# The Volume of Lactated Ringer's Solution Required to Maintain Preload and Cardiac Index During Open and Laparoscopic Surgery

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**BACKGROUND:** Recent studies have emphasized the importance of perioperative fluid restriction. However, fluid restriction regimens may increase the likelihood of insufficient perioperative fluid administration or may result in excess intravascular crystalloid replacement. We postulate that the use of transesophageal echocardiography may reduce the amount of crystalloid administered during open and laparoscopic colorectal surgery.

**METHODS:** Fifteen ASA I and II patients scheduled for open colorectal surgery, and 15 patients scheduled for laparoscopic surgery were studied. Lactated Ringer's solution was infused during the procedures. Left ventricular end diastolic volume index (LVEDVI) and cardiac index were assessed throughout surgery and used to guide the rate of lactated Ringer's solution administration. Statistical analysis was performed with Student's *t*-test for unpaired samples.

**RESULTS:** The rate of crystalloid administration required to maintain baseline LVEDVI and cardiac index was $5.9 \pm 2$ $mL \cdot kg^{-1} \cdot h^{-1}$ for open surgery and $3.4 \pm 0.8$ $mL \cdot kg^{-1} \cdot h^{-1}$ for laparoscopic surgery ($P < 0.01$). This slower rate for laparoscopic surgery was offset by the longer surgical duration.

**CONCLUSION:** The rate of crystalloid solution to maintain baseline LVEDVI and cardiac index was greater in open surgery than laparoscopic surgery, and lower than commonly recommended for colorectal surgery.

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Intraoperative hypervolemia or hypovolemia from inaccurate estimation of fluid requirements during surgery has been associated with problems, such as gut mucosal hypoperfusion,[1,2] cardiovascular morbidity, tissue healing complications,[3] increased length of hospital stay[4] and delayed return of gastrointestinal function.[5,6] There is no consensus about optimal perioperative fluid replacement during intraabdominal surgery.[7–10] Conventionally, perioperative fluid requirements have been adjusted based on the patient's surgical procedure. During open abdominal surgery, third space, evaporative losses and surgical trauma are considered the most important determinants of intravascular crystalloid replacement. Laparoscopic surgery, however, should have less evaporative and third space losses because of reduced surgical trauma, but adds conditions, such as pneumoperitoneum and steep Trendelenburg or reverse Trendelenburg position, that may temporarily modify ventricular preload and intravascular fluid requirements.

Transesophageal echocardiography (TEE) is useful to evaluate ventricular filling and cardiac index[11–16] and guide fluid therapy. Although we know that fluid requirements are increased during open intraabdominal surgery, the amount of crystalloid replacement needed to maintain left ventricular end diastolic volume index (LVEDVI) or cardiac index has not been determined. Current fluid therapy recommendations[17,18] are probably excessive. We postulate TEE guidance may reduce the amount of crystalloid administered during open and laparoscopic colorectal surgery, and that open surgery will require more crystalloid replacement than laparoscopic surgery.

## METHODS

After institutional ethics committee approval (Facultad de Medicina, Pontificia Universidad Católica, Santiago, Chile), written informed consent was obtained from 15 patients scheduled for open colorectal surgery (group O) and 15 patients scheduled for laparoscopic colorectal surgery (group L). All patients were ASA physical status I–II and had no contraindication to the use of TEE. The decision on the surgical technique was not influenced by this study. All patients received an identical bowel preparation of only

