular carcinoma	3
Hemangioma	2
Cholangiocarcinoma	1
Oriental cholangiohepatitis	1

Methods

Ten consecutive patients undergoing LDRH and ten consecutive patients undergoing NDRH with AIH between March 1996 and May 2002 were reviewed retrospectively (Table I for NDRH indications). As AIH is part of our standard of care for any major hepatic resection, informed consent for AIH was obtained from each patient. Major hepatic resection was defined as the removal of three or more segments. Patients undergoing minor resections did not undergo AIH. Patient inclusion criteria included preoperative hematocrit of $>30\%$, age <80 years, and no history of significant coronary artery disease. Table I reveals the indications for non-donor related right hepatectomy.

Two to four units of whole blood were removed after induction of anesthesia and placed into citrate phosphate dextrose blood storage bags. Crystalloid and/or colloid were infused to replace the volume of blood removed to maintain intravascular volume guided by central venous pressure (CVP) measurements. Cell Saver was used selectively when appropriate.

All of the LDRH and NDRH were done using the CUSA or harmonic scalpel for parenchymal dissection. Central venous pressures were maintained no higher than 6 mmHg and all patients were placed in the Trendelenburg position during parenchymal dissection. All of the removed whole blood was re-infused into the patient at the completion of the resection.

Postoperative surveillance included hematocrit postoperative day 1 and 7, comparison of average number of units of AIH blood given back, average estimated intraoperative blood loss, average intraoperative fluid replacement, average length of stay, average operating room time between the two groups, and number of units of allogeneic blood transfusions.

Results

Ten consecutive patients undergoing LDRH and ten consecutive patients undergoing NDRH with AIH were compared (Table II). All of the patients underwent right hepatic resections. The operative mortality was 0% in both groups with no morbidity related to AIH. None of the patients required postoperative or intraoperative allogeneic blood transfusions. A mean of 2.4 units and 3.4 units of blood were removed from the LDRH and NDRH groups respectively. Average hematocrit postoperative day 1 and day 7 were 31.74 and 31, versus 29.45 and 27.98, for the LDRH and NDRH groups respectively. Average estimated blood loss and average fluid replacement were 1101 ml and 6621 ml, versus 690 ml and 4825 ml, for the LDRH and NDRH groups respectively. Average hospital length of stay was 11.2 days and 7.9 days for the LDRH and NDRH groups respectively, and average operating room time was 9.1 hours versus 4.1 hours for the LDRH and NDRH groups respectively. *p*-values between the groups were not significant except for the hospital length of stay and operating room time.

Table II. Comparative data

	LDRH	NDRH	*p*-value
Average number of units of AIH removed	2.4	3.4	NS
Average postoperative day #1 hematocrit	31.74	29.45	NS
Average postoperative day #7 hematocrit	31	27.98	NS
Average estimated blood loss (ml)	1101	690	NS
Average fluid replacement (ml)	6621	4855	NS
Average length of stay (days)	11.2	7.9	<0.05
Average operating room time (hours)	9.1	4.1	0.0004

Discussion

Acute isovolemic hemodilution is intentional intraoperative hemodilution induced by the isovolemic exchange of whole blood with colloid or crystalloid solutions to preserve autologous blood while maintaining normovolemia [10], with the concept being a hemodiluted patient with a lower hematocrit value will lose a smaller portion of his/her red cell mass during surgery when compared with a patient with a normal hematocrit and an identical amount of bleeding. Early success with colloid and crystalloid resuscitation in hypovolemic shock patients who refused allogeneic transfusions had initially sparked the interest in AIH for surgical procedures [11]. The technique was first introduced and popularized in the 1970s by Konrad Messmer [7]. AIH has been employed successfully in a variety of other surgical specialties including orthopedic, general surgery, gynecology and cardiac surgery, as well as our earlier report in major hepatic resections [6].

Two major consequences of hemodilution are a reduction of arterial oxygen content and an augmentation in blood flow due to reduced viscosity [7–9]. Several compensatory mechanisms act to offset the reduction in arterial oxygen content. The most important of these is an increase in cardiac output, brought about mainly by elevated stroke volume [13]. Increased oxygen extraction and a rightward shift of the hemoglobin dissociation curve also play a role, especially with prolonged or severe hemodilution. The pivotal role of increased cardiac output in maintaining oxygen delivery during hemodilution emphasizes the importance of maintaining a normal intravascular volume to sustain an increased stroke volume. Thus, the safety of isovolemic hemodilution hinges on relatively intact left ventricular function and coronary circulation. The reduced blood viscosity of hemodilution enhances microcirculation flow [7] and should theoretically translate into improved tissue perfusion.

A major contraindication to AIH is a limited capacity to compensate for reduced oxygen delivery by augmentation of cardiac output and coronary perfusion. One clinical study raised safety concerns for AIH in elderly patients, and certainly, caution is warranted in the presence of ventricular dysfunction or coronary artery disease [13]. AIH is also contraindicated in other disease states that compromise oxygen delivery, such as impaired lung function, or increased oxygen consumption such as multiple organ failure or sepsis.

There is no agreement on the "end points" of hemodilution, both in terms of safety and optimal oxygen delivery. There is no standard nomenclature for degrees of hemodilution but it is generally accepted that a hematocrit level of 28% is consistent with hemodilution, 20% is extreme hemodilution, and 15% is profound hemodilution. Hemodilution is a safe procedure for patients >60 years of age, although caution should be exercised with extreme hemodilution in the elderly. Extreme hemodilution is better tolerated in young patients who have a better capacity to maintain constant circulating blood volume. In most clinical studies in non-cardiac surgery, the aim was a hematocrit range between 25% and 30%.

In LDRH, the vessels are not ligated prior to parenchymal division, therefore LDRH may be associated with increased blood loss and longer operative times. No patients undergoing LDRH or NDRH required allogeneic blood product transfusions. Average hematocrit postoperative day 1 and 7 between the two groups showed no significant differences. The length of hospital stay was longer for the LDRH due to post-operative complications in two patients. One patient required emergent transplantation due to hepatic vein thrombosis from factor V Leiden deficiency; and the other patient had postoperative bile leak. If these two patients are removed from the analysis, the overall length of hospital stay is 7.25 days in the LDRH group, rendering the p-value insignificant.

This study demonstrates that AIH can be safely and effectively used in patients, with the guidelines mentioned previously, undergoing LDRH and NDRH to prevent unnecessary exposure to the risks of allogeneic blood product transfusions, especially when combined with the use of cell saver. AIH is a physiologically attractive concept and has been gaining popularity among different surgical specialties. As more experience is gained with this technique, specific guidelines should evolve for the use of acute isovolemic hemodilution.

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