Peristaltic Pneumatic Compression of the Legs Reduces Fluid Demand and Improves Hemodynamic Stability during Surgery

A Randomized, Prospective Study

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ABSTRACT

Background: Perioperative fluid restriction might be beneficial in specific clinical settings. In this prospective, randomized and blinded study, we assessed whether peristaltic pneumatic compression of the legs can support restrictive fluid management strategies by reducing intraoperative fluid demand and improving hemodynamic stability.

Methods: Seventy patients scheduled for minor surgery were randomly assigned to receive either intraoperative peristaltic pneumatic compression or placebo compression. Both groups received fluid therapy according to a goal-directed protocol with a crystalloid base rate of 2 ml·kg⁻¹·h⁻¹ and bolus infusions of 250 ml crystalloids triggered by hypotension, tachycardia, or high Pletch Variability Index.

Results: Patients treated with peristaltic pneumatic compression received less intravenous fluid: median (interquartile range) 286 (499) versus 921 (900) ml (P < 0.001), resulting in a median difference of 693 ml (95% CI, 495–922 ml) and a median difference of 8.4 ml/kg (95% CI, 5.3–11.5 ml; P < 0.001). After the anesthesia induction phase, median overall infusion rates were 12.2 (14.1) ml·kg⁻¹·h⁻¹ in the control group and 1.9 (0.4) ml·kg⁻¹·h⁻¹ in the pneumatic peristaltic compression group (P < 0.001).

Among patients treated with pneumatic peristaltic compression, the median cumulative time of hypotension was shorter [0 [12.5] min vs. 22.6 [22.8] min; P = 0.002]. Fewer hypotensive events were recorded (39 vs. 137; P = 0.001), and median lowest individual systolic pressure was higher (92 [8] vs. 85 [16] mmHg; P = 0.002).

Conclusions: This study demonstrates that peristaltic pneumatic compression of the legs significantly improves hemodynamic stability and reduces fluid demand during minor surgery.

What This Article Tells Us That Is New

• Among patients undergoing minor surgery, application of intraoperative peristaltic pneumatic leg compression reduced fluid demand while improving hemodynamic stability.

What We Already Know about This Topic

• Intraoperative volume therapy often results in postoperative positive fluid balance.

Intraoperative fluid restriction has various undesirable effects on cardiovascular performance. Namely, decreased central sympathetic drive depresses cardiac contractility and redistribution of blood from the intrathoracic to the extrathoracic compartment and positive pressure ventilation lower cardiac preload. Consequently, blood pressure routinely drops with anesthesia induction. In the clinical setting, large amounts of intravenous fluid may be administered to counteract this decrease in blood pressure. The aim

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Intraoperative fluid restriction has various undesirable effects on cardiovascular performance. Namely, decreased central sympathetic drive depresses cardiac contractility and redistribution of blood from the intrathoracic to the extrathoracic compartment and positive pressure ventilation lower cardiac preload. Consequently, blood pressure routinely drops with anesthesia induction. In the clinical setting, large amounts of intravenous fluid may be administered to counteract this decrease in blood pressure. The aim
is to restore preload and to substitute for assumed fluid loss from preoperative fasting. It is a strategy that might be associated with adverse effects. For example, liberal fluid therapy may exert a detrimental effect on gastrointestinal function as well as affecting the integrity of the endothelial barrier. Also, fluid overload has been identified as an independent predictor of mortality in postoperative patients in a surgical intensive care unit.

These observations have challenged the current routine of perioperative fluid management and stimulated interest in intraoperative fluid restriction. Preventing the redistribution of blood from the intrathoracic to the extrathoracic compartment, which regularly occurs with induction of anesthesia, might be an option to restore preload while avoiding the adverse effects of intravenous fluids. Although passive leg raising or Trendelenburg positioning are simple autotransfusion maneuvers that could serve this goal, they are not feasible in many clinical situations. However, external compression of the extremities—preferably of the legs—might mimic the effects of these positioning maneuvers. Intermittent pneumatic compression is an established therapeutic intervention for various indications such as lymphedema, post-thrombotic ulcers, arterial claudication, and also for intraoperative prevention of thromboembolism. Peristaltic pneumatic compression (PPC) is a variation of intermittent pneumatic compression, using higher pressures and longer compression cycles. Compression therapy has previously been shown to reduce the adverse hemodynamic effects of pneumoperitoneum during laparoscopy.

