The Shedding of Blood, and Its Measurement: Is It Normalized Deviance?

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RECENTLY, AS PART OF our APEX ***CRNA Update*** research, we performed rather unscientific polling of colleagues who are in training, recently out of training, and those who are veteran clinicians (ie, in practice for > 5 years). We posed a simple question to them. Some questions were asked over beers, others by email, and a few by ZOOM. While our question did not undergo the usual reliability and validity testing, nor was IRB approval or informed consent obtained, and no statistical analysis was performed, the question posed to each individual was this:

> ***Did you receive formal, evidence-supported education and training in your basic anesthesia program on how to measure blood loss in a range of surgical patients?***

In our sample of 14 (OK, we admit that this is not going to get published anywhere on that puny sample size) some responded "No," a few responded something like "Well, we already knew how to do that from what we were doing before anesthesia training," and 1 indicated "I think so, but I can't remember."

Monitoring blood loss during surgical procedures carries enormous significance and is a major responsibility of the CRNA. Many clinical decisions and interventions are made based on the assessment of a patient's blood loss. Many of those decisions have far-reaching, downstream consequences for the patient, especially when a blood transfusion is involved but also related to how much crystalloid or colloid should be administered.

If you consider that question for a moment:

> ***Did you receive formal, evidence-supported education and training in your basic anesthesia program on how to measure blood loss in a range of surgical patients?***

...What's your response?

> ***And we might add to it: In your postgraduate continuing education, have you encountered evidence-based research and strategies designed to improve your estimation of operative blood loss?***

It was interesting that in our unscientific polling, 2 in the "veteran" group said that they never let the suction bottle out of their line of view because as one put it, "It can fill up in a matter of seconds, and we seem to be the only one who is aware of it."

Whether you received formal, informal, or no focused education and training during your basic program in the monitoring and estimation of blood loss during surgery, let's take a deep dive into the issues associated with it. In doing so, we will address 5 key questions that while independent from one another, share a common foundation:

1. Why it is important to monitor and assess blood loss?
2. How good are we at estimating shed blood loss?
3. What evidence-based techniques and approaches are available to the clinician to assess blood loss?
4. What can be done to elevate its universal and formal inclusion into the basic and continuing education curricula of the CRNA?
5. What's new or in development to improve our estimation of blood loss?

Question 1: Why is monitoring and assessing blood loss important?

This seems like a straightforward and easy question to answer, but let's suspend our biases here and look at the question with a curious, open-minded, and scientific perspective.

There is considerable evidence demonstrating the value of estimating blood loss, especially with respect to:

- Pre-surgical and anesthetic planning. For example, deciding between regional or general anesthesia, considering the need for autologous donation, discussing risks of blood loss and transfusion with the patient, judging the need for alerting the blood bank, etc.
- Intraoperative indicator for volume and fluid type replacement (crystalloid, colloid, red cell, or component therapy).
- Determining if the blood shed is due to anatomic trauma from surgery or if due to coagulopathy.
- Use as a quality-assurance metric for the surgeon, blood bank, and performance review, even for hospital accreditation.

Surgical blood loss is measured or estimated from a variety of sources.

The items on this list, and there may be other reasons that you might add, carry great weight. Whether we are assessing blood pressure, oxygenation, lung function, cardiac performance, depth of anesthesia, muscle relaxation, or temperature—all essential tasks of ours—the assessment method must be accurate. If we gather the information that is imprecise, faulty, or otherwise misleading, the implications for the patient may be grave.

The measurement of blood loss is rarely considered as a single factor in any clinical decision about how to proceed with patient care. While certainly important, the determination of the amount of blood lost is just one piece of the decision-making equation. There are other important and clinically observed metrics that bear on any intervention related to that loss as well. These include the patient's blood pressure, heart rate, oximetry value, skin color, urine output, serial hemoglobin measurement, and a gestalt based on the experience and knowledge of the providers.

The assessment of surgical blood loss is a fundamental patient-management responsibility of ours. The optimization of hemostasis and a focus on reducing blood loss, are goals of the surgical and anesthesia teams. We often go into the care of our patient with an estimated blood volume and a calculated tolerance for how much blood might be shed before aggressive management, including transfusion, is considered. Precise knowledge of the amount of loss is essential knowledge!

