ANESTHESIOLOGY

An Effective and Efficient Testing Protocol for Diagnosing Iron-deficiency Anemia Preoperatively

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EDITOR'S PERSPECTIVE

What We Already Know about This Topic

- Iron-deficiency anemia is common and increases perioperative morbidity and mortality
- Timely diagnosis facilitates treatment and may reduce complications

What This Article Tells Us That Is New

- The investigators implemented a novel screening system in which anemia automatically triggered evaluation for iron deficiency using previously collected blood
- The automated system identified iron-deficiency anemia far better than clinicians using normal procedures

ABSTRACT

Background: Iron-deficiency anemia is a common perioperative condition and increases perioperative morbidity and mortality. Timely diagnosis and treatment are important. This retrospective cohort study tested the hypothesis that a newly developed preprocedure evaluation protocol diagnoses more patients with iron-deficiency anemia than the traditional practice of obtaining a complete blood count followed by iron studies.

Methods: The preprocedure anemia evaluation is an order for a complete blood count and reflex anemia testing, which can be completed with a single patient visit. A hemoglobin concentration of 12 g/dl or less with serum ferritin concentration less than 30 ng/ml or transferrin saturation less than 20% defined iron-deficiency anemia. Northwestern Medicine's database was queried for preoperative clinic patients, age 16 to 89 yr, before (2015 to 2016) and after (2017 to 2018) protocol implementation. The proportion of patients diagnosed with iron-deficiency anemia before and after the preprocedure anemia evaluation implementation was compared.

Results: Before implementing the protocol, 8,816 patients were screened with a traditional complete blood count. Subsequent iron studies at the providers' discretion diagnosed 107 (1.2%) patients with iron-deficiency anemia. Some patients were still screened with a complete blood count after implementing the protocol; 154 of 4,629 (3.3%) patients screened with a complete blood count and 738 of 2,828 (26.1%) patients screened with the preprocedure anemia evaluation were diagnosed with iron-deficiency anemia. The preprocedure anemia evaluation identified a far larger proportion of patients with iron-deficiency anemia than did the traditional complete blood count when compared both before (relative risk [95% CI], 21.5 (17.6 to 26.2); $P < 0.0001$) and after (7.8 [6.6 to 9.3]; $P < 0.0001$) its implementation.

Conclusions: The preprocedure anemia evaluation improved identification of iron-deficiency anemia preoperatively. It is more effective and efficient, allowing anemia evaluation with a single patient visit.

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Previously undiagnosed anemia is identified in 5 to 75% of elective surgical patients, depending on the associated comorbidities of patients.[1,2] One third of these patients are anemic because of iron deficiency.[2] Preoperative anemia has been associated with increased morbidity after surgery,[3] commonly related to blood transfusion therapy, including increased rates of postoperative infection and mortality.[4–7] Blood is expensive and poorly reimbursed,[8,9] and transfused patients are more likely to require intensive care services and have prolonged lengths of stay in the hospital.

The relationships among anemia, transfusions, and adverse outcomes have prompted investigations into the optimal preoperative treatment of anemia. Although iron supplementation is the treatment of iron-deficiency anemia, oral iron is rarely effective because time to surgery is typically short and adherence to treatment is low because of patients' inability to tolerate oral iron preparations.[10] Preoperative intravenous iron infusions show significant promise as an alternative to erythrocyte transfusions. Newer intravenous iron preparations are safer, better tolerated, more cost-effective, and clinically more effective than older products when used to treat anemic patients before planned surgery.[10] The optimal timing for effective iron infusion therapy is 22 to 28 days before surgery.[11] However, responses to iron infusion therapy vary depending on the patient's bone marrow capacity, and significant changes can be seen as early as 1 week after intravenous iron administration, especially if erythropoietin is used. In one study of intravenous iron infusion, 97% of the patients doubled

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their reticulocyte count within 48h of the infusion, with an increase in hemoglobin concentrations of 0.5 to 2.4 g/dl by day 7.[12] One of the barriers to effective treatment of anemia with intravenous iron infusions is timely diagnosis of iron-deficiency anemia before surgery.

Traditionally, patients must first be identified as anemic on a preoperative complete blood count. Then those patients have to return to a laboratory for additional blood draws for further anemia evaluation. This was the practice at the Northwestern Memorial Hospital Preoperative Clinic (Chicago, Illinois) before January 2017. An additional battery of tests, including reticulocyte count, iron studies, vitamin B_{12} concentration, and thyroid function tests and creatinine concentration, is required to diagnosis the type of anemia.

We developed a patient blood management program for iron-deficiency anemia management before surgery to streamline the process of diagnosing anemia and determining the type of anemia. We designed and developed a "preprocedure anemia evaluation" laboratory order set, which allows for reflex anemia testing for patients with a hemoglobin concentration less than or equal to 12g/dl on initial complete blood count testing. With the implementation of the preprocedure anemia evaluation, an anemia clinic embedded within the preoperative clinic was created that provides intravenous iron infusions as well as erythropoietin and vitamin B_{12} injections, as indicated. This retrospective cohort study tested the hypothesis that the preprocedure anemia evaluation will allow for diagnosis of iron-deficiency anemia in a larger proportion of patients compared to the traditional approach.