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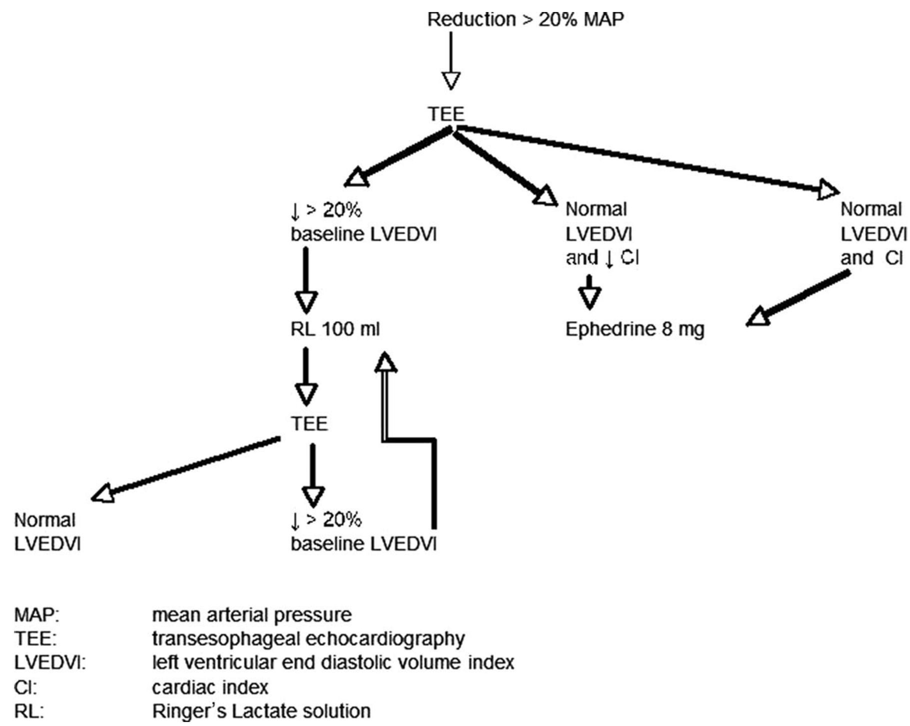


**Figure 1.** Decision algorithm for volume or ephedrine administration according to Transesophageal echocardiography (TEE) measurements.

clear liquids by mouth during the 24 h before surgery. During that time they also received an oral Fleet® bowel preparation diluted in 1000 mL of a clear soft drink twice, 6 to 8 h apart. During the 8 h immediately before surgery, patients received 1000 mL of lactated Ringer's solution.

After standard monitoring (continuous electrocardiogram, noninvasive arterial blood pressure, and pulse oximetry), anesthesia was induced with fentanyl 2–4 $\mu$g/kg thiopental 5–6 mg/kg, and vecuronium 0.1 mg/kg. The trachea was intubated and ventilation was adjusted to an end-tidal carbon dioxide tension at 30–35 mm Hg. During surgery, anesthesia was maintained with isoflurane 1–1.5 minimum alveolar anesthetic concentration in combination with nitrous oxide (50%), in oxygen. Supplemental bolus doses of fentanyl 1–2 $\mu$g/kg were administered to maintain mean arterial blood pressure (MAP) and heart rate within 20% of baseline values (mean value of 3 determinations made at rest the day before surgery). Muscle relaxation was maintained with supplemental 1 mg doses of vecuronium throughout surgery. Nasopharyngeal temperature and urine output were monitored during surgery. Patients were actively warmed with a forced air warning system to maintain temperatures above 36°C.

Before TEE probe insertion, a nasogastric tube was used to empty air from the stomach and then removed. TEE was performed by the same anesthesiologist (VM, American National Board of Echocardiography Testamur) with the Philips Envisor C echocardiograph. The TEE determinations made were LVEDVI and cardiac index. LVEDVI was measured in the mid-esophagus according to the modified Simpson's method.[16] Cardiac output was determined according to the method described by Perrino et al.[14] Baseline measurements of LVEDVI and cardiac index were made during maintenance of anesthesia before surgical stimulation and after a period of at least 5 min of MAP and heart rate within ±20% of baseline values. These measurements were made with the patient in the surgical position and the operating table at a neutral level. Additional TEE assessments were made 5 min after establishing pneumoperitoneum (group L) and every 30 min, or each time MAP decreased more than 20% of baseline values.