What is so special about blood?

It is not our intent to review all the unique characteristics of blood here, but rather to provide a brief overview of this river of life and why it merits our close observation when it is spilled.

Characteristics of blood

- It is intrinsic to our life and vital to our every function
- Generally, 38°C, or about 1 degree higher than our core temperature
- An adult has about 5 to 6 liters of blood; a newborn about a cup full
- Blood is 55% plasma, 90% is H_2O, proteins, electrolytes, glucose, wastes
- Blood is 45% is RBCs, white cells, and the platelets
- Red blood cells produced at 2 and 3 million produced every second in the bone marrow
- Red blood cells lifespan is up to 120 days, iron is recycled
- Red blood cells carry O_2 in conjunction with hemoglobin delivering it to the cells
- Blood ferries CO_2 for its eventual elimination

- Blood plays a thermoregulatory role
- Blood contains immunomodulating proteins and cells; all vital roles in our defense
- 1 cubic mL contains 4–6 million red blood cells, 4,500–11,000 WBCs, 150–400K platelets
- 1 cubic mL has a host of immune globulins and clotting factors
- White blood cells are highly specialized defense specialists, lifespan days to years
- Platelets have a life span of about 10 days
- Normal hemoglobin is 13.5–17.5 g/dL for men, hematocrit of 41%–53%
- Normal hemoglobin and hematocrit are a little lower for women
- Prior to 1900, blood was viewed as the same for all—leading to many transfusion deaths
- Blood type is a function of the antigens which coat the red blood cells
- Over 30 blood group systems exist, including the ABO, Rh, and Kell groups
- Blood is something others may need—we may elect to give it to others
- Blood has great worth and can be sold
- Can be lifesaving but can transmit life-threatening disease
- Blood is a tissue transplant with immunological consequences.

This partial list of the characteristics of blood serves to remind us of how precious a commodity it is. Essential to life, there is no current substitute for it despite two decades of intense effort to create a synthetic replacement. It can't be made, and only largely through volunteer efforts of altruistic donors can it be replaced via transfusion.

Given its critically important role in life as we know it, our responsibility in assessing its loss cannot be overemphasized. Measuring and recording blood loss are considered standard and essential metrics, including mandatory documentation in the operative note by the Joint Commission. [(1)] Monitoring and assessing its loss is an essential role that we assume and one we are mandated to perform during surgical anesthetic care.

Question 2: How good are we at estimating shed blood?

If you step into an operating room anywhere in the US you will find standard monitoring equipment, perhaps varying in appearance, but common in their technological and methodological design. This includes oximetry, inhaled and exhaled gas analysis, pressure measurement, heart rate, and rhythm detection, temperature, and other metrics that are crucial to the care we render. In fact, we are mandated to record these during surgical procedures, and our monitoring arrays provide a seamless and efficient way to do so. Further, we know that the values displayed are accurate indicators of the patient's status.

Yet while the assessment and recording of shed blood is also a mandated standard of care, there is currently no "gold standard" method for accurately measuring the shed blood of a patient. In fact, in our APEX review of very rich literature on the subject, we found a strong consensus that our traditional approach to assessing blood loss is largely characterized as unreliable.

Ideally, every drop of shed blood should be documented.

Imagine, for just a moment, if we reported that oximetry, blood pressure, exhaled carbon dioxide measurements were "unreliable". Yet, in everyday clinical practice we've become somewhat resigned to our imprecision or our frank inadequacy in accurately quantifying the amount of blood shed by our patients during their operative procedures.

Decisions about fluid replacement, or in the case of if, when, and how much to transfuse, might be vastly improved if we can incorporate accurate (precise?), real-time quantification of shed blood into our clinical decision making. There is obviously a great deal at stake and our inability to achieve this should be addressed.

Estimating shed blood during operative procedures and in controlled experiments reveals considerable inaccuracies as we generally tend to underestimate during large blood loss situations and overestimate during low blood loss cases. Let's look at several studies that focused on the related issues.

