HHS Public Access

Author manuscript

Transfusion. Author manuscript; available in PMC 2015 April 27.

Published in final edited form as:

Transfusion. 2014 April ; 54(4): 972–971. doi:10.1111/trf.12348.

Transfusion Complications in Thalassemia Patients: A Report from the Centers for Disease Control and Prevention (CDC)

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Abstract

Background and Study Objectives—Transfusions are the primary therapy for thalassemia but have significant cumulative risks. In 2004, the Centers for Disease Control and Prevention (CDC) established a national blood safety monitoring program for thalassemia. The purpose of this report is to summarize the patient population as well as previous non-immune and immune transfusion complications at the time of enrollment into the program. A focus on factors associated with allo- and auto-immunization in chronically transfused patients and a description of blood product preparation and transfusion practices at the participating institutions are included.

Study Design and Methods—The CDC Thalassemia Blood Safety Network is a consortium of thalassemia centers, longitudinally following patients to determine transfusion-related complications. Enrollment occurred from 2004 through 2012 and annual data collection is ongoing. Demographic data, transfusion history, and previous transfusion and non-transfusion complications were summarized for patients enrolled between 2004 and 2011. Logistic analyses of factors associated with allo- and auto-immunization were developed. Summary statistics of infections reported at the time of enrollment were also calculated.

Results—The race/ethnicity of the 407 thalassemia patients enrolled in the Network was predominantly Asian or Caucasian and 27% were immigrants. The average age was 22.3 years ± 13.2 and patients received an average total number of 149 ± 103.4 units of red blood cells. Iron-induced multi-organ dysfunction was common despite chelation. At study entry, 86 patients had previously been exposed to possible transfusion-associated pathogens, including Hepatitis-C (61), Hepatitis B (20), Hepatitis A (3), Parvovirus (9), HIV (4), malaria (1), staphylococcus aureus (1) and babesia (1). As 27% of the population was born outside of the United States (India, Pakistan,

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Disclaimer: The findings and conclusions in this paper are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

CONFLICTS OF INTEREST: The authors declare that they have no conflicts of interest relevant to the manuscript submitted to TRANSFUSION.

Thailand, China, Vietnam and Iran accounting for 57%), the source of infection cannot be unequivocally tied to transfusion. In total, 24% of transfused patients were reported to have possible transfusion-associated pathogens. Transfusion reactions occurred in 48% of patients, including allergic, febrile, and hemolytic; 19% of transfused patients were alloimmunized (defined as a having an antibody to a foreign red blood cell antigen). The most common antigens were E, Kell and C. One hemolytic reaction to an anti-Mi^{a} antibody was noted. Years of transfusion was the strongest predictor of alloimmunization. However, initiating transfusions in infancy may induce immune tolerance. Autoantibodies occurred in 6.5% and were predicted by previous alloimmunization ($p < .0001$). Local institutional transfusion policies, rather than patient characteristics, were the major determinants in the preparation of red-blood cells for transfusion.

Conclusion—Hemosiderosis and immunologic and non-immunologic transfusion reactions are major problems in thalassemia patients. Infections continue to be a problem in thalassemia and new pathogens have been noted. National transfusion guidelines for red cell phenotyping and preparation are needed in thalassemia to decrease transfusion-related morbidity.

Keywords

Transfusion Practices (Oncology- Hematology); Hematology – Red Cells; Transfusion Complications - Non Infectious

INTRODUCTION

Worldwide, there are over 60,000 births annually of serious forms of thalassemia.[1,2] The World Health Organization considers thalassemia to be a major health burden.[1,2] Transfusions are the primary therapy for thalassemia but have significant risks including hemosiderosis, transfusion reactions, alloimmunization, and infections. In 1998, Congress and the Centers for Disease Control and Prevention (CDC) established a blood safety monitoring surveillance system called the Universal Data Collection (UDC) Project. In 2004, this program was expanded to include thalassemia. The goals of the program are to monitor blood safety and to develop and test strategies for the prevention and management of complications in patients with thalassemia.