However, its use in a general surgical population to promote volume restriction has not been assessed. Hypothesizing that PPC would reduce intraoperative fluid demand, we compared fluid demand among patients undergoing minor surgery under standardized, goal-directed fluid management.

Materials and Methods

Study Design

An institutional ethics committee (University of Bonn, Germany) approved this prospective, randomized, and blinded study, which has been registered (NCT01072305). Patients scheduled for elective minor ear, nose, and throat surgery without anticipated significant blood loss were randomized to either a control or PPC group. Both groups received fluid therapy according to an identical goal-directed protocol. The primary endpoint was the difference in total volume of fluid administration. An a priori sample size analysis based on the assumption of normal distribution indicated that 32 patients per group would provide 80% power to detect a statistically significant difference of 500 vs 750 ml with a SD of 300 ml (Cohen’s d = 0.72) at an α level of 0.05. Because the distribution of actual data clearly deviated from a normal distribution, nonparametric testing was used in the final analyses.

After written informed consent was obtained, 70 patients were included in the current investigation between February and June 2009. To minimize patient risk and confounding factors, all patients with a history of clinically significant cardiac arrhythmia, impairment of renal function requiring fluid or electrolyte intake restrictions, or category P3 or P4 on the ASA (American Society of Anesthesiologists) Physical Status Classification System, as determined during preanesthetic evaluation, were excluded from the study. All patients wore class I antithrombotic stockings as part of clinical routine.

General Anesthesia

Patients were allowed solid food until 1:30 AM and water or tea until 5:30 AM, according to institutional practice. General anesthesia was induced by 1 μg/kg remifentanil administered by an intravenous infusion pump during 2 min and bolus 2.5 mg/kg propofol. Tracheal intubation was facilitated with 0.4 mg/kg rocuronium. Anesthetic depth was monitored using a bispectral index monitor (BIS® 1000 monitor; Aspect Medical Systems, Newton, MA) and maintained in a target range of 40–60, either as total intravenous anesthesia with propofol/remifentanil or with inhaled isoflurane/remifentanil, according to institutional practice (total intravenous anesthesia for sinus surgery or for patients at risk for postoperative nausea and vomiting). Additional monitoring consisted of standard five-lead electrocardiogram, noninvasive blood pressure measurement, and fingertip pulse oximetry using a multiparameter bedside monitor (Datex S/5, Datex-Ohmeda, Helsinki, Finland). In addition, Masimo Rainbow SET™ Pulse CO-Oximetry (Masimo Corporation, Neuchatel, Switzerland) provided Pleth Variability Index (PVI) readouts from an additional fingertip sensor. PVI, while not part of the routine monitoring regime at our institution, is the only currently available noninvasive monitoring parameter that has been shown to predict fluid responsiveness.

Its use was incorporated in the study protocol to extend validity of results to modern fluid management regimes that are based on early detection of hypovolemia. Technically, PVI measures the respiratory variability of the pulse amplitude in fingertip transmission plethysmography. All patients received ondansetron and 4 mg dexmedetomidine and 4 mg dexamethasone as prophylaxis at the end of the operation.