Those of us who are involved in the care of patients undergoing debridement and grafting during surgery for the patient with burns appreciate how prodigious the bleeding can be and the challenge of its quantification. A study investigated assessments made by junior and senior burn surgeons and experienced anesthesia providers in their accuracy in assessing blood loss. [(2)] "Eyeballing" the loss of blood in 46 burn surgeries revealed great individual under- and over-estimations of blood loss, though the differences improved somewhat when each member of the team expressed their assessment, and there was an effort to collaborate on arriving at a final estimation.

In 5 of the 46 procedures, there was a need for late transfusion due to underappreciation of actual blood loss based on low postoperative hemoglobin levels. The study also employed gravimetric analysis (weighing) of soiled swabs and dressings, but this technique was found to underestimate actual blood loss by almost 50%.

We are all aware that multilevel spine surgery can be associated with substantial blood loss. In another relevant study, 60 patients having multilevel, posterior spine surgery were prospectively studied. [(3)] Hemoglobin and fluid volume were measured from all the surgical sponges, the suction containers, and the cell salvage equipment. In this technically sophisticated study, the volume and concentration of hemoglobin from all collection materials and the suction canister were measured and converted into the volume of blood lost. This was then compared with the providers' estimation of blood loss that was documented on the anesthesia record.

On average, the estimated loss was 40% greater than the actual measured blood loss. The authors detailed the many difficulties involved with estimating blood loss and the risks associated with getting it wrong. One major problem that they pointed out was the challenge that is exacerbated by attempts to assess serosanguineous solutions. They cautioned that there was a very real danger of overzealous administration of crystalloid and colloid solutions due to incorrect blood loss estimations, as well as the possibility of an unnecessary transfusion.

In these studies, we see both over- and underestimations of blood loss; it is typical of the literature and clinical experience associated with subjective visual determinations.

A study from the urological surgical literature involved 52 consecutive patients undergoing radical retropubic prostatectomy. The surgeons and anesthesia providers provided their estimations of blood loss which were then compared to a formula-based calculation of blood loss. [(4)]

The formula-based approach was justified scientifically in the text of the paper and involved the following (feel free to skip this as the calculation is cumbersome!):

> The actual blood loss (ABL) was calculated as the average ABL_n resulting from two computations of the following formula: $ABL_n = (EBV \times (H_i - H_f)) / ((H_i + H_f)/2) + (500 \times T_u)$ where: (1) estimated blood volume (EBV) was assumed to be 70 cm^3/kg; (2) H_i and H_f represent Hgb_i and Hgb_f for one computation and Hct_i and Hct_f for the second computation, and (3) T_u being the sum of autologous whole blood (AWB), packed red blood cells (PRBC), and cell saver (CS) units transfused. For each patient, ABL was compared with EBL_A and EBL_S.

We believe you would agree that the calculation is quite cumbersome to perform and involves recruiting lab values into the mix. But in fairness to the scientific rigor of the paper, the authors did import systematic research to support the use of the calculation. The bottom line was that both surgeons and anesthesia providers significantly underestimated blood loss in these cases.

A close look at a treacherous domain: obstetrical bleeding

CRNAs are critical to the safe delivery of obstetrical services, many with practices heavily devoted to obstetrical anesthesia. In our review of relevant publications involving blood loss measurement, we discovered a systematic review in the midwifery literature looking at blood loss during obstetrical delivery meriting our detailed look. [5]

The authors reminded us that the loss of blood during childbirth has long been reported as a major cause of poor outcomes and continues to this day, not just in the third world, but in developed nations such as the US. Many interventions have been implemented in contemporary practice to moderate risk, but as any CRNA knows, blood loss during delivery can onset with astonishing suddenness, be difficult to control, and progress with grave consequences. Not only is control of bleeding essential, but also is the vital need to quantify shed blood to best inform decision making.

Most of the blood loss resulting from delivery of a child occurs within the first 60 minutes after birth, with uterine atony and uncontrolled surgical bleeding as the major causes. [5, 6] In routine clinical practice, it is the visual estimation of blood loss that predominates despite the widely appreciated inaccuracies and challenges associated with this approach. Improving this situation has obvious, important implications for the individual patient. In the broader view, the accurate quantification of blood loss is critical for research that evaluates interventions designed to moderate bleeding, such as antifibrinolytic therapy.

