Changes in Intravascular Volume during Acute Normovolemic Hemodilution and Intraoperative Retransfusion in Patients with Radical Hysterectomy

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Background: Changes in blood volume during acute normovolemic hemodilution (ANH) and their consequences for the perioperative period have not been investigated sufficiently.

Methods: In 15 patients undergoing radical hysterectomy, preoperative ANH to a hematocrit of 24% was performed using 5% albumin solution. Intraoperatively, saline 0.9% solution was used for volume substitution, and intraoperative retransfusion was started at a hematocrit of 20%. Plasma volume (indocyanine green dilution technique), hemocrit, and plasma protein concentration were measured before and after ANH, before retransfusion, and postoperatively. Red cell volume (labeling erythrocytes with fluorescein) was determined before and after ANH and postoperatively.

Results: Mean normal plasma volumes (1,514 ± 143 ml/m²) and reduced red cell volumes (707 ± 79 ml/m²) were measured preoperatively. Blood (1,150 ± 196 ml) was removed and replaced with 1,333 ± 204 ml of colloid. Blood volume before and after ANH was equal and amounted to 3,740 ml. Intraoperatively, plasma volume did not increase until retransfusion despite infusing 3,389 ± 1,021 ml of crystalloid (corrected for urine output) to compensate for an estimated surgical blood loss of 727 ± 726 ml. Postoperatively, after retransfusion of all autologous blood, blood volume was 255 ± 424 ml higher than preoperatively before ANH. Despite mean calculated blood loss of 1,256 ± 892 ml, only one patient received allogeneic blood.

Conclusions: During ANH, normovolemia was exactly maintained. After surgical blood loss of 1,256 ± 892 ml, crystalloid and colloid supplies of 5,752 ± 1,462 ml and 1,667 ± 548 ml, respectively, and complete intraoperative retransfusions of autologous blood in every patient, mean blood volume was 250 ml higher than preoperatively before ANH. (Key words: Autologous blood; colloid infusion; erythrocyte volume; plasma volume; surgical blood loss.)

Although blood and blood products are safer than ever before, transfusion of allogeneic blood and blood components still involves some risks. In an effort to avoid such risks, acute normovolemic hemodilution (ANH) has become popular. ANH is defined as “the removal of blood from a patient immediately before operation, either before or shortly after induction of anesthesia, and simultaneous replacement with an appropriate volume of crystalloid or colloid fluids, alone or in combination, such as to maintain the circulating volume.” Effectiveness of ANH, however, is controversial. Several mathematical considerations dealing with the effectiveness of ANH are based on the condition of accurately maintaining normovolemia in the perioperative period. However, we are unaware of any information documenting the exact impact of ANH and intraoperative retransfusion on blood volume. Maintaining perioperative normovolemia involves the exact replacement of surgical blood loss with appropriate intravenous infusions per volume. This may be difficult, because estimating surgical blood loss is difficult. In addition, mathematical efforts to simulate ANH are based on estimated “normal” and not on measured red cell, plasma, and blood volumes; consequently, their results are of limited validity. In this clinical study, both compartments of blood volume were measured in the course of ANH and at the end of surgery.

Materials and Methods

The study was approved by the ethics committee at our institution and all patients gave written informed consent. Fifteen patients with the preoperative diagnosis of carcinoma of the cervix scheduled for radical hyster-
Electrocardiography, direct arterial blood pressure, central venous pressure, pulse oximetry, repetitive determinations of hemoglobin concentration and hematocrit (at least every 30 min), and arterial blood gases. Additional fentanyl and cis-atracurium were given intraoperatively as appropriate.

**Experimental Procedure**

All measurements were performed during periods of stable anesthesia and hemodynamics. Before ANH, no intravenous infusions were applied. In a time interval of 30 min, duplicate baseline measurements of plasma volume (PV), hematocrit, and plasma protein concentration (Prot) were carried out. Red cell volume (RCV) was simultaneously measured with the first of the duplicate measurements of PV (measuring procedures of the different measuring methods discussed later).