Materials and Methods

We obtained permission from the Institutional Review Board at Northwestern University (Chicago, Illinois) to collect and analyze retrospective data from patients seen in the preoperative clinic. This study (Northwestern University Institutional Review Board identification number STU00207504) was granted a waiver of consent because there was no direct patient contact, and all patient data were deidentified. Patient records were queried from the Northwestern Medicine Enterprise Data Warehouse, a centralized and secure database repository for patient information. All patients (ages 16 to 89 yr of age) with completed appointments at the preoperative clinic between January 1, 2015, and May 15, 2016, and between January 1, 2017, and May 15, 2018, who were scheduled for either surgery or procedures requiring anesthesia and who had a complete blood count or a preprocedure anemia evaluation ordered at the time of the clinic appointment were included in the study. Demographic information, including age, sex, race, body mass index, and American Society of Anesthesiologists (ASA) Physical Status classification, were collected. We also downloaded laboratory data including hemoglobin concentration, hematocrit, serum iron, serum ferritin, total iron-binding capacity, transferrin saturation, reticulocyte count, creatinine concentration, estimated glomerular filtration rate, thyroid-stimulating hormone and vitamin B_{12} concentrations. Once downloaded from the Enterprise Data Warehouse, all data were deidentified. This is the primary analysis of these data.

Between January 2015 and May 2016, patients (ages 16 to 89 yr) scheduled for surgery with completed appointments at the preoperative clinic were screened for preoperative anemia based on established clinic criteria using the traditional approach of indicated testing with follow-up at the discretion of the ordering provider. A complete blood count was ordered at the discretion of the clinicians or the surgical service. The preoperative clinic has guidelines that recommend complete blood count testing for patients based on the potential for significant blood loss, the planned procedure, a history of anemia, alcohol abuse, bleeding, liver or kidney disease, dyspnea, hematologic disorders, malignancy, inflammatory bowel disease, body mass index less than 16 kg/m^2, malnutrition, palpitations, or syncope.

The preprocedure anemia evaluation was implemented by the preoperative clinic on January 1, 2017. With the preprocedure anemia evaluation order, the phlebotomist is directed to obtain two vials of blood during the initial preoperative clinic visit. For complete blood count testing, the patient's blood is placed into a lavender-top blood tube containing EDTA, an anticoagulant used for most hematology tests. For additional testing for serum iron concentration, serum ferritin concentration, total iron-binding capacity, transferrin saturation, creatinine concentration, estimated glomerular filtration rate, thyroid-stimulating hormone concentration, and vitamin B_{12} concentration, the blood is collected in a green-top blood tube containing heparin. First, the lavender-top blood tube is routed to the hematology testing department, and based on the results of the complete blood count, a second order is automatically initiated to test the second vial of blood, a green-top heparinized blood tube, in the chemistry diagnostic department (fig. 1). The World Health Organization (Geneva, Switzerland) defines anemia as a hemoglobin less than 12g/dl for women and less than 13g/dl for men. We set the hemoglobin trigger for secondary testing at 12g/dl or lower to simplify the process. A reticulocyte count is done using the original lavender-top blood tube that had been used for the initial complete blood count. If the hemoglobin concentration is higher than 12g/dl, the green-top blood tube is discarded, and the patient is not charged for the secondary set of laboratory tests.

Because the preprocedure anemia evaluation was introduced as an option for evaluating anemia in the preoperative period, it was ordered at the discretion of the provider. The traditional approach of ordering a complete blood count was still available. As such, in addition to patients being tested with the preprocedure anemia evaluation, some patients were screened for preoperative anemia using the traditional approach with complete blood count, with