Using sophisticated (and expensive) direct colorimetric measurements of blood loss during vaginal delivery, a seminal paper found the incidence of postpartum hemorrhage was underestimated by 89% using a visual blood loss assessment. [7] Another study found just the opposite in a similar patient population, finding that visual assessment of blood loss was 20% greater than the direct measured blood loss in almost 60% of the cases. [8] The error associated with visual estimation worsened in both studies as the blood loss increased beyond 300 mL. We will discuss colorimetric measurement a bit later.

Yet, another study published in a high-impact journal reported significant inaccuracies in blood loss measurements during operative and normal vaginal delivery, with visual estimates of blood loss that significantly under- and overestimated loss with no consistent pattern. [9] The visual assessment of blood loss was noted to not only be consistently inaccurate but resulted in either overly aggressive or inadequate treatment regimens.

A systematic review from the midwifery literature took a global look at the issue making several key points. [5] We summarize these as follows:

- There is a great challenge in estimating blood shed with the birthing of a child, no matter if it is a "normal" vaginal delivery, a complicated vaginal delivery, or surgical sectioning.
- The estimation of blood loss is confounding and daunting to everyday practitioners.
- In the obstetrical suite, large-volume–blood loss is associated with the most inaccurate assessments.
- Objective data such as vital signs, serial hematocrit, and patient observation are helpful but are of little help in the actual measurement of shed blood.
- There is no place in a study of high methodological purity for the visual assessment of blood loss.
- Blood loss during the birthing process is a significant issue and there is a great need for estimation methods that are characterized by a high degree of accuracy, implemented with minimum equipment, and great practicality.

Research reported in the *AANA Journal* in 2019 involved 163 simulated blood loss observations involving all members of the surgical team working in a university hospital system. [10] All participants visually estimated the amount of blood placed on surgical sponges at 4 different stations, with each simulation varying in the number of sponges and the amount of blood placed on the sponges.

There were gross inaccuracies in both over- and underestimating the amount of blood present, with underestimations predominating. The accuracy of the estimations worsening as the amount of blood present increased. There was no correlation to the type of surgical team member, years of experience, or self-assessed ability to accurately quantify the amount of blood present. The authors concluded that "inaccurate visual estimations of blood loss might endanger patient safety."

A final study we will look at in addressing question #2 comes from general surgery literature. Three different operative simulations were performed in this study that enlisted 17 anesthesia providers, 22 surgeons, and 21 nurses and technicians. [11] The researchers used known quantities of porcine blood placed on tapes, sponges, and suction canisters. The 3 scenarios consisted of a low volume (50 mLs), a medium loss (300 mLs), and a high (900 mLs) blood loss procedure. The participants' estimations, years of experience, type of experience, and their reported confidence in the assessments were recorded.

The 3 scenarios, that is low/medium/high loss procedures, demonstrated an overall mean error of inaccuracies of 52%, 61%, and 85% respectively, defined as how far from the true value (over or under) was recorded. For example, a 50% error would mean that in estimating a true 100 mL loss, you recorded either 50 or 150 mLs as your observed loss.

Interestingly, there was no association between job type, years of experience, or confidence in the ability to assess loss. The authors concluded that "visual estimation of operative blood loss is unreliable and inaccurate."

A recent editorial in *Anesthesia & Analgesia* provided a scathing view of relying too heavily on visual estimations of blood loss for clinical decision making. [12] The authors and experienced anesthesia clinicians noted that we lack a reliable quantitative method for measuring shed blood and those visual estimations of blood loss are "universally accepted to be inaccurate."

Question 3: What techniques are available for us to assess surgical blood loss?

Visual (eyeballing) estimations of blood loss

We will return to this method when we address question 4, but during everyday clinical practice, blood that is suctioned into a canister or container of some sort can be accurately measured visually, the task assisted by marked volume units. When irrigation or other fluid (amniotic for example) is combined, additional considerations must be factored in. Blood lost into sponges, laparotomy pads, drapes, or other surfaces that are visually assessed result in measurements that are highly subjective and inaccurate.

Direct measurement

We encountered many studies that used a direct measurement approach involving the actual collection, to the extent possible, of shed blood. The use of a suction and collecting canister is one example, as is the use of a collecting basin or an impenetrable drape strategically placed to capture blood are common. The latter approach was commonly noted in obstetrical cases, but often the actual method of performing this was not described nor was the technique of measuring the blood.