After baseline measurements, blood was removed at a rate of about 60 ml/min and simultaneously replaced with 5% albumin solution at almost the same rate. First, approximately 500 ml/m² of blood were removed. We aimed at infusing 15% more colloid than the amount of blood removed. The hemodilution bags were weighed on a precision scale so that the volume of blood withdrawn could be evaluated immediately. For fine tuning, frequent determinations of hematocrit were carried out at the end of ANH to reach a target hematocrit of 24%. The hemodilution procedure took about 20 min.

After completion of ANH and a steady state interval of 30 min without any further infusions but before beginning surgery, simultaneous single measurements of PV, hematocrit, Prot, and RCV were taken. After these measurements, 15 ml bupivacaine 0.5% and 0.1 mg fentanyl were injected into the epidural catheter; 10 min later, surgery began with skin incision. At 1.5-h intervals, 5 ml of bupivacaine 0.5% were given intraoperatively to maintain the blocked level at approximately the sixth thoracic dermatome.

The study protocol comprised exact infusion, retransfusion, and transfusion strategies for the intraoperative period. From the beginning of surgery to the point of retransfusion, 0.9% saline solution was infused continuously. The amount of intraoperative crystalloid infusion was continuously adapted to the current estimated surgical blood loss and the current urine production using the following formula: Target amount of crystalloid infusion = estimated blood loss × 5 + urine output.

An experienced anesthetist estimated blood loss by visual assessment of swabs, gowns, and the suction system. If hemodynamic variables tended to reflect hypovolemia (i.e., decrease in central venous pressure by > 7 mmHg in relation to preoperative post-ANH measurements; four cases), 250–1,000 ml of 5% albumin solution were administered in addition.

The intraoperative transfusion trigger for beginning retransfusion was established at a hematocrit of 20%. Immediately before intraoperative retransfusion of autologous blood, simultaneous single measurements of PV, hematocrit, and Prot were taken in every patient. When this hematocrit value was reached, fraction of inspired oxygen was switched to 1.0 to increase the physically dissolved oxygen. In most cases, the retransfusion procedure took place late during the surgery, when major blood loss had ceased. In eight cases, the transfusion trigger was not reached; in these cases, all autologous blood was retransfused during closure of the abdominal wall. Initially, we planned to transfuse allogeneic blood after retransfusion of ANH blood if hematocrit decreased to less than 20%, but this did not occur in any patient.

In a time interval of 30 min, postoperative duplicate measurements of PV, hematocrit, and Prot were taken immediately after closure of the abdominal wall while the patient remained under stable anesthesia without obvious blood loss. Postoperative RCV was simultaneously measured with the first of the duplicate measurements of PV.

**Determination of Plasma Volume**

Immediately before each dye injection, a calibration curve was constructed by twice measuring 10 ml of a patient’s blood having two known indocyanine green concentrations (1.25 and 2.5 µg/ml of whole blood, respectively; indocyanine green, Paesel, Frankfurt, Germany). Optical density of blood (corrected for blank) was read at 800 and 900 nm in a densitometer developed by one of the authors (H. B.). At the same time, blood
samples were taken to determine hematocrit (centrifugation of blood samples without correction for plasma trapping; variation coefficient < 2%) and Prot (Biuret method; variation coefficient < 2%). Afterward, in a dose of 0.25 mg/kg of body weight, ICG was injected as a bolus over 5 s into the central venous catheter ($T_0$ = time of injection). From the second to the fifth minute after injection, blood was continuously withdrawn by means of a calibrated pump from the arterial catheter through a cuvette, which was attached to the densitometer in a closed system. Density of blood at injection time was derived by monoexponential extrapolation of the density curve between minutes 2 and 5 back to $T_0$. If this value is put into the calibration curve $C_B o$, the theoretical whole-blood concentration of the dye at injection time, which is the initial distribution volume, can be obtained.

Theoretical plasma concentration of the dye at injection time ($C_P o$) was calculated as $C_P o = C_B o / (1 - \text{hematocrit})$. PV was calculated as $PV = D / C_P o$, where $D$ is the injected amount of dye. This method is referred to as the whole-blood method for PV determination, methodological aspects of which were published previously. This method provides reproducible results within 10 min in the operating room (mean difference and variation coefficient between double measurements: 0.3% and 6.2%, respectively).