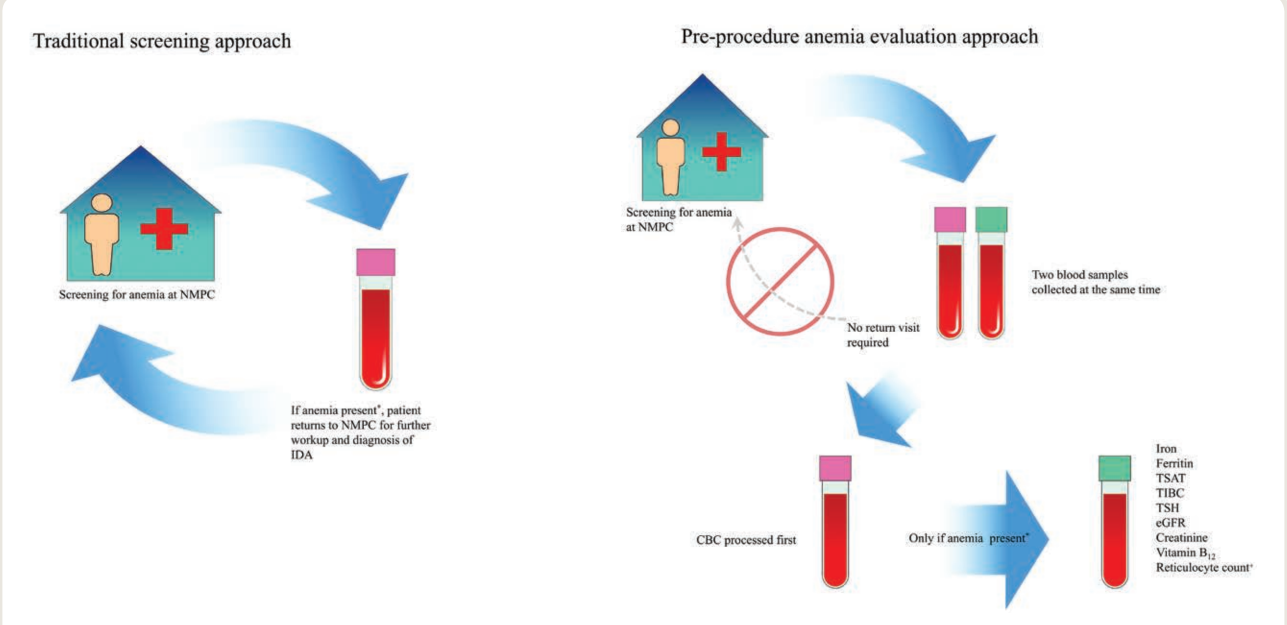

Fig. 1. Pictogram depicting traditional screening *versus* using the preprocedure anemia evaluation for iron-deficiency anemia. *Anemia defined as hemoglobin less than or equal to 12g/dL. †Reticulocyte count processed from original lavender top tube. CBC, complete blood count; eGFR, estimated glomerular filtration rate; IDA, iron-deficiency anemia; NMPC, Northwestern Memorial Hospital Preoperative Clinic; TIBC, total iron-binding capacity; TSAT, transferrin saturation; TSH, thyroid-stimulating hormone.

follow-up diagnostic anemia testing at the discretion of the ordering provider. The preoperative clinic guidelines for recommending preoperative testing of hemoglobin concentration remained the same after the implementation of the preprocedure anemia evaluation option. During the period of January 1, 2017, to May 15, 2018, we collected data for all patients who were tested using either the traditional approach (complete blood count with further testing for diagnosing the type of anemia at the discretion of the provider) or the preprocedure anemia evaluation.

We chose patients screened in the period between January 2015 and May 2016 as a control group. Patients seen in the preoperative clinic during this period were compared with patients seen in the preoperative clinic between January 2017 and May 2018. The data were analyzed from January 1, 2015, to May 15, 2016, and January 1, 2017, to May 15, 2018. This allowed for 17 months of data before preprocedure anemia evaluation implementation and 17 months of data after implementation of the preprocedure anemia evaluation.

Our primary outcome was the proportion of patients seen in the preoperative clinic who were diagnosed with iron-deficiency anemia using the preprocedure anemia evaluation (January 2017 to May 2018) compared with those diagnosed with iron-deficiency anemia using traditional complete blood count testing before (January 2015 to May 2016) and after (January 2017 to May 2018) implementation of the preprocedure anemia evaluation. Our secondary outcome was the proportion of patients diagnosed with anemia who were subsequently diagnosed with iron-deficiency anemia using the preprocedure anemia evaluation compared with those diagnosed with iron-deficiency anemia using traditional complete blood count testing both before and after implementation of the preprocedure anemia evaluation. The goal of the secondary outcome was to compare the effectiveness of the preprocedure anemia evaluation with that of the traditional anemia evaluation in identifying iron deficiency once anemia is diagnosed. A diagnosis of iron-deficiency anemia is made when a patient with anemia has a serum ferritin concentration less than 30 ng/ml or transferrin saturation less than 20%.[13] Once a diagnosis of iron-deficiency anemia is made, follow-up evaluations are done in collaboration with other specialized providers.

Statistical Analysis

No statistical power calculation was conducted before the study. The sample size was based on the available data in the selected time periods. All continuous data (*e.g.*, age, body mass index) were found to be nonnormally distributed by the Shapiro–Wilk W test and so are reported as medians (interquartile range). Ordinal data were reduced to nominal data (*e.g.*, ASA Physical Status) and are reported as number (percentage) of patients, as were the nominal data (*e.g.*, sex). In our preplanned analysis of these data, the hypothesis that the preprocedure anemia evaluation will allow for diagnosis of iron-deficiency anemia in a larger proportion of patients compared with the traditional approach was tested first using a 2 × 3 chi-square test with a two-tailed $P < 0.05$ as the criterion for rejection of the null hypothesis followed by three 2 × 2 chi-square *post hoc* tests with a two-tailed $P < 0.0167$ as the criterion for rejection of the null hypothesis for each test application (StatsDirect version 3.1.22, December 21, 2018, United Kingdom). Secondary hypotheses were similarly tested.

Given the time series nature of the delivery of the preprocedural anemia evaluation, we conducted a *post hoc* grouped linear regression analysis (StatsDirect) of the proportion of patients diagnosed with iron-deficiency anemia per month by traditional anemia evaluation and by preprocedure anemia evaluation. First, we did an analysis of the proportion of patients diagnosed with iron-deficiency anemia per month by traditional anemia evaluation in 2015 to 2016 and by preprocedure anemia evaluation in 2017 to 2018. Next, we analyzed the proportion of patients diagnosed with iron-deficiency anemia per month by traditional anemia evaluation in 2017 to 2018 and by preprocedure anemia evaluation in 2017 to 2018. Finally, we analyzed the proportion of all patients diagnosed with iron-deficiency anemia per month by traditional anemia evaluation and by preprocedure anemia evaluation. The criterion for rejection of the null hypothesis was a two-tailed $P < 0.05$.