Gravimetric measurement

In the many papers that we reviewed the gravimetric method was commonly used. In this approach, blood-soaked materials are weighed, subtracting the previously determined dry weight of each item, and that amount added to blood captured in the drapes and any containers that were used. Two representative studies, both with different conclusions, will be presented.

In a paper from the gynecological surgery literature, random samplings of laparotomy cases was selected over a 2-month period. [13] The blood in the sponges was carefully assessed by the OR staff by using the standard weight-based (gravimetric) approach. Blood that was in the sponges was then analyzed using colorimetric analysis by a Beckman spectrophotometer, and using the patient's preoperatively assessed hemoglobin, the amount of blood in the soaked sponges was determined. We will discuss the colorimetric approach shortly. The colorimetric and gravimetric measurements were then compared. There was poor to no correlation of the measures. The authors concluded that the use of a gravimetric approach was not clinically useful due to its inaccuracy.

Another study using gravimetric measurement was conducted in the delivery room of 52 women having a vaginal delivery. [(14)] Visual estimation by all delivery room personnel was compared to standardized gravimetric analysis of shed blood. The personnel, regardless of professional role, routinely underestimated their visual assessments of the gravimetric determination by up to 28%.

The authors voiced their concern that the recognition of postpartum bleeding is of utmost importance to patient safety and outcome, finding the gravimetric method to be accurate and vastly superior to visual assessment. They further argued that visual or "eyeballing" methods "should be eliminated from practice."

These results were confirmed in another similar study involving 150 vaginal births where the gravimetric method was compared to visual estimations. [(15)] The authors of this study found that estimated blood loss was routinely 30% less than the visual estimations by all members of the delivery team, regardless of years of experience or self-reported confidence in their visual accuracy.

The discerning CRNA may ask if the weighing of blood needs any "adjustment" when considering its translation as a volume issue. There is an important point of physics that needs clarifying for any study, or advocate of, gravimetric analysis before it can be considered as good science. When weighing a blood-soaked surgical absorber such as a sponge, it is assumed that the volume of blood lost is in mLs. This measurement is fundamentally grounded in the concept of density, which is mass per unit volume.

Water has a density of 0.9975 g/mL, commonly described as 1 gram of water = 1 mL. [(16)] There are some studies that support that the density of shed blood and water are "close enough" such that when weighing a sponge before (dry) and after (blood contaminated) should be a reliable method to measure the volume of blood in mLs.

Gravimetric analysis can succumb to certain confounding variables like saline irrigation, other body fluids, and even solid body tissues, all of which can contaminate the material being weighed. Unless carefully factoring these possibilities in this method too may prove to yield suspect measurements.

Although tedious and resource-intensive to perform, gravimetric evaluation of intraoperative blood loss does, when done properly, appears to be an accurate approach. When done routinely by staff who become facile with its method, it can be incorporated into the clinical setting providing good information that can be practically employed.

Photometry or colorimetric measurement

We encountered photometry and colorimetric methods, both essentially the same, frequently in our review of the literature, either as the primary technique used to assess blood loss or as part of a sophisticated research effort. In the latter circumstance, a photometric approach is often presented as a kind of gold standard to which another approach was compared. The technique is indeed sophisticated, involved, resource intensive, and expensive, and is largely relegated to research efforts.

Part of the photometric technique involves the conversion of blood pigment to alkaline hematin. As noted above, we often saw this alkaline hematin method being referred to as a gold standard for measuring blood. One example study we encountered captured carefully measured blood collected from gynecologic surgeries and then in a simulation of postpartum events, deposited this known quantity of blood onto sanitary pads and towels. These materials were then collected in a plastic bag and given to a trained technologist who was unaware of the quantity of applied blood.

A dedicated auto-extractor instrument rapidly removed the blood moving it into an appropriate liquid solution where it was blended, filtered, and its optical density determined. Based on a baseline, preoperative hemoglobin levels, and an applied formula, a measured amount of blood loss can be revealed.

There are other associated methods that we found involving the measurement of oxyhemoglobin by spectrophotometry. In this case swabs, sponges, lap tapes, even paper pads that have blood on them are placed in a washing device with a previously known amount of water, plus a detergent-like chemical, and ammonium hydroxide to liberate the hemoglobin. The solution is then centrifuged, filtered, and measured by a photoelectric colorimeter similar in nature to our pulse oximeter.