The distributions of the phenotype and genotype of North American thalassemia patients today, as well as their transfusion management, are dramatically different from those in the past decades.[3] The majority of patients, previously of Mediterranean descent, are now largely of Asian and Middle Eastern origin.[3] The diverse thalassemia phenotypes found in this population results in different transfusion exposure than the Mediterranean population. There is limited data on the transfusion complications in this population including alloimmunization rates. Pilot data suggests this diverse population in North America may be at greater risk for alloimmunization.[3–13] Knowledge of other transfusion complications such as anaphylaxis and hemolytic reactions is also incomplete because these events are rarely compiled and reported. Importantly, the thalassemia population, which has the highest transfusion exposure of chronic diseases, provides the opportunity to study emerging transfusion-associated infections.

The purpose of this report is to summarize the patient population of the CDC Thalassemia Blood Safety Network as well as previous non-immune and immune complications at the time of enrollment into the program. A focus on factors associated with allo- and auto-immunization in chronically transfused patients and a description of blood product preparation and transfusion practices at the participating institutions are included.

MATERIALS AND METHODS

The CDC Thalassemia Blood Safety Network (Network) is a consortium of thalassemia centers in the United States that has a longitudinal cohort study of patients to determine risk factors for transfusion-related complications. This report describes the population at the time of their enrollment between 2004 and 2011. Individuals from thalassemia centers located in Boston, MA; Chicago, IL; Philadelphia, PA; New York, NY; Oakland, CA; Los Angeles, CA; and Atlanta, GA participated.

Demographic, physical examination, and laboratory data were collected at enrollment and entered into a central database at the CDC. Demographic data collected included clinical diagnosis, gender, race, ethnicity, genotype and phenotype. Historical data included information regarding immunizations, infection exposures, surgical procedures, organ dysfunction, age of transfusion initiation, chelation therapy, type of red cell product, transfusion reactions, and antigen matching. Data were collected from chart review, patient interviews, blood banking records, and laboratory testing. Organ dysfunction was defined as a history of requiring medical treatment for heart disease, diabetes (type 1 or 2), hypoparathyroidism, hypothyroidism, growth hormone deficiency or gonadal failure.

Infection

Information on previous exposure to infectious pathogens was collected on enrollment intake forms. In addition, specimens were mailed to the CDC annually for pathogen screening. The protocol and standard assays are provided in Appendix 2. Institutional Review Board approval of the protocol and consent forms was obtained at all participating institutions and consent forms were signed by each patient prior to enrollment.

Transfusion Complications

Adverse transfusion reactions were reported according to a Manual of Operations based on National Healthcare Safety Network Hemovigilance Module published transfusion complication definitions including: hemolytic transfusion reactions (acute, delayed), febrile non-hemolytic, allergic, transfusion-associated circulatory overload, transfusion-related acute lung injury, post-transfusion purpura, transfusion-associated GVHD, transfusion-transmitted infection, hypotensive reactions, and transfusion–associated dyspnea.[14,15] Alloimmunization was defined as a having an antibody to a foreign red blood cell antigen while autoimmunization was defined as the presence of an antibody to an antigen on the patients' own red cells.

Transfusion Protocol Guidelines and Institutional Practices—Data were collected regarding institutional practices related to transfusion. A prospective questionnaire was sent

to the participating institutions and their principal investigator regarding their institution's preparation methods of red cell products and transfusion practices. Preparation methods of red cells was classified as leukoreduced (by filtration methods), washed, and/or irradiated. Data regarding screening for alloantibodies and autoantibodies at each thalassemia center was obtained. Antigen matching was determined as one of three categories: ABO/D; ABO/D, C, E, Kell; and "extended."

Statistical Methods—Patients were characterized as "chronically transfused" if they had a history of chronic transfusions and received eight or more transfusions within a 12 month period, "intermittently transfused" if they had not been chronically transfused but had received one to seven transfusions within a 12 month period, or "never transfused" at the date of study entry. Patients were classified as β-thalassemia Major (TM), β-thalassemia Intermedia (TI), Hemoglobin (Hb) E-β-thalassemia (E-thal) or α-thalassemia (α-thal) syndrome (including HbH disease and HbH/Constant Spring) based on their diagnosis, clinical course, and genotype. Demographic variables such as age, gender, and race were summarized for the total population and for each transfusion group. For chronically transfused patients, the years of transfusion exposure was calculated by subtracting the age at which the patient began transfusion from their age at enrollment. Continuous variables such as current age, age at start of transfusion therapy, and number of transfusions in the year prior to enrollment were compared between the transfusion groups utilizing ANOVA or Student's t-tests. Discrete variables, such as the prevalence of alloimmunization, were compared across groups utilizing chi-square or Fisher's exact tests. Logistic regression models were used to identify independent predictors of allo- and auto-immunization status in chronically transfused patients. All analyses were performed at the data coordinating center (CDC) with SAS/STAT® Software version 9. P-values < 0.05 were considered statistically significant.