Pneumatic Compression

The compression device (Lympha Press®, Villa Sana GmbH & Co., Weiboldshausen, Germany; fig. 1A) consists of a compressor and a cuff covering the entire leg, from toe to groin. The cuff contains 12 overlapping chambers that are consecutively inflated to a preset pressure in a cyclic manner (fig. 1B). The target pressure in each chamber can be individually chosen with the only restriction that the pressure in each chamber cannot exceed the pressure in the next distal chamber. We chose a pressure of 60 mmHg in the first (distal) chamber and 38 mmHg in the last (proximal) chamber. The sequential inflation of all chambers takes no more than...
60 s. The compressor is then stopped and, during a pause of 4 s, the inflated air is allowed to escape the cuffs. The next cycle begins again with inflation of the distal chamber. The chamber pressures were chosen based on elementary physiologic considerations so as to maximize therapeutic effects by using sufficiently high pressures and pressure gradients while preventing compromise of limb perfusion by avoiding peak chamber pressures above mean arterial pressure.

**Randomization and Blinding Procedure**

On arrival in the operating room, immediately before anesthesia induction, patients were randomly allocated to either the control or PPC group by a sealed envelope procedure. An assistant that had no influence on anesthetic and fluid management applied the compression device to the patient in absence of the attending anesthesiologist. In the control group, the cuffs were placed on the operating table next to the patient’s legs. The patient’s legs and the cuffs were covered with drapes placed on a frame (fig. 1C), the compression device was activated and run continuously from induction of general anesthesia to wound closure in both groups in order to ensure identical compressor noise and cuff motion. Independent observers verified that the blinding procedure made it impossible for the anesthesiologist to discriminate between control versus PPC group assignment based on visual or auditory perception. However, group assignment was revealed to the anesthesiologist at the end of the operation and before transfer to the postanesthesia care unit (PACU) because the anesthesiologist checked for local adverse effects of compression therapy. Knowledge of group assignment after surgery could not affect study outcome because all anesthesiologist decisions that could potentially affect study outcome had already been made. Patients were aware of group allocation because the device was applied before anesthesia induction.

**Fluid Management Protocol**

All patients received a base rate of crystalloid infusion of 2 ml · kg⁻¹ · h⁻¹ (Jonosteril®; Fresenius Kabi AG, Bad Homburg, Germany; constituents in mmol/l: Na⁺ 137, K⁺ 4, Ca²⁺ 1.65, Mg²⁺ 1.25, Cl⁻ 110, acetate 36.8; further constituents: water, HCl for titration to pH of 5.0–7.0). Provided that BIS was within the target range of 40–60 (fig. 2), an additional 5-min bolus infusion of 250 ml Jonosteril® was administered if one or more of the following criteria were fulfilled: hypotension, tachycardia, or high PVI. Assessment of these criteria was performed every 2.5 min. Fluid bolus doses were limited by protocol to 2,000 ml/h to avoid fluid overload. The protocol could be abandoned at any time at the attending anesthesiologist’s discretion if clinical judgment indicated that further administration of intravenous fluid would be harmful to the patient, and the use of alternative interventions (e.g., vasopressor, catecholamine) was...
indicated. If blood loss exceeded 250 ml, it was to be substituted volume to volume with 6% hydroxyethyl starch (Voluven; Fresenius Kabi AG). Fluid administration data were reported up to the end of surgery. In the PACU, patients of both groups were restricted to 500 ml Jonosteril. Patient follow-up ended with PACU discharge.

**Data Collection**

All data were collected prospectively and patients were observed until PACU discharge. All data were analyzed on an intention-to-treat basis. Before surgery, sex, age, weight, height, and the type of the scheduled procedure were recorded. During anesthesia, the monitoring data were digitally recorded as trend data every 2.5 min using the relevant manufacturer-provided data-acquisition software (Datex-Ohmeda, Masimo Corporation). BIS values, amount of fluid given, details of anesthetic management, and intraoperative bleeding were recorded manually every 10 min. For 16 patients, network-based electronic data-acquisition was not available. Therefore, data for these patients was recorded manually. PACU data for four patients was inaccessible at time of study evaluation.

**Statistical Analysis**

Demographic data are presented as mean value ± SD. All other data are presented as median (interquartile range) unless stated otherwise. For statistical analysis, the SPSS software package (version 17, SPSS Inc., Chicago, IL) was used. Demographic details were compared using a two-tailed Student t test for independent samples for continuous and a chi-square test for nominal and categorical variables. For all other comparisons, a two-tailed Mann–Whitney U test was used with CI computations for median difference. Significance was assumed at a P value of less than 0.05 in all statistical tests with Bonferroni correction applied for secondary (hemodynamic) outcome parameters.