These approaches are obviously highly involved and as described, are not likely to provide the everyday, real-world clinician with a practical method of assessing blood loss. The initial collection process of blood-soaked materials, rinsing, and analysis is highly resource-, labor-, and time intensive, and also expensive. We even found a validating study of the photometric technique using radioactive chromium-tagged red blood cells. So, rest assured, while the technique works and there is no shortage of ongoing activity in the domain, the approach is not likely, in its current form, to penetrate everyday practice.

Formula-based measurement

This approach takes many forms and relies on the calculation of shed blood based on the estimation of a patient's blood volume, sex, height, weight, and serial changes in laboratory hemoglobin and hematocrit values. Additionally, any fluids administered must be inputted into the somewhat cumbersome—at least in our view—formula.

One example (17) follows, but first the formula, then the explanation (this formula description can be skipped for all but the most interested):

$$\text{Hemodilution HGB} = [\text{Starting HGB} - (\text{EBL/TBV})\text{x L}] - [(\text{EBL/TBV}) \text{ x H}] - [(\text{VR/TBV}) \text{ x r}]$$

Legend for the hemodilution formula:

The starting HGB is the pre-donation hemoglobin in a bench (animal) study, or when used in a surgical patient, is the preoperative hemoglobin, or when applied to traumatic cases, could be estimated as the average hemoglobin for the person's age and sex. Blood loss coefficient, L = 5.111 g/dL; EBL, estimated blood loss; equilibration coefficient, H = 6.722 g/dL; resuscitation coefficient, r = 2.617 g/dL; TBV, total blood volume; VR, volume replacement.

Because of the inaccuracy of visual estimation and the complexity and cumbersome nature of other forms of analysis, some advocate for formula-based approaches to blood loss estimation. The above formula is one of these, and while we feel it both cumbersome to use in everyday practice, and based on some assumptions that may not be constant in all cases, we wanted to present it as it is appearing in the literature. (17)

These formulas are generally based on concepts related to hemodilution after blood loss and crystalloid infusion and an effort to better quantify loss using reverse or retrospective logic, that reveals how the patient reached this point in time. Studies of formula-based calculations are showing up in the literature as a systematic, logic-based way to estimate the response of hemoglobin levels to blood loss and fluid replacement.

Out-of-the-box approaches

We came across a few rather novel approaches that while interesting, seem to us as not being likely to gather much traction. For example, 2 different studies from 2 different medical disciplines used ultrasound to quantify the diameter of the inferior vena cava as a way to estimate the amount of blood lost. (18, 19) The authors observed that there were changes (smaller in size) that were noted before other more classic signs of shock ensued. We were initially intrigued by this work as another interesting example of the application of ultrasound technology to solve an important problem. However, after reflecting, the approach seems crude and insensitive, akin perhaps to observing if the ice cream in your freezer is melting as a way of determining if your refrigerator is plugged in.

Another intervention involved the exploitation of the purported sensitivity of central venous blood oxygen saturation as a metric of the amount of blood loss experienced. [(20)] While the work has apparently only involved animal models, and as you know we try to avoid these due to their questionable translation to humans, it is nonetheless out there. At a minimum, we had questions about the approach as it seems that initial blood volume, drugs the patient may be taking, need for a central line to be placed, and even body mass might easily perturb measurement.

A pictographic approach involves visual comparison of photographs of blood-soaked sponges with known amounts of blood and using that as a reference guide for providers to assess blood-contaminated items during a real case. We found several studies reporting the use of this technique. One very typical paper used color photos in the OR for staff to compare soaked sponges and other blood-captured items. [(21)]

This study was performed in a simulation center where clinicians were asked to estimate blood loss in a mock C-section delivery scenario. The authors reported that their institution-specific photo guide improved the accuracy of judging the amount of blood present in the various blood collection items.

The concern we had with this is that there are many different types of blood capture materials and devices manufactured by a variety of companies. Each institution would have to create its own unique tools. This was also a simulation study with questionable and/or unknown translations to actual cases.