**Calculations**

Body surface area was calculated according to Gehan and George. The amount of intravascular protein (IVP) was calculated as follows:

$$\text{IVP} = PV \times \text{Prot} \quad (1)$$

For preoperative and postoperative PV and Prot, the calculated mean of the duplicate determinations was taken.

Whole body hematocrit (WBH) was derived by simultaneous measurement of PV and RCV and calculated as follows:

$$\text{WBH} = \frac{\text{RCV}}{\text{RCV} + PV} \quad (2)$$

F-cell ratio was calculated as follows:

$$\frac{\text{WBH}}{\text{Hct}} \quad (3)$$

where Hct is the large vessel hematocrit, which is measured by means of centrifugation of the blood samples.

Blood content of ANH bags

$$= (\text{weight of full ANH bags} - 110 \text{ g}) / 1.05 \text{ g/ml} \quad (4)$$

with 110 g being the sum of CPDA1 fluid content (70 g) and weight of empty ANH bags (40 g). Specific gravity of blood was taken as being 1.05.

Surgical loss of erythrocytes was calculated according to the following formula:

$$\text{Loss of erythrocytes} = \text{RCV}_{\text{start}} - \text{RCV}_{\text{end}} \quad (5)$$

In this and the following equations, “start” represents preoperative values before ANH, and “end” represents postoperative values. Calculated loss of erythrocytes was completely caused by surgery, because in every patient, all ANH blood was retransfused before the postoperative RCV measurements were taken.
Surgical blood loss was calculated as follows:

\[
\text{Blood loss} = \text{loss of erythrocytes/} Hct_m \quad (6)
\]

where \( Hct_m \) is the mean of all hematocrit values measured during surgery (from the beginning of skin incision until closure of the abdominal wall) in a frequency of at least 1 determination in 30 min.

**Saved Erythrocytes due to Acute Normovolemic Hemodilution**

For theoretical reflections on effectiveness of ANH performed in the current study, a theoretical postoperative hematocrit (\( Hct_{\text{end t}} \)) without ANH could be calculated using the following equation:

\[
Hct_{\text{end t}} = Hct_{\text{start}} / e^{\text{surgical blood loss/BV}_{\text{start}}} \quad (7)
\]

For this and the following equations, mean values of our patients’ measured blood volume (BV) and hematocrit before ANH and calculated surgical blood loss (equation 6) were used.

Theoretical mean intraoperative hematocrit (\( Hct_m \)) without ANH could be calculated as follows:

\[
\text{Surgical blood loss} = \frac{BV_{\text{start}}}{Hct_m} \times (Hct_{\text{start}} - Hct_{\text{end t}}) / Hct_m \quad (8)
\]

\[
Hct_m = \frac{BV_{\text{start}}}{\text{surgical blood loss}} \times (Hct_{\text{start}} - Hct_{\text{end t}}) \quad (8)
\]

Equation 8 is a linear equation which gives a very close approximation of exponential equation 7 in a hematocrit range of \( Hct_{\text{end}} / Hct_{\text{start}} = 1.0 - 0.5 \). The mean value of \( Hct_{\text{end}} / Hct_{\text{start}} \) measured in this study was 0.7.

Consequently, theoretical loss of erythrocytes without ANH can be calculated as follows:

\[
\text{Surgical loss of erythrocytes} = \text{surgical blood loss} \times Hct_m \quad (9)
\]

Again, the mean value of our patients’ calculated surgical blood loss was inserted into the equation.

The respective difference in the mean measured loss of erythrocytes provides the theoretical saving of erythrocytes due to ANH:

\[
\text{Saved erythrocytes} = \text{measured loss of erythrocytes} - \text{theoretical loss of erythrocytes} \quad (10)
\]

**Statistical Analysis**

As all measured and calculated data described earlier were normally distributed as tested by Kolmogorov-Smirnov tests; they are presented as means ± SD. The amount of blood removed and of colloid supplied during ANH, as well as estimated and calculated blood loss, were compared using paired Student \( t \) tests. One-way analysis of variance for repeated measures was performed comparing intragroup differences. Post hoc testing was conducted using the Student-Newman-Keuls method for multiple comparisons. A value of \( P < 0.05 \) was considered significant.