Results

A total of 38,027 patients scheduled for surgery or procedures requiring anesthesia were seen in the preoperative clinic during both time periods. Patient characteristics and laboratory measurements of the three groups were similar (table 1). The occasionally unavailable patient characteristic (*e.g.*, body mass index) data were assumed to be missing at random. Indeterminate follow-up results were not included in the summarized data. No effort was made to impute missing data.

Before the preprocedure anemia evaluation implementation, from January 1, 2016, to May 15, 2017, 17,902 patients completed appointments, of which 49% (8,816 of 17,902) were screened using the traditional preoperative clinic approach of ordering a complete blood count; 21% (1,826 of 8,816) of those patients were anemic (defined as hemoglobin less than or equal to 12 g/dl). Six percent (107 of 1,826) of those with anemia and 1.2% (107 of 8,816) of the screened patients were diagnosed with iron-deficiency anemia. Of the anemic patients, 1.3% (24 of 1,826) did not have iron-deficiency anemia, and 93% (1,695 of 1,826) did not have follow-up anemia testing.

After the preprocedure anemia evaluation was implemented, 20,125 patients had preoperative clinic appointments during the investigative period of January 1, 2017 to May 15, 2018, of which 23% (4,629 of 20,125) were screened using the traditional complete blood count method and 14% (2,828 of 20,125) were screened using the preprocedure anemia evaluation. Of the 4,629 patients tested using the traditional approach, 17% (781 of 4,629) were anemic. Of the 781 anemic patients, 20% (154 of 781) were diagnosed with iron-deficiency anemia, 7% (59 of 781) did not have iron-deficiency anemia, and 73% (568 of 781) did not have follow-up diagnostic anemia testing. Of the 2,828 patients tested using the preprocedure anemia evaluation, 37% (1,055 of 2,828) were diagnosed with anemia, and 100% had reflex iron studies. Of this cohort of 1,055 anemic patients, 70% (738 of 1,055) were diagnosed with iron-deficiency anemia, 25% (262 of 1,055) did not have iron-deficiency anemia, and 5% (55 of 1,055) had iron studies (ferritin and transferrin saturation values) that were indeterminate (fig. 2).

Using the preprocedure anemia evaluation testing protocol in the preoperative clinic resulted in 95% (1,000 of 1,055) of patients who had a hemoglobin less than or equal to 12 g/dl with complete diagnostic follow-up anemia evaluations. This compares to only 7% (131 of 1,826) of anemic patients who had their anemia diagnosed with traditional complete blood count testing before the preprocedure anemia evaluation implementation having appropriate diagnostic anemia testing. With traditional testing after implementation of the preprocedure anemia evaluation, only 27% (213 of 781) of patients had complete diagnostic anemia testing.

The preprocedure anemia evaluation identified a far larger proportion of patients with iron-deficiency anemia (26.1%, 738 of 2,828) than did the traditional complete blood count before implementation of preprocedure anemia evaluation (107 of 8,816 = 1.2%; relative risk [95% CI], 21.5 [17.6 to 26.2]; $P < 0.0001$) and after its implementation (154 of 4,629 = 3.3%; relative risk [95% CI], 7.8 [6.6 to 9.3]; $P < 0.0001$; table 2). The proportion of patients identified with iron-deficiency anemia with traditional complete blood count in 2017 to 2018 was 2.7 times that identified in 2015 to 2016 (95% CI, 2.1 to 3.5; $P < 0.0001$).

In patients diagnosed with anemia, the preprocedure anemia evaluation identified a larger proportion of patients with iron-deficiency anemia compared with the proportion identified by screening with traditional complete blood count in both time periods (table 3). In addition, the preprocedure anemia evaluation identified a larger proportion of patients with anemia of any type compared with the proportion identified by screening with traditional complete blood count in both time periods (table 4).

The grouped linear regression analysis of the proportion of patients diagnosed with iron deficiency per month by traditional and preprocedure anemia evaluations indicated that the proportion of patients diagnosed with the preprocedure anemia evaluation diverges markedly from the trend projected by the traditional evaluation data (table 5 and fig. 3). Specifically, the vertical separation (*i.e.*, the difference of the Y intercepts of between the proportion of patients diagnosed with iron-deficiency anemia per month by the two methods *vs.* the months the data were collected) was

Table 1. Characteristics of Patients Screened for Anemia in 2015 to 2016 and 2017 to 2018