So where does this leave us with respect to question #3: What techniques are available for us to assess surgical blood loss?

In our extensive review of the published literature, we came away with the following caveats and takeaway points:

- CRNAs are charged with managing surgical blood loss as a basic clinical responsibility, this necessitates valid (accurate) and reliable (consistent) detection and measurement of intraoperative bleeding.
- Research grounded in optimizing patient outcomes clearly demonstrates the importance of measuring blood loss and acknowledges our deficiencies in doing so.
- Current guidelines recommend ongoing visual estimation of shed blood based on observing the surgical field, suction canisters, sponges, and surgical drapes, but curiously note that "the available literature is insufficient to assess the impact of estimated measures of blood loss on patient outcomes." [(22)]
- Visual estimations of blood loss predominate in the literature and routine clinical practice. These *generally* underestimate blood volume loss based on other approaches, but their overall accuracy is very poor.
- There is ample call by authors who suggest that blood loss is a failed, or even neglected quality indicator such that increased emphasis on minimalistic surgical interventions is a priority.
- There is troubling and significant disagreement among techniques to assess blood loss complicated by individual, case-by-case variation.
- There is some movement afoot suggesting that the use of formula-based techniques may be the best standard methodology to estimate blood loss, but such formulas should be easy to use, easy to interpret and be reproducible. There is insufficient evidence that this threshold has been reached.
- A recent systematic review on the subject emphasizes the importance of finding a solution to the problem of blood loss estimation, and that there is a need for the widespread adoption of a practical and reproducible model. [(23)]

Question 4: What can be done to elevate its universal and formal inclusion into the basic and continuing education curricula of the CRNA?

It seems that our imprecision, or frank failure, to clinically provide consistently accurate measurement of blood loss is an example of 'the elephant in the room.' By which we mean it is an obvious problem that we generally avoid discussing or acknowledging on an everyday issue.

That we've become so insensitive to the insensitivity of our blood loss estimations is an example of what the sociologist Vaughan described as the 'normalization of deviance' in her study of the 1986 space shuttle *Challenger* explosion. This is the phenomenon that insidiously grows in an organization when its workers become so insensitive to deviant or flawed practice that they no longer see it as problematic.

Teaching programs have formal and detailed lectures, readings, and follow-up simulations or experiences with monitoring strategies directed at hemodynamics, arrhythmia detection, depth of anesthesia assessment, evoked potentials, crisis management, and even safe assessment of patient positioning. Yet blood loss estimation is often relegated to a less prominent position in the curriculum, despite blood literally being the liquid version of the essence of life.

We certainly do need a real-time, reliable, and valid method for the direct estimation of shed blood during surgical procedures. This should be taught, and encouraged, in our basic and continuing education programs in a much more formal manner, along with illuminating the fragile nature of our current clinical performance. The benefits of doing so include:

- The potential to deliver better and safer intraoperative and postoperative care.
- A mechanism to allow such estimation as a reasonable and fair metric for quality assurance performance by surgeons and staff.
- Real-time, point-of-care decision making regarding fluid and transfusion decisions.
- Improved documentation of intraoperative and postoperative blood loss relevant to institutional reporting, certification, and accreditation.
- Prompting out-of-the-box solutions and encouraging research by the new generation of anesthesia providers.

One problem in raising the curricular bar for in-depth exploration of blood loss estimation is that both simulations and didactic education have been proposed previously but long-range clinical application and retention are unknown at this time, and very likely to degrade.

Despite this, we believe that program directors, their faculty, clinical preceptors, clinicians, and our professional society practice leaders should advocate for change. This should occur both at the grassroots student education level as well as at both the regional and national continuing education program levels.

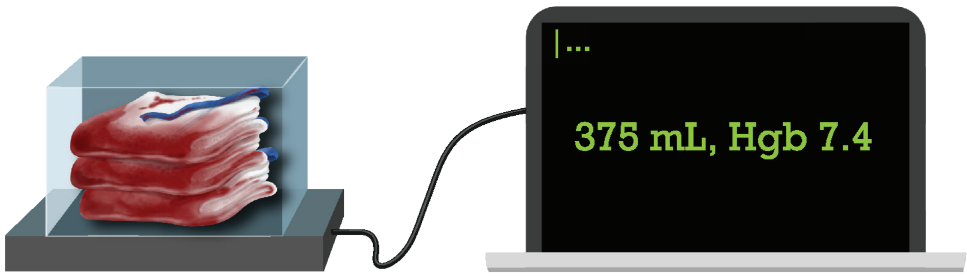
Question 5: What's new or in development to improve our estimation of blood loss?