A maintenance infusion of lactated Ringer's solution was administered at 3 mL · kg$^{-1}$ · h$^{-1}$ to all patients throughout the study period. Surgical time was defined as the interval between the beginning of induction until tracheal extubation. A decrease of MAP after induction and before the insertion of the TEE probe was treated by administering 100 mL of lactated Ringer's solution and 6–8 mg of ephedrine. This was repeated 3 min later if MAP had not returned to baseline values. Additional amounts of lactated Ringer's solution were administered every time the MAP decreased more than 20% from baseline values according to the algorithm shown in Figure 1. When the measurements made every 30 min showed a reduction more than 20% of LVEDVI or cardiac index without a reduction of MAP, the same algorithm shown in Figure 1 was applied. Blood loss was determined every 30 min measuring suction bottles (subtracting the surgical field irrigation) and weighing sponges (subtracting their dry weight). Depending on the patient's clinical condition and co-morbidity, the anesthesiologist in charge of the patient administered red blood cells when the hematocrit reached 25% to

  

Table 1. Demographic Data

| | Group O | Group L | *P* |
|---|---|---|---|
| Age (yr) | 60.4 ± 10 | 55.5 ± 11 | 0.22 |
| Weight (kg) | 67.5 ± 13 | 74.1 ± 21 | 0.31 |
| Height (cm) | 160 ± 10 | 163 ± 7 | 0.45 |
| Gender (m/f) | 7/8 | 6/9 | |

Data are mean ± SD or *n*.
M = male; F = female.

Table 2. Type of Surgery and Duration of Surgery

| | Group O | Group L |
|---|---|---|
| Total colectomy | 1 | 3 |
| Right hemicolectomy | 6 | 1 |
| Left hemicolectomy | 7 | 1 |
| Anterior resection | 0 | 1 |
| Sigmoidectomy | 1 | 9 |
| Duration of surgery (h) | 3.1 ± 0.7 | 4.7 ± 1.2* |

Data are mean ± SD or *n*.
* $P < 0.05$.

Table 3. General Data During Surgery

| | Group O | Group L |
|---|---|---|
| Total amount of fluid administered (mL) | 1217 ± 470 | 1217 ± 629 |
| Total amount of fluid administered ($mL \cdot kg^{-1} \cdot h^{-1}$) | 5.9 ± 2.0 | 3.4 ± 0.8* |
| Estimated blood loss (mL) | 286 ± 121 | 193 ± 25* |
| Urine output ($mL \cdot kg^{-1} \cdot h^{-1}$) | 0.48 ± 0.4 | 0.37 ± 0.2 |

Data are mean ± SD or *n*.
* $P < 0.05$.

30%. In group L intraabdominal pressure (IAP) was maintained at a maximum of 15 mm Hg.

Based on a retrospective analysis of open colorectal surgery data, it was estimated that 30 patients (15 in each group) were needed to detect a difference of at least 30% in the total amount of intravascular volume administered between groups (power = 80%, $\alpha$ error = 0.05).

Data are reported as mean ± SD. Normality of data was tested with the Kolmogorov-Smirnov test. Comparisons between groups were performed with unpaired Student's *t*-test, Mann-Whitney's test or $\chi^2$ test. Statistical analyses were performed using R (language and environment for statistical computing, freely available from http://www.r-project.org/). A *P* value ≤0.05 was considered statistically significant.

## RESULTS

All the patients enrolled completed the study. No demographic differences between groups were observed (Table 1). The type of surgery performed in each group is shown in Table 2. The duration of surgery in group L (4.7 ± 1.2) was significantly longer than that in group O (3.1 ± 0.7) ($P < 0.01$). Fluid replacement was performed exclusively with lactated Ringer's solution in all patients. Four patients in group L and three in group O had hypertension treated preoperatively with angiotensin converting enzyme inhibitors. One patient in group O was also receiving $\beta$ blockers. None of the patients was receiving diuretics preoperatively.

At induction, six patients in group O and four in group L required at least one dose of ephedrine. During maintenance, one patient required ephedrine in group L and none required ephedrine in group O. The volume of lactated Ringer's solution administered during surgery, estimated blood loss, and urine output are shown in Table 3. No patient received red blood cells. The rate of lactated Ringer's solution administration during surgery was 5.9 ± 2.0 $mL \cdot kg^{-1} \cdot h^{-1}$ in group O and 3.4 ± 0.8 $mL \cdot kg^{-1} \cdot h^{-1}$ in group L, a statistically significant difference. By random chance, the difference in average rate of administration was exactly offset by the difference in average duration, so that the average volume of lactated Ringer's solution, 1217 mL, was exactly the same in both groups.