**Results**

**Patients Characteristics**

All 70 enrolled patients completed the study (fig. 3). Patient characteristics, anesthetic management, and surgical procedures did not differ significantly between control and PPC groups (tables 1 and 2). There were no complications attributable to the fluid protocol or the PPC treatment. Neither was there a statistically significant difference in intraoperative blood loss. One patient in the control group lost approximately 400 ml of blood and received 250 ml 6% hydroxyethyl starch. Two patients in the PPC group lost approximately 500 ml of blood each; both received 500 ml 6% hydroxyethyl starch. Vomiting in the PACU was not observed among patients of either study group.

**Fluid Therapy**

The intraoperative fluid protocol was fully adhered to in all 70 patients. Five patients (three patients in the control...
group, two patients in the intervention group) received an additional 500 ml crystalloid in violation of study protocols. Patients in the intervention group received significantly less crystalloid fluid, with a median amount of 286 (499) versus 921 (900) ml (fig. 4; $P = 0.001$), corresponding to a median difference of 693 ml (95% CI, 495–922 ml). Stratification by anesthetic technique did not substantially alter these results (data not shown). Details of fluid therapy and hemodynamic data for all patients are summarized in table 3. Volume responsiveness, defined as resolution of the critical parameter deviation after infusion of no more than 500 ml crystalloid, was observed in 78.0% of all recorded events. Patients receiving PPC were significantly more often volume responsive (94 vs. 66.7%; $P = 0.001$). The amount of fluid given corresponds to median infusion rates of 5.7 (10.3) ml $\cdot$ kg$^{-1}$ $\cdot$ h$^{-1}$ in the intervention group, and 19.2 (22.8) ml $\cdot$ kg$^{-1}$ $\cdot$ h$^{-1}$ in the control group ($P = 0.001$). To exclude the initial phase of induction of anesthesia from the analysis of the amount of fluid given, we also assessed fluid demands during the last 20 min of the surgical procedure (i.e., “steady state”). Patients in

![Modified consort diagram. No formal screening step was performed because patient inclusion was limited by logistical constraints. BIS = bispectral index; BP = blood pressure; HR = heart rate; IV = intravenous; MAP = mean arterial pressure; PPC = peristaltic pneumatic compression; PVI = Pleth Variability Index; SAP = systolic arterial pressure.](http://anesthesiology.pubs.asahq.org/pdfaccess.ashx?url=/data/journals/jasa/931111/)

**Table 1.** Peristaltic Pneumatic Compression: Patient Characteristics, Mean ± SD (N = 70)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Control (n = 35)</th>
<th>PPC (n = 35)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex, men/women, No.</td>
<td>25/10</td>
<td>23/12</td>
<td>0.60</td>
</tr>
<tr>
<td>Age, yr</td>
<td>44 ± 18</td>
<td>45 ± 15</td>
<td>0.18</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>83 ± 17</td>
<td>77 ± 16</td>
<td>0.58</td>
</tr>
<tr>
<td>Height, cm</td>
<td>176 ± 8</td>
<td>173 ± 9</td>
<td>0.57</td>
</tr>
<tr>
<td>BMI, kg/m$^2$</td>
<td>26.5 ± 4.3</td>
<td>25.5 ± 3.7</td>
<td>0.29</td>
</tr>
<tr>
<td>Fasting time, min</td>
<td>809 ± 126</td>
<td>800 ± 128</td>
<td>0.67</td>
</tr>
<tr>
<td>ASA category, P1/P2, No.</td>
<td>23/12</td>
<td>24/11</td>
<td>0.62</td>
</tr>
<tr>
<td>SAP baseline</td>
<td>123 ± 11</td>
<td>126.7 ± 17</td>
<td>0.39</td>
</tr>
<tr>
<td>aHT prevalence, No.</td>
<td>4</td>
<td>3</td>
<td>0.71</td>
</tr>
</tbody>
</table>

aHT = arterial hypertension; ASA = ASA (American Society of Anesthesiologists) Physical Status Classification System; BMI = body mass index; PPC = peristaltic pneumatic compression; SAP = systolic arterial pressure.
Effects of PPC on Fluid Demand