**Results**

In all patients (\( N = 15 \)), surgical procedures involved pelvic lymphadenectomy and radical hysterectomy. Mean operation time was 3.8 ± 1.1 h. Mean age was 44 ± 14 yr; mean height was 163 ± 7 cm; mean weight was 62 ± 11 kg; and mean body surface area was 1.69 ± 0.16 m². Preoperative (before and after ANH), intraoperative (before retransfusion), and postoperative variables are shown in table 1. During ANH, PV increased significantly by 390 ± 236 ml, and RCV decreased significantly by 394 ± 76 ml. BV (PV + RCV) was unchanged. The \( f \)-cell ratios (equation 3) did not change during hemodilution.

Before retransfusion, PV did not change with respect to the value after ANH, although more than 4 l of crystalloid were infused to compensate for an estimated blood loss of about 700 ml at that point. As mentioned earlier, at the time of retransfusion, PV, but not RCV, was measured. Therefore, exact values for BV and RCV at that time cannot be given. Calculating BV and RCV before retransfusion (using a mean \( f \)-cell ratio of 0.89) would indicate a decrease in BV and RCV of about 250 and 160 ml, respectively, compared with measured values after ANH.

After termination of surgery and retransfusion of all ANH blood in all patients, there was a significantly higher postoperative PV of 524 ± 321 ml with respect to the state before ANH. RCV decreased by 266 ± 210 ml, and consequently, there was an increase in BV of 255 ± 426 ml. Surgical blood loss (equation 6) was underestimated by more than 400 ml. No patient intraoperatively received allogeneic blood; only one patient received two units of allogeneic erythrocytes in the recovery room.

Theoretical postoperative hematocrit (\( Hct_{\text{end}} \)) without ANH (equation 7) amounted to 25.7% in comparison
BLOOD VOLUME CHANGES DURING NORMOVOLEMIC HEMODILUTION

Table 1. Preoperative, Intraoperative, and Postoperative Variables (N = 15)