RESULTS

Patient Characteristics

Of the 407 thalassemia patients enrolled in the CDC transfusion surveillance study between 2004 and 2011, 284 (70%) patients were diagnosed as TM, 58 (14%) α-thal syndromes, 37 (9%) TI, and 28 (7%) E-thal. Fifty-five percent of participants were female. There were two major racial groups: Asian (207) and White (175) which accounted for 94% of the population. An additional 4% were classified as Black (see Table 1). Seventy-three percent of the population was born in the United States, and 27% outside the United States (India, Pakistan, Thailand, China, Vietnam and Iran accounting for 57%). Of the 110 patients born outside of the US, 104 were transfused and the majority started transfusion therapy before their first visit to a US Thalassemia Treatment Center (TTC), although data about the location or other details of these transfusions is not available.

Eighty percent (327) of the patients had been chronically transfused, 9% (38) had only been intermittently transfused, and 10% (42) were never transfused (Table 1). Diagnostic categories of the patients who had been chronically transfused included: TM (82%), TI (6%), E-thal (6%), and α-thal syndromes (6%). Forty-nine percent of the chronically

transfused patients were White and 48% Asian. At study entry, the median age of the chronically transfused patients was 31.3 years, range <1 to 58. The median age of transfusion initiation was 1 year with a mean age of 4.5 ± 8.2 years. The mean estimated years of transfusion exposure was 18.5 ± 12.3. The average number of transfusions in this group during the year prior to enrollment was 15.6 ± 5.8.

Among the 38 intermittently transfused patients, there were 15 α-thal syndromes, 11 TM, 8 TI, and 4 E-thal patients. The median age was 17.3 years with a range of 1 to 61. The proportion of Asians in the intermittently transfused group was higher than in the chronically transfused group: 68% vs. 48% ($p = 0.02$). Also, the percentage of females was higher: 76% compared to 53% ($p = 0.007$). Most patients with β^0 thalassemia major were chronically transfused; 4%, however, were included in the intermittently transfused population receiving less than 8 annual transfusions in some years. As transfusion was intermittent in this group, an estimate of the years of transfusion exposure was not possible.

The diagnostic categories in the patients who had never been transfused were: 23 patients with α-thal syndromes, 9 patients with TI, 6 TM, and 4 E-thal. Untransfused patients were younger with a median age of 7 years (range 1 to 53). Thalassemia major patients in the non-transfused category were young infants under the age of one year who had not yet begun chronic transfusion at study enrollment.

General Complications

Hemosiderosis occurred in all groups. As expected, the average measurement of ferritin was significantly higher in the chronically transfused patients (median=1375.85 μg/L) compared to the other two groups (intermittent: 356 μ/L; non-transfused: 80.5 μ/L; $p < 0.0001$). Seventy-eight percent of all patients had received chelation therapy. In the total population, a history of organ dysfunction requiring medical treatment was common and included: cardiac disease (13%), gonadal failure (17%), growth hormone deficiency (8%), hypothyroidism (8%), hypoparathyroidism (1%), diabetes (10%), cirrhosis (2%), and thrombotic events (7%). Sixteen and a half percent had more than one organ system involved. Thrombotic events were often serious, and included 6 cases of pulmonary embolism, 5 superior vena cava syndromes, 4 deep vein thromboses, 3 cardiac thromboses, 2 portal vein thromboses, and 2 patients with renal thrombosis. Of the 26 chronic transfusion patients with thrombosis, 25 had a splenectomy and 21 had concomitant central venous access. Overall, 31 patients were on chronic anticoagulant therapy. Most complications occurred in the chronically transfused population; however, cardiac, gonadal, thrombotic, and other complications were noted in 16% of the intermittently transfused.