Most of the blood lost during surgical interventions is captured on surgical sponges of some form, as well as by suction and collected, in transparent containers. Based on this, an emergent technology, and a wide literature citing the need to do better, the FDA approved a device that employs discriminant computer image analysis to measure blood loss. [24, 25]

The initial technological application to the FDA was termed the "Triton System" developed by Gauss Surgical, Inc., CA, which utilized a mobile computer imaging platform with machine learning algorithms that measure hemoglobin mass absorbed by the surgical sponges. It works off an iPad allowing for easy maneuvering and scanning of blood-soaked materials as they are passed off the sterile area to a staff member with the iPad in hand. The scanned information is wirelessly sent to an application software program for processing, which in part excludes saline and other non-blood solutions and materials. Within seconds a cumulative value is displayed of the measured hemoglobin transformed as a volume.

Similar instrumentation relying on the same image analysis principles also received subsequent FDA approval designed to measure the amount of hemoglobin present in transparent containers that capture blood and other fluids during operative procedures under a variety of ambient light conditions. [26] The goal of both instrumentation approaches would ideally involve their collaborative use such that real-time assessments are available to the clinician providing the best point-of-care decision making.

New Emerging Technologies to Accurately Measure Blood Loss



The technology used here is termed "feature extraction technology." The image analysis system advantages cloud-based vision servers connected to an iPad, using the iOS to visually access the transparent canister in such a way that both the color and viscosity of the fluid layer are standardized and sent for wireless analysis of several key properties and characteristics.

We've oversimplified the physics here for brevity purposes, but the reports use technological approaches that appear to complement each other, and there is some evidence supporting their reliability and validity in assessing operative blood loss.

Clinical contemplations

- Describe your personal experience in your initial training program with respect to monitoring and estimating blood loss. Was it a formal process in the classroom and/or simulation center, or was it primarily taught (or self-taught) in the operating room by your clinical preceptors?
- Have you had any experience or exposure to blood loss estimation in any of your postgraduate, continuing education programs?
- How would you rate your ability to accurately estimate blood loss?
- What are your department's or institution's policies on how blood loss is estimated? Is it a collaborative effort among the anesthesia provider(s), the surgeon(s), and other OR staff members? Or does it usually fall to you to come up with a final tally?
- Other than visual estimation, what experiences do you have with the other methods of blood loss measurement such as gravimetric, colorimetric, and pictographic approaches?
- What is your impression of the Triton System for quantifying blood loss, even if you've not had direct exposure to it?
- What, if any, unique approaches to blood loss estimation can you envision?

Summary and conclusions

The routine measurement and documentation of operative blood loss is a primary responsibility of the CRNA and should be performed systematically and with as much precision as possible. The standardization of high-risk procedures is a tenet of improving quality and safety. As such, the quantification of blood loss in all surgical cases, whether minor or major, is essential.

No matter if the case is in the main OR, the obstetrical suite, or in some other diagnostic or satellite unit, the loss of blood is of physiological significance, and it is clear from research and clinical experience that visual estimates are inherently inaccurate. When possible, quantitative methods are encouraged. The most recent, and we believe balanced, meta-analysis suggests that colorimetric methods have the greatest accuracy in the determination of blood loss estimates. [26] The authors of that study urge the adoption of colorimetric analysis due to its validated accuracy and that it provides immediate, real-time assessment of surgical blood loss. That said, colorimetric analysis is resource-intensive and not likely to be universally available.

The challenge of assessing operative blood loss is a daily one and more attention should be given to it in both our fundamental training programs and ongoing continuing education seminars. Blood is a precious, and life-sustaining commodity, it should be regarded with great respect, and when spilled it should be quantified as precisely as possible and documented as it drives clinical decision making.

It may be that over time, and our observation of similar insensitivity by our colleagues, that the way that we determine blood loss evolved into a kind of normalized deviance. That should change, beginning now.

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