<table>
<thead>
<tr>
<th></th>
<th>Before ANH</th>
<th>After ANH</th>
<th>Before Retransfusion</th>
<th>Postoperative</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV (ml)</td>
<td>2,550 ± 247</td>
<td>2,941 ± 274*</td>
<td>2,846 ± 464</td>
<td>3,074 ± 376*</td>
</tr>
<tr>
<td>PV (ml/m²)</td>
<td>1,514 ± 143</td>
<td>1,748 ± 171*</td>
<td>1,695 ± 305</td>
<td>1,831 ± 266*</td>
</tr>
<tr>
<td>RCV (ml)</td>
<td>1,193 ± 157</td>
<td>799 ± 114*</td>
<td>-636 ± 147‡</td>
<td>927 ± 216*</td>
</tr>
<tr>
<td>RCV (ml/m²)</td>
<td>707 ± 79</td>
<td>472 ± 47*</td>
<td>379</td>
<td>552 ± 129*</td>
</tr>
<tr>
<td>BV (ml)</td>
<td>3,745 ± 313</td>
<td>3,740 ± 347</td>
<td>-3,482 ± 561‡</td>
<td>4,000 ± 517*</td>
</tr>
<tr>
<td>BV (ml/m²)</td>
<td>2,222 ± 162</td>
<td>2,220 ± 188</td>
<td>2,074</td>
<td>2,383 ± 360*</td>
</tr>
<tr>
<td>HCT (%)</td>
<td>35.9 ± 3.5</td>
<td>23.7 ± 2.3*</td>
<td>20.5 ± 3.4‡</td>
<td>25.1 ± 3.8*</td>
</tr>
<tr>
<td>f-cell</td>
<td>0.89 ± 0.05</td>
<td>0.90 ± 0.05</td>
<td>0.91 ± 0.05</td>
<td>0.91 ± 0.05</td>
</tr>
<tr>
<td>Plasma protein concentration (g/liter)</td>
<td>62 ± 5</td>
<td>57 ± 4*</td>
<td>45 ± 5‡</td>
<td>47 ± 4*</td>
</tr>
<tr>
<td>Plasma protein concentration (g/liter)</td>
<td>157 ± 18</td>
<td>169 ± 21*</td>
<td>127 ± 23‡</td>
<td>144 ± 20*</td>
</tr>
<tr>
<td>Central venous pressure (mmHg)</td>
<td>8 ± 4</td>
<td>11 ± 4</td>
<td>13 ± 4</td>
<td>14 ± 5*</td>
</tr>
<tr>
<td>Mean arterial pressure (mmHg)</td>
<td>69 ± 11</td>
<td>67 ± 14</td>
<td>69 ± 14</td>
<td>70 ± 11</td>
</tr>
<tr>
<td>Heart rate (beats/min)</td>
<td>68 ± 12</td>
<td>73 ± 10</td>
<td>75 ± 13</td>
<td>77 ± 13*</td>
</tr>
<tr>
<td>Blood removed (ml)</td>
<td>1,150 ± 196</td>
<td>1,111 ± 196</td>
<td>1,193 ± 291</td>
<td>1,667 ± 548</td>
</tr>
<tr>
<td>Colloid infused (ml)</td>
<td>1,333 ± 204‡</td>
<td>1,483 ± 291</td>
<td>1,462 ± 606</td>
<td>1,477 ± 256*</td>
</tr>
<tr>
<td>Infusion of saline solution (ml)</td>
<td>0</td>
<td>1,483 ± 1,408</td>
<td>5,752 ± 1,462</td>
<td></td>
</tr>
<tr>
<td>Estimated blood loss (ml)</td>
<td>0</td>
<td>727 ± 726</td>
<td>853 ± 790</td>
<td></td>
</tr>
<tr>
<td>Calculated blood loss (ml)</td>
<td>0</td>
<td>572 ± 550</td>
<td>1,256 ± 892§</td>
<td></td>
</tr>
<tr>
<td>Urine production (ml)</td>
<td>794 ± 550</td>
<td>1,543 ± 793</td>
<td>1,553 ± 793</td>
<td></td>
</tr>
</tbody>
</table>

Values are mean ± SD.

ANH = acute normovolemic hemodilution; PV = plasma volume; RCV = red cell volume; BV = blood volume; HCT = hematocrit; IVP = intravascular protein; CVP = central venous pressure; MAP = mean arterial pressure; HR = heart rate; ~ = before retransfusion; BV and RCV were calculated by an f-cell ratio of 0.89.

* P < 0.05 difference with respect to value before ANH.
† P < 0.05 difference between blood removed and colloid supply.
‡ P < 0.05 difference with respect to the value after ANH.
§ P < 0.05 difference between estimated and calculated blood loss.

with postoperative hematocrit with ANH of 27.2% (corrected for postoperative hypervolemia). Theoretical mean intraoperative hematocrit (Hctₘ) without ANH (equation 8) amounted to 30.5%, in comparison with measured Hctₘ with ANH of 21.9%. Mean theoretical loss of erythrocytes without ANH (equation 9) was 383 ml, in comparison with mean measured loss of erythrocytes with ANH (equation 5) of 266 ml. Consequently, mean calculated amount of erythrocytes theoretically saved due to ANH (equation 10) was 117 ml.

Discussion

As far as we know, double-label measurements of BV in the course of ANH did not exist before this study. We investigated a small number of patients with homogeneous preoperative PV and RCV values undergoing ANH and a defined surgical procedure with a standardized infusion and transfusion strategy.