	Screened with Traditional Complete Blood Count 2015 to 2016	Screened with Traditional Complete Blood Count 2017 to 2018	Screened with Preprocedure Anemia Evaluation 2017 to 2018
Sample size	8,816	4,629	2,828
Male	3,773 (42.8%)	2,159 (46.6%)	913 (32.3%)
Female	5,043 (57.2%)	2,470 (53.4%)	1,915 (67.7%)
Age, yr	58 (46 to 67)	(N = 4,628) 62 (51 to 70)	56 (43 to 67)
Body mass index, kg/m^2	(N = 8,809) 29 (25 to 34)	(N = 4,626) 28 (25 to 33)	(N = 2,826) 28 (24 to 33)
Race			
Black	1,532 (17.4%)	778 (16.8%)	690 (24.4%)
White	5,126 (58.1%)	3,172 (68.5%)	1,571 (55.6%)
American Indian	22 (0.2%)	8 (0.2%)	10 (0.4%)
Asian	234 (2.7%)	126 (2.7%)	97 (3.4%)
Hispanic or Latino	704 (8.0%)	367 (7.9%)	335 (11.8%)
Native Hawaiian	2 (0.0%)	5 (0.1%)	2 (0.0%)
Other	1,196 (13.6%)	173 (3.7%)	123 (4.3%)
American Society of Anesthesiologists Physical Status			
1	545 (7.0%)	164 (4.2%)	93 (3.9%)
2	4,630 (59.5%)	2,201 (56.1%)	1,262 (53.5%)
3	2,510 (32.3%)	1,508 (38.4%)	968 (41.1%)
4	93 (1.2%)	49 (1.2%)	35 (1.5%)
Serum creatinine, mg/dl*	(N = 6,833) 0.87 (0.74 to 1.05)	(N = 3,599) 0.87 (0.73 to 1.05)	(N = 1,788) 0.84 (0.70 to 1.07)
Estimated glomerular filtration rate*			
> 60 ml/min/1.73 m^2	5,609 (82.3%)	2,879 (81.6%)	1,328 (77.4%)
≤ 60 ml/min/1.73 m^2	1,203 (17.7%)	651 (18.4%)	387 (22.6%)
Hemoglobin, g/dl	13.4 (12.3 to 14.5)	13.6 (12.5 to 14.6)	12.7 (11.4 to 13.7)
Hematocrit, %	40.4 (37.5 to 43.0)	40.7 (38.0 to 43.3)	38.5 (35.2 to 41.3)
Reticulocyte count, %	(N = 12) 1.45 (1.1 to 2.2)	(N = 25) 1.4 (1.0 to 2.0)	(N = 963)† 1.5 (1.1 to 2.1)
Serum iron, µg/dl	(N = 165) 42 (25 to 67)	(N = 281) 55 (34 to 80)	(N = 997)† 47 (29 to 68)
Serum ferritin, ng/ml	(N = 168) 34 (11 to 141)	(N = 278) 46 (15 to 126)	(N = 1,017)† 39 (12 to 121)
TIBC, µg/dl	(N = 161) 324 (291 to 394)	(N = 264) 333 (287 to 386)	(N = 926)† 333 (288 to 389)
Transferrin saturation, %	(N = 161) 13 (7 to 21)	(N = 264) 18 (10 to 24.5)	(N = 926)† 15 (9 to 22)
TSH, mIU/l‡	(N = 391) 1.55 (0.87 to 2.50)	(N = 359) 1.59 (0.90 to 2.96)	(N = 1,041) 1.53 (0.99 to 2.39)
Vitamin B_{12}, pg/ml	(N = 68) 436.5 (287 to 695)	(N = 95) 512 (329 to 811)	(N = 912)† 426.5 (300 to 642)

The data are reported as median (interquartile range) or number (percentage) of patients.

*Includes patients evaluated separately for kidney dysfunction. †Excludes values that were indeterminate. ‡Includes patients evaluated separately for thyroid disease.

TIBC, total iron-binding capacity; TSH, thyroid-stimulating hormone.

−0.227 (95% CI, −0.247 to −0.206), consistent with the overall difference in the proportion of patients diagnosed with iron-deficiency anemia by the two methods (table 2).

Discussion

The preprocedure anemia evaluation identified a larger proportion of patients with iron-deficiency anemia (26.1%) than did screening with traditional complete blood count with follow-up testing, both before implementation of the preprocedure anemia evaluation (1.2%) and after its implementation (3.3%). The grouped linear regression analysis of the proportion of patients diagnosed with iron-deficiency anemia per month by traditional and preprocedure anemia evaluations indicated that the proportion of patients diagnosed with the traditional method in 2017 to 2018 is a natural progression of the trend observed before implementation of the preprocedure anemia evaluation (2015 to 2016), but the proportion diagnosed per month with the preprocedure anemia evaluation diverges markedly from the trend projected by the traditional evaluation data.