The PPC group also received significantly less fluid within the last 20 min of the operation: 1.9 (0.4) vs 12.2 (14.1) ml · kg⁻¹ · h⁻¹ (P < 0.001). After an initial postinduction peak, time-averaged infusion rates remained close to constant. In particular, the efficacy of PPC did not appear to diminish with ongoing use.

Hemodynamic Stability

The decrease in arterial blood pressure after induction of general anesthesia, average arterial blood pressure, and heart rate did not differ between groups. Lowest individual systolic arterial pressures and mean arterial pressures were significantly lower in the control group (table 3), while lowest individual diastolic arterial pressures were similar in both groups (data not shown). In total, we recorded 176 volume bolus-triggering events as defined by the fluid protocol (systolic arterial pressure <90 mmHg, mean arterial pressure <60 mmHg or 20% below values before skin incision: 141 events; PVI >14%: 60 events). Tachycardia (heart rate >90 beats/min) was not observed in any of the patients. Volume-triggering events occurred significantly less often among patients in the PPC group (39 vs. 137; P < 0.001).

Arterial hypotension was recorded significantly less often in the intervention versus control group (31 vs. 110 events; P = 0.001), with at least one hypotensive event in 37 versus 77% of patients (P < 0.001) and a median frequency of 0 (1.5) versus 2 (4) hypotensive events per patient (P < 0.001). Events with a high PVI also were observed less often in the intervention group (14 vs. 46 events in the control group; P < 0.001).

As the use of PVI cannot be considered routine monitoring, we performed a subgroup analysis, excluding all patients who had received at least one fluid bolus solely on the basis of an increased PVI. For this analysis, 19 control patients and 6 PPC patients were excluded. Both the primary endpoint difference (median difference 767 ml, 95% CI, 560–1299 ml; P < 0.001) and differences in indicators of hemodynamic stability (data not shown) that were statistically significant in the entire dataset remained so in subgroup analysis.

Discussion

In this prospective, randomized controlled trial, we demonstrated that PPC of the legs reduces intraoperative fluid demand and improves hemodynamic stability when used in combination with an event-driven fluid protocol during minor ear, nose, and throat surgery.

**Effects of PPC on Fluid Demand**

Patients with PPC received approximately 700 ml less crystalloid fluid and responded better to fluid boluses. Episodes of arterial hypotension were less frequent among these patients and the cumulative time of arterial hypotension was

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**Table 2. Peristaltic Pneumatic Compression: Anesthetic Management and Surgical Details, Mean ± SD (N = 70)**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Control (n = 35)</th>
<th>PPC (n = 35)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgery duration, min</td>
<td>44.5 ± 27.5</td>
<td>38.3 ± 25.4</td>
<td>0.25</td>
</tr>
<tr>
<td>Anesthesia type (TIVA/inhaled anesthetics), No.</td>
<td>12/23</td>
<td>18/17</td>
<td>0.15</td>
</tr>
<tr>
<td>Propofol, mg/kg</td>
<td>7.4 ± 2.2</td>
<td>9.0 ± 6.3</td>
<td>0.50</td>
</tr>
<tr>
<td>Mean MAC</td>
<td>0.53 ± 0.1</td>
<td>0.55 ± 0.1</td>
<td>0.77</td>
</tr>
<tr>
<td>Remifentanil, μg · kg⁻¹ · min⁻¹</td>
<td>0.24 ± 0.15</td>
<td>0.25 ± 0.13</td>
<td>0.61</td>
</tr>
<tr>
<td>Bispectral index</td>
<td>44 ± 5</td>
<td>44 ± 6</td>
<td>0.77</td>
</tr>
<tr>
<td>Surgery type, No.*</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>FESS</td>
<td>10</td>
<td>14</td>
<td>0.24</td>
</tr>
<tr>
<td>Septoplasty</td>
<td>11</td>
<td>5</td>
<td>0.11</td>
</tr>
<tr>
<td>Tonsillectomy</td>
<td>5</td>
<td>2</td>
<td>0.26</td>
</tr>
<tr>
<td>Tympanoplasty</td>
<td>6</td>
<td>7</td>
<td>0.68</td>
</tr>
<tr>
<td>Various†</td>
<td>5</td>
<td>7</td>
<td>0.46</td>
</tr>
<tr>
<td>Significant blood loss, No.‡</td>
<td>1</td>
<td>2</td>
<td>0.54</td>
</tr>
</tbody>
</table>