The objective of reducing allogeneic transfusions has led to diminishing the transfusion trigger to a hemoglobin concentration of 70 g/l²⁴ or 60 g/l²⁵ in recent years. Weiskopf et al. demonstrated that ANH to a hemoglobin concentration of 50 g/l does not produce evidence of inadequate tissue oxygenation in conscious, healthy, resting volunteers.²⁶ Such a low hemoglobin level should also be safe in patients without cardiopulmonary diseases during stable anesthesia, which reduces oxygen consumption,²⁷–²⁹ and hyperoxic ventilation, which in addition improves tissue oxygenation.³⁰ Postoperative hemoglobin concentration, however, should be high enough such that increased oxygen consumption due to shivering or increased posttraumatic metabolism can be covered and basic physical activities can be performed by patients.³¹–³³ This situation could lead to introducing two transfusion triggers: One for the intraoperative period during hemodynamic stability, stable anesthesia, and hyperoxic ventilation, and one for the postoperative period, when there are higher oxygen consumption and normoxic ventilation. By accepting a low intraoperative hematocrit (15–20%) and postoperatively increasing this value before extubation by retransfusion of autologous
blood, ANH could realize this principle. We performed ANH to a low but not minimal hematocrit, because in clinical practice, the amount of surgical bleeding during extensive surgery frequently is not constant, and in case of suddenly extensive bleeding, hematocrit could easily decrease below the lowest acceptable value.

Regardless of whether or not using ANH will lead to a reduction in transfusions of allogeneic erythrocytes, its proper use will lead to the highest possible postoperative RCV after major blood losses which do not necessarily involve allogeneic transfusions. Consequently, ANH may offer an economical way of preserving the patients’ preoperative resources of erythrocytes. It was not the original intention of this study to completely answer the question of effectiveness of ANH in avoiding allogeneic transfusions; however, these data can be used to aid the efficiency calculations done by others.

Preoperative State

The possibility of already existing slightly hypovolemic states preoperative, which often cannot be recognized by routine monitoring, represent a serious dilemma with regard to perioperative fluid therapy. Comparing our patients’ PV values before ANH (table 1) with normal PV values established by Pearson et al.34 (PV = 1,395 × body surface area; 99% limits ± 25%) revealed that mean preoperative PV was 109% of predicted normal. The same comparison for RCV showed a preoperative deficit of 115 ml/m² for our patients’ RCV (normal RCV for women: 822 ml/m²; 99% limits ± 25%).34 The comparison with normal values established in our laboratory in 10 female volunteers (RCV = 848 ± 54 ml/m²)19 also showed that RCV of the investigated patients was significantly below normal. A slightly elevated PV and reduced RCV resulted in a normal preoperative BV (about 99% in comparison with normal values established by Pearson et al.).34 The reasons for this deficit in RCV are unclear. Increased vaginal bleeding from the tumor, iron deficiency, or tumor anemia could be some explanations. A preoperative deficit in RCV of more than 100 ml/m² obviously may be of importance for the perioperative transfusion strategy as well as for effectiveness of ANH.

Period of Acute Normovolemic Hemodilution

As presented in table 1, in the present investigation, normovolemia was maintained and BV was not elevated after ANH, despite administering 15% more volume of colloid than blood removed. In a previous investigation in our laboratory, PV before and after preoperative ANH was measured in 12 patients also scheduled for gynecologic surgery using the same measuring method for PV as used in this study.35 Mean PV before ANH was 3,148 ± 327 ml, and 1,018 ± 75 ml of blood, corresponding to 653 ± 47 ml of plasma, were removed. Supplying 1,088 ± 93 ml of 5% albumin solution was supposed to result in a theoretical PV after ANH of 3,583 ml; however, measured PV after ANH was only 3,414 ± 340 ml. Consequently, the deficit of 169 ml was 16.6% in relation to the volume of blood removed. An increased extravasation rate of albumin during or after ANH with 4% albumin solution was shown by Payen et al.36 by means of radioactively labeled human serum albumin. The authors concluded that for ANH, the volume of colloid infused should be higher than that of blood withdrawn. The causes for an increased extravasation rate of albumin in the course of ANH remain to be elucidated. The fact that replacing blood removed with a 10% surplus of 5% albumin solution will better maintain hemodynamic stability during ANH than replacing in a ratio of 1:1 has been determined previously.26 According to these findings, we decided to infuse 15% more of colloid than blood removed for ANH in the current investigation.