Although reflex testing to diagnose anemia has been proposed,[14,15] implementation of such reflex anemia testing has not been described. Typical automated reflex

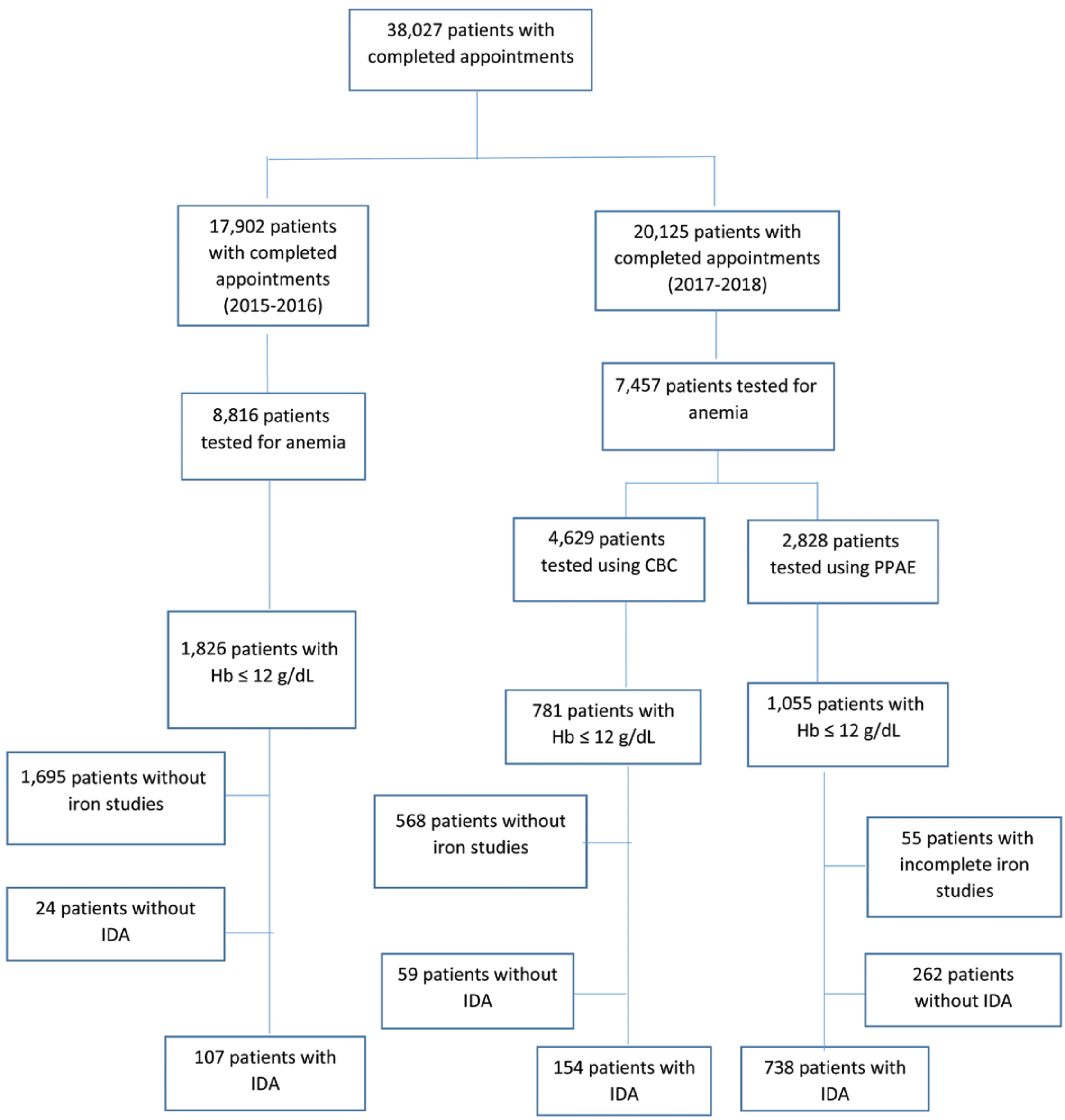

Fig. 2. Flow diagram of results of the study. CBC, complete blood count; IDA, iron-deficiency anemia; Hb, hemoglobin; PPAE, preprocedure anemia evaluation.

laboratory testing follows a simple algorithm by which the same vial of blood is reanalyzed within the same medical laboratory department for further diagnostics when the initial value is abnormal. The preprocedure anemia evaluation presents a challenge because it requires two different laboratory departments and two different types of blood tubes with different additives designed to stabilize and preserve the specimen for analytical testing. The logistics involved in actualizing the design of the preprocedure anemia evaluation order is outlined under Materials and Methods and illustrated in figure 1.

The process with the preprocedure anemia evaluation differs from the traditional approach of anemia evaluation, which involves multiple patient visits for blood draws and laboratory testing to first determine the presence of anemia and then to diagnose the type of anemia. Preprocedure anemia evaluation reflex testing eliminates the need for return visits for further blood draws and laboratory testing. In addition, it does not require the provider to act on the results of the complete blood count. The preprocedure anemia evaluation order is placed once, and the entire process of reflex testing is automated. The diagnostic tests in the preprocedure anemia evaluation evaluates for both

Table 2. Patients Diagnosed with Iron-deficiency Anemia Using the Preprocedure Anemia Evaluation *versus* Traditional Complete Blood Count

	Screened with Traditional Complete Blood Count 2015 to 2016	Screened with Traditional Complete Blood Count 2017 to 2018	Screened with Preprocedure Anemia Evaluation 2017 to 2018
Screened	8,816	4,629	2,828
Diagnosed with iron-deficiency anemia	107 (1.2%)	154 (3.3%)	738 (26.1%)
P value and relative risk (95% CI) *vs.* complete blood count 2015 to 2016	N/A	< 0.0001 2.7 (2.1 to 3.5)	< 0.0001 21.5 (17.6 to 26.2)
P value and relative risk (95% CI) *vs.* complete blood count 2017 to 2018	N/A	N/A	< 0.0001 7.8 (6.6 to 9.3)

N/A, not applicable.