Baseline cardiac index and LVEDVI values were similar between groups and were kept within normal limits during surgery (Figs. 2–4). No differences within and between groups were found when baseline LVEDVI and cardiac index values were compared with the ones obtained at the end of surgery (Figs. 3 and 4, respectively). Postoperative hospital length of stay was 4.5 ± 1.3 days in group L and 10.1 ± 4.5 days in group O ($P < 0.05$).

## DISCUSSION

The amount of fluid required to maintain LVEDVI and cardiac index was a remarkably modest: 1.2 L in both groups, based on TEE-guided replacement. Although the administration rate during open surgery was nearly twice the rate of laparoscopic surgery, the longer duration of laparoscopic surgery exactly compensated for the difference in rate, resulting in nearly identical requirements for total crystalloid replacement. The decreased rate of crystalloid replacement for laparoscopy has also been demonstrated for laparoscopic cholecystectomy.[19] Some studies suggest that laparoscopic surgery may actually increase the neuroendocrine response to surgical trauma when compared to open surgery.[20,21]

The effects of increased IAP and sometimes extreme Trendelenburg or reverse Trendelenburg positions on cardiac index and LVEDVI are not easy to explain because, except for the one measurement made 5 min after establishing of pneumoperitoneum, measurements were made without considering the patient's position. It has been described that an IAP of 15 mm Hg induces minimal cardiovascular changes.[22] The reverse Trendelenburg position causes a reduction of left ventricular end-diastolic area[23] and, consequently, of LVEDVI, without reduction of MAP. This reduction of LVEDVI could not have been detected if there was no TEE measurement scheduled at that time or it did not generate a reduction of MAP that was greater than 20%.