Using the same method for measuring PV as used in this study but without also measuring RCV, Haller et al. postulated a systematic increase in f-cell ratio during ANH.35 Based on the two-compartment model of the entire vascular bed brought forward by LaForte et al. this would mean that there is a change in the relation between macrovascular and microvascular hematocrit, a change in the relation between the macrovascular compartment volume and the whole blood volume, or both in the course of ANH.37,38 In the current investigation using a double-label technique for BV measurement, we could not find a significant difference between f-cell ratios before and after ANH. The reason for these contradictory findings is unclear. We can only conjecture that it could be a question of the rate of blood removal and simultaneous replacement, which might vary from one clinical study to another. Another explanation, which in our opinion is less probable, is that the postulate being based on single-label measurements, which is now contradicted by the gold standard (double-label measurement of BV), is false.

Period before Retransfusion

Before this investigation, we expected PV to increase until retransfusion of autologous blood, due to the standardized crystalloid infusion regimen used, to compensate for surgical bleeding. It was suggested that losses of up to 30–40% of blood volume usually can be treated...
adequately with crystalloids. As shown in table 1, values of BV calculated by means of an f-cell ratio of 0.89 led to the assumption of decreasing BV until retransfusion, accompanied by a major decrease in Prot and IVP (12 g/l and 42 g, respectively). Consequently, the applied infusion regimen using crystalloids was not sufficient to compensate for a mean blood loss of 730 ml (20% of patients’ BV) during intraabdominal surgery, especially as the calculated surgical blood loss before retransfusion (equation 6; calculated value: 749 ml; RCV before retransfusion calculated by an f-cell ratio of 0.89) indicated that surgical blood loss at that time was correctly estimated.

Preoperative Versus Postoperative Volume Balance
After retransfusion and additional colloid supply, PV increased significantly so that mean postoperative BV was about 250 ml higher than the preoperative measurement before ANH. Postoperative normovolemia after major surgery is not a matter of course. A previous investigation in our laboratory using the same PV measuring method as used in this study showed postoperative hypovolemia in patients after surgery due to ovarian cancer. As a result, the reason for postoperative slight hypervolemia in the current investigation requires clarification. The protein balance shows that loss of 96 g of protein (calculated by protein supply — change in IVP) was replaced to a sufficient extent by supplying 83 g of protein. In contrast, there was a deficit in protein supply of 45 g in relation to protein loss (145 g) in the previous investigation of patients with ovarian cancer (mentioned previously). Thus, a sufficiently balanced protein supply seems to be the reason for postoperative slight hypovolemia in the current investigation.

As mentioned previously, in our view, ANH is part of a concept of economically treating patients’ preoperative resources of erythrocytes. A recently published meta-analysis did not conclusively answer questions regarding the effectiveness of ANH. The amount of erythrocytes saved by ANH depends on three factors: (1) the initial hematocrit; (2) hematocrit at the end of ANH; and (3) most importantly, the amount of surgical blood loss, which mostly cannot be predicted. As an indication for ANH, an expected blood loss of 20% to 30% of the patients’ estimated BV was proposed. In the current investigation, mean surgical blood loss was 1,256 ml (34% of the patients’ measured BV). Theoretical saving of only 117 ml of erythrocytes in combination with the postoperative hematocrit of 27.2% (corrected for the high postoperative BV) means that without ANH, the postoperative hematocrit would not have been substantially different, and an intraoperative transfusion of allogeneic blood probably would not have been necessary in more than one patient. However, performing ANH reduced surgical loss of erythrocytes by 44% (117 ml in relation to the measured loss of erythrocytes of 266 ml) and consequently led to a postoperative RCV that was 11% higher.

Our data showed that ANH with a 15% surplus of 5% albumin solution in relation to blood removed maintained normovolemia. After ANH, an infusion regimen supplying only crystalloid did not seem to be sufficient to compensate for a surgical blood loss of about 20% of patients’ BV during intraabdominal surgery. Retransfusing of autologous blood led to a higher postoperative BV with respect to the preoperative value before ANH. By reducing surgical loss of erythrocytes, ANH could promote economical treatment of patients’ preoperative resources of erythrocytes.

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