Table 3. Patients Diagnosed with Anemia and Subsequently Diagnosed with Iron-deficiency Anemia Using the Preprocedure Anemia Evaluation *versus* Traditional Complete Blood Count

	Screened with Traditional Complete Blood Count 2015 to 2016	Screened with Traditional Complete Blood Count 2017 to 2018	Screened with Preprocedure Anemia Evaluation 2017 to 2018
Diagnosed with anemia	1,826	781	1,055
Diagnosed with iron-deficiency anemia	107 (5.9%)	154 (19.7%)	738 (70.0%)
P value and relative risk (95% CI) *vs.* complete blood count 2015 to 2016	N/A	< 0.0001 3.4 (2.7 to 4.2)	< 0.0001 11.9 (9.9 to 14.4)
P value and relative risk (95% CI) *vs.* complete blood count 2017 to 2018	N/A	N/A	< 0.0001 3.5 (3.1 to 4.1)

N/A, not applicable.

Table 4. Patients Diagnosed with Anemia in the Preprocedure Anemia Evaluation and Traditional Complete Blood Count Groups

	Screened with Traditional Complete Blood Count 2015 to 2016	Screened with Traditional Complete Blood Count 2017 to 2018	Screened with Preprocedure Anemia Evaluation 2017 to 2018
Screened	8,816	4,629	2,828
Diagnosed with anemia	1,826 (20.7%)	781 (16.9%)	1,055 (37.3%)
P value and relative risk (95% CI) *vs.* complete blood count 2015 to 2016	N/A	< 0.0001 0.81 (0.75 to 0.88)	< 0.0001 1.8 (1.7 to 1.9)
P value and relative risk (95% CI) *vs.* complete blood count 2017 to 2018	N/A	N/A	< 0.0001 2.2 (2.0 to 2.4)

N/A, not applicable.

iron-deficiency anemia and vitamin B_{12}-deficiency anemia, the most common, easily treatable types of anemia. It also tests for common medical conditions causing anemia, such as chronic kidney disease and hypothyroidism. If the reflex tests are normal, it is highly likely that anemia of chronic disease (also known as anemia of inflammation) or a congenital hemoglobinopathy are the reasons for low hemoglobin in this preoperative population.

One of the authors (B.J.S.) worked extensively with the information technology department and the clinical laboratory to create the preprocedure anemia evaluation process. The design and implementation involved personnel resources but did not require additional expenditures, such as laboratory equipment. Reproducing this testing is readily feasible but is dependent on functionality of laboratories and information services at other institutions. The preprocedure anemia evaluation was codified to direct the phlebotomist in the preoperative clinic or at any diagnostic center within our institution to draw the appropriate tubes of blood even if they are not familiar with this test. This order is available to all providers and all patients within our institution. The success of the automated reflex process involved extensive information technology innovations within the patient's electronic record, the phlebotomy areas, the diagnostic laboratory receiving area, and the hematology and chemistry testing departments. Information technology processes had to direct phlebotomists to collect blood in the correct tubes and the routing mechanisms in the laboratory to send the blood tubes to the correct testing departments. Information technology support was necessary to trigger the chemistry laboratory to run the secondary tests based on the results of the complete blood count. The goal in developing the preprocedure anemia evaluation was to maximize efficiency and efficacy in diagnosing treatable types of anemia in preoperative patients. The time between when patients are scheduled for surgery and the surgery date is limited. Patients are inconvenienced by multiple appointments and often cannot return for another blood draw. The secondary goal was to decrease unnecessary testing with its associated costs. We could have obtained two vials of blood on every patient and ordered all of the tests regardless of the hemoglobin value but that would be wasteful for patients without anemia.

The preprocedure anemia evaluation is ordered in place of a complete blood count. The reflex tests to evaluate anemia are processed only when anemia is noted on the first component of the preprocedure anemia evaluation, the complete blood count (fig. 1). The only additional cost is the cost of the green-top blood collection tube containing heparin, which at our institution is $0.18. This cost is nominal compared with the previously described direct and indirect costs of anemia related to increased complications, length of stay, infection, and intensive care services. It is important to reiterate that anemia, like any other disease, should be treated. Addressing chronic conditions can improve both perioperative and long-term outcomes.

Diagnosis of iron-deficiency anemia is limited by an individual physician's knowledge of the significance of anemia, expertise in evaluating anemia, and bandwidth for additional work.[15] Providers often do not appreciate the significant association of adverse events in surgical patients with anemia[3] and are often unaware of the importance of diagnosing iron-deficiency anemia. Physicians may have a sense of futility of managing patients with anemia in the preoperative period because they often think there is not time to evaluate and treat anemia preoperatively.