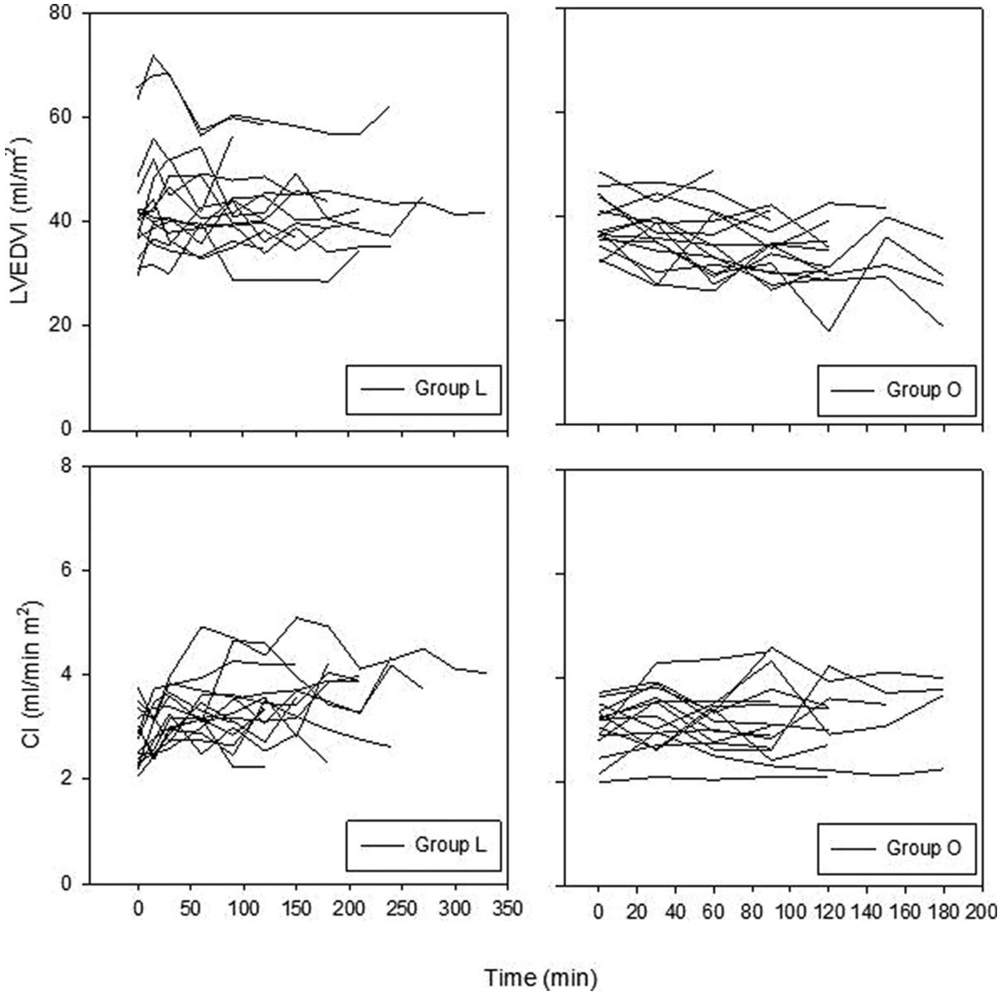


**Figure 2.** Cardiac index (CI) and Left ventricular end diastolic volume index (LVEDVI) values during surgery in both groups.

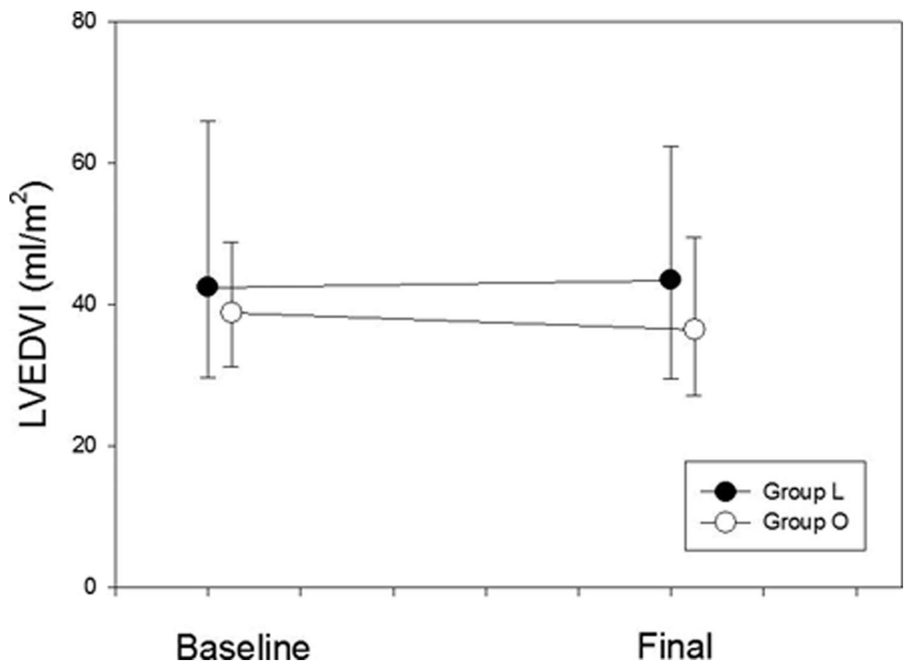


**Figure 3.** Baseline and final Left ventricular end diastolic volume index (LVEDVI).

Some studies suggest that excess intravascular volume replacement worsens surgical outcomes.[3,5,6] However, other studies have shown a better postoperative fitness when large amounts of crystalloids are used.[22,24] Our results suggest that volume replacement therapy must be adapted to the specific requirements of each patient. Current guidelines[17,18] may recommend excessive replacement.