* Includes combined procedures; † Various includes abscess drainage, cervical cyst resection, lacrimal duct operation, lymph node extirpation, and tumor resection; ‡ Significant blood loss was more than 250 ml.

FESS = functional endoscopic sinus surgery; MAC = minimal alveolar concentration; PPC = peristaltic pneumatic compression; TIVA = total intravenous anesthesia.
shorter. All of these effects were statistically significant and of clinically relevant magnitude. The extent to which PPC supported fluid restriction was higher than expected.

Estimates of the amount of pooled blood that can be recruited from capacity vessels of the legs vary in the literature. They range from absence of sustained autotransfusion \(^28\) to recruitment of 1,000 ml \(^29\). Quantitative studies using radionuclide scanning estimate autotransfusion capacity at approximately 150 ml for Trendelenburg position \(^30\) and 300 ml for passive leg raising. \(^31\) The observed group difference of 700 ml between study groups, with a rate of 5.7 (10.3) and 19.2 (22.8) ml \(\cdot \) kg \(^{-1} \cdot \) h \(^{-1}\), respectively, as described in recent studies. \(^6,14\)

**Table 3. Peristaltic Pneumatic Compression: Fluid Therapy and Hemodynamic Details, Median (Interquartile Range) \((N = 70)\)**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Control ((n = 35))</th>
<th>PPC ((n = 35))</th>
<th>(P) Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluid therapy</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Crystallloid, ml</td>
<td>921 (900)</td>
<td>286 (499)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Median difference (95% CI), ml</td>
<td>693 (495–922)</td>
<td>286 (499)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Overall rate, ml (\cdot) kg (^{-1}) (\cdot) h (^{-1})</td>
<td>19.2 (22.8)</td>
<td>5.7 (10.3)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Steady state rate, ml (\cdot) kg (^{-1}) (\cdot) h (^{-1})</td>
<td>12.2 (14.1)</td>
<td>1.9 (0.4)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Lowest individual ABP, mmHg</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>SAP</td>
<td>85 (18)</td>
<td>92 (8)</td>
<td>0.005</td>
</tr>
<tr>
<td>MAP</td>
<td>61 (16)</td>
<td>67 (9)</td>
<td>0.022</td>
</tr>
<tr>
<td>Hypotension, cumulative time, min</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>SAP &lt;90 mmHg</td>
<td>15 (22.5)</td>
<td>0 (12.5)</td>
<td>0.003</td>
</tr>
<tr>
<td>MAP &lt;60 mmHg</td>
<td>2.5 (7.5)</td>
<td>0 (0)</td>
<td>0.006</td>
</tr>
<tr>
<td>High PVI, cumulative time, min</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>PVI &gt;14%</td>
<td>10 (7.5)</td>
<td>0 (10)</td>
<td>0.001</td>
</tr>
<tr>
<td>Event: Hypotension</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Group, No.</td>
<td>110 (19)</td>
<td>31 (6)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Patient, No.</td>
<td>2 (4)</td>
<td>0 (1.5)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Event: High PVI</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Group, No.</td>
<td>46</td>
<td>14</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Patient, No.</td>
<td>1 (1)</td>
<td>0 (1)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