A limitation of this study is that we did not mandate use of the preprocedure anemia evaluation once it was implemented. As a result, despite extensive educational efforts, some preoperative clinic providers were slow adopters

Table 5. Grouped Linear Regression of the Proportion of Patients Diagnosed with Iron-deficiency Anemia by Traditional and Preprocedure Anemia Evaluations per Month (Expressed as a Fraction of a Year)

	Slope 1 and Slope 2	Difference in Slopes (95% CI)	*P* Value	Corrected Y Mean 1 ± SE and Y Mean 2 ± SE	Common Slope	*P* Value	Vertical Separation (95% CI)	*P* Value
Traditional anemia evaluation 2015 to 2016 preprocedure anemia evaluation 2017 to 2018	0.008 and –0.018	0.025 (–0.036 to 0.087)	0.406	0.008 ± 0.017 0.267 ± 0.017	–0.005	0.745	–0.259 (–0.325 to –0.193)	< 0.0001
Traditional anemia evaluation 2017 to 2018 preprocedure anemia evaluation 2017 to 2018	0.031 and –0.018	0.049 (–0.014 to 0.112)	0.124	0.036 ± 0.009 0.262 ± 0.009	0.007	0.666	–0.226 (–0.252 to –0.200)	< 0.0001
Traditional anemia evaluation 2015 to 2018 preprocedure anemia evaluation 2017 to 2018	0.013 and –0.018	0.030 (–0.006 to 0.067)	0.104	0.028 ± 0.005 0.254 ± 0.008	0.011	0.023	–0.227 (–0.247 to –0.206)	< 0.0001

A slope of 0.013 proportion of patients diagnosed with iron-deficiency anemia per year for the traditional anemia evaluation 2015 to 2018 data means the percentages of patients diagnosed with iron-deficiency anemia increased 1.3% per year. Vertical separation is the distance between the lines with common slopes through the traditional anemia evaluation data and the preprocedure anemia evaluation data and is therefore the difference between the Y intercepts (corrected Y mean 1 and Y mean 2) of those lines. The vertical separation of the traditional anemia evaluation 2015 to 2018 and the preprocedure anemia evaluation 2017 to 2018 lines (and its 95% CI) provides evidence that the substantial increase in the proportion of patients diagnosed with iron-deficiency anemia by the preprocedure anemia evaluation is not a result of the natural increase with time in the proportion of patients diagnosed with iron-deficiency anemia by the traditional anemia evaluation.

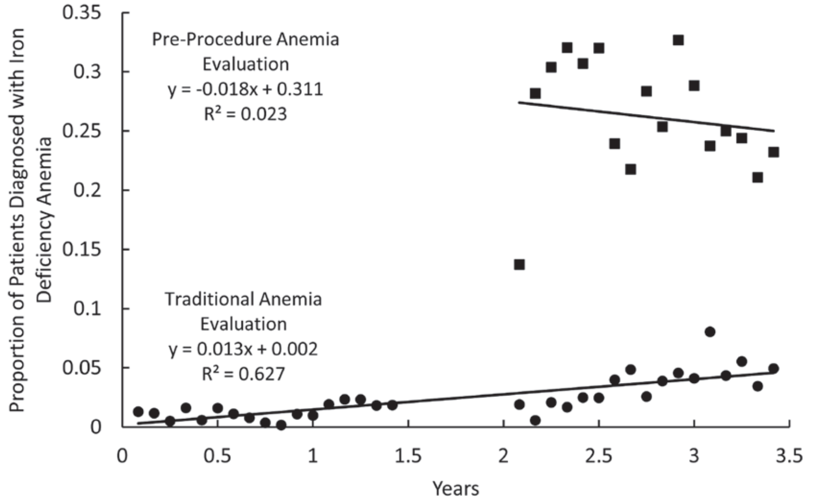

Fig. 3. *Post hoc* linear regression analyses of the proportion of patients diagnosed with iron-deficiency anemia per year by complete blood count and by preprocedure anemia evaluation as functions of the month of data collection (expressed as a fraction of a year) beginning with January 2015.

and continued to screen for anemia using the traditional approach. This was not a prospective study, so the patients screened for anemia after implementation were not randomly assigned to traditional anemia screening or the preprocedure anemia evaluation. Thus, there may be confounding factors that contributed to the increased proportion of screened patients diagnosed with iron-deficiency anemia by the preprocedure anemia evaluation. This study is also limited in that we could not account for patients who may have had iron studies outside of our institution. Our current practice uses the preprocedure anemia evaluation as the only diagnostic test for evaluating a preoperative complete blood count, diagnosing anemia, and testing for iron deficiency.

Diagnosing treatable causes of anemia in a timely manner preoperatively is an important component of patient blood management programs focused on limiting harmful and costly blood transfusions[8,9] Early identification of iron-deficiency anemia and treatment with intravenous iron infusions to optimize hemoglobin concentration preoperatively is recommended.[16,17]

Conclusions

This study shows that the use of the preprocedure anemia evaluation, a specially developed comprehensive testing process, is more effective and efficient in diagnosing iron-deficiency anemia than traditional methods of evaluating anemia in patients preoperatively. Early diagnosis should allow for earlier treatment of iron-deficiency anemia with a greater likelihood of correction of anemia. The scope of our study was not to evaluate outcomes or rates of transfusions. Exploring whether this expedited process for diagnosing anemia affects outcomes or need for transfusions are subjects of a future study.

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Competing Interests

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