Surgical procedures were common in this population. Splenectomy was reported in 45% of patients, and was more prevalent in the transfused patients: 52% in chronically transfused, 29% in intermittently transfused, and 7% non-transfused ($p < 0.0001$). The mean age at the time of splenectomy was 10 years ±6.3. The majority of splenectomies occurred before 15 years of age, with 20% occurring before age 5. Asians were less likely than Whites to have undergone splenectomy (32% vs. 65%, $p < 0.0001$). However, Asians were younger (17.9 ± 9.6) compared to Caucasians (27.5 ± 14.7). Other procedures included central venous access devices in 27% and cholecystectomy in 14% of patients.

Infections—At study entry, 86 patients' intake forms revealed previous exposure to transfusion-associated infectious diseases, including Hepatitis C (61), Hepatitis B (20), Hepatitis A (3), Parvovirus (9), HIV (4), malaria (1), staphylococcus aureus (1) and babesia (1). In total, 24% of transfused patients had laboratory evidence of previous exposure to one or more infectious diseases.

Transfusion Complications—A history of transfusion reactions was reported in 48% of transfused patients. Chronically transfused patients were more likely to have had a reaction than intermittently transfused patients (50% vs. 22%, p = 0.002). Transfusion reactions occurred in 55% of males compared to 42% of females (p = 0.02) but were not related to race or splenectomy status.

Fifty-two percent of patients with transfusion reactions reported having only an allergic reaction, 16% experienced only febrile reactions, and 27% had multiple transfusion reactions of varied types. Most allergic reactions were mild to moderate in severity; however there were two anaphylactic reactions, one transfusion-associated hypotensive event and one episode of transfusion-associated dyspnea. There were 17 reported hemolytic transfusion reactions. Source documents were able to confirm nine of these were hemolytic immunologic transfusion reactions. The other cases occurred with allergic and febrile reactions but did not provide immunologic testing or laboratory evidence of hemolysis. Other complications included transfusion-associated tachycardia, acute vertigo, and transient vomiting. There were no episodes of transfusion-related acute lung injury.

Alloantibodies: Overall, 19% (68/365) of all transfused patients had alloantibodies. Twenty-three percent of chronically-transfused patients were alloimmunized, compared to 13% of the intermittently-transfused (p=.30) Forty-seven percent of alloimmunized patients had multiple antibodies: Anti-E, anti-K or anti-C were identified in 70% of these patients (Table 2). One TM patient of Chinese ancestry developed anti-Mi^{a} antibody. The hemolytic transfusion reactions that occurred were caused by anti-E, anti-Jkb, anti-c, anti-Jka, anti-S, anti-Kell, anti-f, and two cases of warm autoantibodies.[15] Current age, race, and splenectomy were also associated with alloimmunization. The average age of patients with alloantibodies was 29.4 years (± 13.3, n=68), and in those without, 20 years (± 12.5, n=261). Caucasians were more often alloimmunized than Asians (29% vs. 13%, p < 0.0001). Alloimmunization was found in 31% of splenectomized patients vs. 11% of non-splenectomized patients (p < 0.0001).

Predictors of Alloimmunization in chronically transfused: In the chronically transfused patients only, the age at which patients began transfusion was significantly associated with the alloimmunization and reflected transfusion exposure. However, in those who began transfusion before one year of age, the proportion of allo-immunized patients was lower despite greater transfusion burden: 11% vs. 18 to 31% in the older age groups (Table 3). The average years of transfusion exposure in alloimmunized patients was higher (25.9 ± 13.1, n=64) vs. the non-alloimmunized (16.4 ± 11.1, n=226; p < .0001). The average number of transfusions received the year prior to enrollment in alloimmunized patients was 18 ± 6.6 (n=64) vs. 15.2 ± 5.2 (n=235) in patients without alloantibodies (p = 0.003). In a stepwise multivariate logistic regression of alloantibody formation in chronically transfused patients

-- which included age at study enrollment (left as a continuous variable), years of transfusion, race (Asian vs. White), and splenectomy status -- only years of transfusion remained a significant independent predictor of alloimmunization (table 4).