**Effects of PPC on Hemodynamic Stability**

Although volume restriction has proven beneficial in various clinical settings, \(^6–10\) it may also result in hypovolemia and hemodynamic instability. \(^32\) In contrast, the use of PPC enhances hemodynamic stability without incurring the risks associated with other interventions that may reduce volume requirements, such as catecholamine therapy. Therefore, we consider the results of this investigation an important finding. Although we expected PPC to blunt hemodynamic reaction to anesthesia induction, the data clearly do not support this hypothesis. The initial decline in arterial blood pressure after induction of general anesthesia was essentially identical in both groups. Apparently, if redistribution of blood plays a role in the development of hypotension during induction, compression of the legs as performed in this study cannot counteract it. During maintenance of general anesthesia, patients with PPC were, however, considerably less hypotensive and required less intravenous fluid. The observation that medium- and long-term effects of PPC were more pronounced than short-term effects during anesthesia induction suggests a potential role of mechanisms beyond prevention of blood redistribution. These mechanisms may include recruitment of extravascular fluid, the prevention of loss of intravascular fluid into the interstitial compartment, or an increase of peripheral resistance.

**Limitations of the Current Study**

The main limitation of our study is that we did not directly investigate outcomes. Minor ear, nose, and throat surgery provides a well-standardized setting to quantify clearly a method’s efficacy with regard to fluid-demand reduction, but it is not amenable to outcome studies because of the low overall rate of severe complications. We deliberately chose to perform an initial study in this clinical setting because no other major alterations of fluid demand by bleeding or other...
fluid losses were to be expected. Although the fact that fluid demand among patients under PPC remained unchanged throughout the operation suggests that the efficacy of this method may be sustained during longer operations, we cannot ruled out the possibility that this effect may decrease gradually during longer applications. When Trendelenburg positioning is applied to normovolemic volunteers, cardiovascular effects persist for the first 7 min only.28 The positive effect of PPC on fluid demand and hemodynamic stability in our study persisted through a much longer period of time. Whether PPC can effectively support fluid restriction in other clinical settings, and whether a beneficial effect on outcomes as it has been observed in specific patient populations using standard fluid restriction regimes8–10 can be reproduced with PPC can only be answered in further studies. The fact that we did not follow up with patients throughout the postoperative period, with regard to postoperative development of fluid balance, constitutes a further limitation of this study because a potential postoperative leveling out of group differences via renal excretion and oral intake cannot be excluded.

Outlook
Future investigations should also focus on further elucidating the mechanisms of PPC action. In this context, cardiac output measurements would allow researchers to discriminate between PPC-induced alterations of total peripheral resistance and effects on intravascular volume status. The obvious next step will be to study the use of PPC in populations for whom fluid restriction has been shown to be beneficial or in which maintaining hemodynamic stability is crucial. We emphasize that, although the present study suggests that PPC may be a valuable adjunct to fluid management, future studies will have to monitor development of fluid balance after discontinuation of compression therapy and investigate effects on outcomes to ascertain how short-term effects may translate into long-term benefits.

Conclusion
In summary, this study demonstrates that PPC of the legs significantly reduces fluid demand and enhances hemodynamic stability during minor ear, nose, and throat surgery. PPC has the potential to support fluid restriction regimens during surgery.

The authors thank Friedrich Bootz, M.D., Ph.D. (Professor, Department of Ear, Nose, and Throat Surgery, University of Bonn, Germany), for his kind cooperation. They also thank the nursing staff in the Department of Anesthesiology and Intensive Care Medicine, Ear, Nose, and Throat Surgery Section, University of Bonn, for their help in conducting this study. Finally, the authors thank Marta García-Granero, Ph.D. (Associate Professor, Department of Genetics, University of Navarra, Pamplona, Spain), for providing the SPSS code to compute CIs for median differences.

References

Anesthesiology 2011; 114:536–44

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