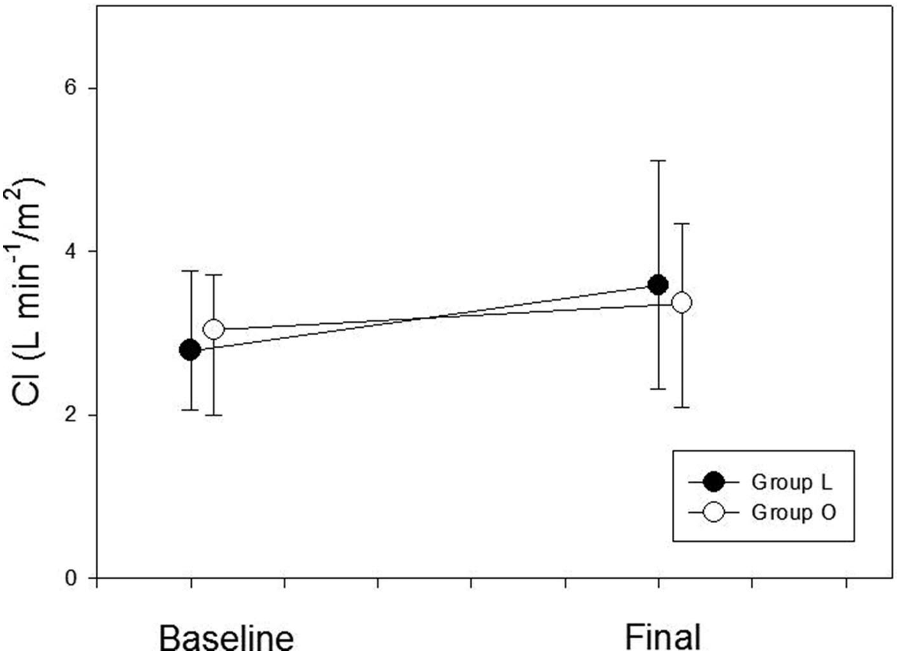


**Figure 4.** Baseline and final cardiac index (CI).

Our results show that cardiac index can be maintained in the presence of a reduced LVEDVI in patients in good cardiovascular condition. This likely results from compensatory mechanisms or a reduction in afterload from isoflurane anesthesia. This shows one of the pitfalls of using LVEDVI as a physiologic target for intraoperative fluid replacement. Perhaps baseline, rather than normal LVEDVI under a stable level of anesthesia, represents a more suitable objective.

We chose to replace intravascular volume loss with crystalloids, as this reflects our clinical practice. We cannot extrapolate from these results to recommendations for replacing volume loss with colloidal solutions.

In both groups, urine output was marginal and probably inadequate according to the standard recommendation.[23] The study design cannot exclude regional blood flow redistribution that could reduce renal blood flow and glomerular filtration rate. However, maintenance of a baseline and normal cardiac index during the study period allow us to think that renal perfusion was normal, and that the urine output reduction observed was a physiological response to surgery.[25] Renal function and perfusion under these study conditions must be evaluated to exclude the possibility of renal hypoperfusion and its consequences.

A possible limitation of our study is that patients could not be randomized to open or laparoscopic surgery, which was determined by surgeon based on the underlying pathology. As a result, there were more sigmoidectomies in group L and more hemicolectomies in group O. This unequal distribution of operations may have influenced our findings.

In addition the isoflurane concentrations were between 1 and 1.5 minimum alveolar concentration during maintenance of anesthesia in both groups. Since we did not use intraoperative electroencephalogram monitoring, there may have been differences in anesthetic depth. Since the range of isoflurane concentration was relatively narrow, and patients in both groups had similar demographic characteristics, we think that it was unlikely that differences in isoflurane dose affected our results.

Although there were no formal contraindication, the addition of nitrous oxide for anesthesia with bowel surgery might be controversial due to its accumulation in the gut. This constitutes a normal practice in our department and we have not seen technical difficulties for surgeons due to gut distension.

In summary, the rate of crystalloid administration required to maintain baseline LVEDVI and cardiac index was $5.9 \pm 2$ mL · kg$^{-1}$ · h$^{-1}$ for open surgery and $3.4 \pm 0.8$ mL · kg$^{-1}$ · h$^{-1}$ for laparoscopic surgery ($P < 0.01$). This slower rate for laparoscopic surgery was offset by the longer surgical duration. The rate of crystalloid solution to maintain baseline LVEDVI and cardiac index is lower than commonly recommended for colorectal surgery.

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