Predictors of Autoimmunization: Autoantibodies occurred in 6.5% of patients; chronically transfused and intermittently transfused patients had a similar risk (6.4% vs. 6.9%). Patients with autoantibodies were significantly older than those without (27 years ± 13 vs. 21 ± 13, $p = 0.0395$). In chronically transfused patients, the risk of autoantibody formation was 10% in splenectomized patients compared to 3% in non-splenectomized patients ($p = 0.02$). Years of transfusion exposure, race, and gender were not associated with the rate of autoimmunization. Eighty-four percent of patients with autoantibodies were alloimmunized, in contrast to only 17% of those without autoantibodies ($p < 0.0001$). A stepwise multivariate logistic regression analysis of autoantibody formation in chronically transfused patients included age at study enrollment, splenectomy status, presence of alloantibodies and years of transfusion exposure. Years of transfusion was included in the model because previous literature has shown an association between transfusion burden and formation of autoantibodies. In our model, only the presence of an alloantibody remained a significant independent predictor of autoimmunization.

Current Blood Processing and Transfusion Practices

For patients transfused in the year prior to study entry (n=330), 31% received blood matched for ABO/D only; 38% were also matched for C, E, and Kell; and 10% received extended phenotypically matched red cells. The extent of matching for 21% was unknown or variable. Additional processing included leukoreduction in 94%, washed packed red blood cells (PRBC) in 35% and irradiated cells in 33%.

Local blood banking practices varied. Two sites utilized standard ABO-Rh typing as their transfusion policy, with extended matching only once an antibody occurred. One site matched preventatively for C and E antigens, and three sites routinely matched for C, E, and Kell antigens. Extended red cell phenotypic matching, including Jkb antigen, was utilized at one site. All blood products were radiated at four sites regardless of individual patient risk. Three sites restricted radiation therapy to only thalassemia patients undergoing transplantation. One site utilized red cell washing as a standard technique of leukocyte depletion while others restricted washing to patients with a history of allergic reactions.

DISCUSSION

As the life span of thalassemia patients has dramatically increased, their cumulative exposure to red cell transfusions has resulted in this disease being the most heavily red-cell-transfused syndrome worldwide. This report is an assessment of the morbidity of transfusion therapy in 407 thalassemia patients monitored by the CDC. It is the first report focusing only on the United States thalassemia population. In this report, half the study population is of Asian ethnicity and 27% immigrated to the United States. It includes information concerning transfusion complications not routinely studied in thalassemia such as serious allergic and hemolytic reactions. These complications and the variability in institutional approaches to

blood typing and processing may provide an impetus for developing national transfusion guidelines for thalassemia.

Hemosiderosis was the most common complication in this population.[16] This cross-sectional report of patients at the time of enrollment at TTC's across the United States was not designed to collect annual detailed information about iron intake, chelation, and iron loading to sensitive organs. However, despite new chelation therapies in this young population, hemosiderosis-induced organ dysfunction remains a serious problem.[12,15,17–19] The prevalence of cardiac disease and endocrine dysfunction is lower than in cross-sectional data from previous decades, but its interpretation is limited by lack of laboratory confirmation, age at diagnosis, and detailed information regarding iron exposure, chelation compliance, treatment and screening practices.[17] Serious thrombotic complications occurred particularly in patients who had undergone splenectomy and central line placement. Cappellini and others have recommended that these high-risk patients should receive preventative anticoagulation therapy.[20]

At enrollment, 24% of the transfused patients reported previous exposure to serious pathogens. While the actual source of infections cannot be unequivocally attributed to transfusion exposure given that some of the pathogens are endemic in areas outside of the US, this rate of exposure is likely an underestimate as exposure data was unknown in some cases and enrollment forms did not query about all possible pathogens. High rates of hepatitis and HIV are expected in this population, which includes adults transfused before adequate blood bank testing was in place.[14,16,21–24] However, since 27% of the thalassemia patients have immigrated from areas that are still not providing uniform infectious screening of red cell transfusions, active infections are likely to occur in immigrant patients of all ages.[25,26] The observations in our study of malaria and babesia are concerning. These organisms are among several that threaten the transfusion blood supply and blood banks do not routinely test for them.[27–33] Recently, the CDC reported a marked increase in the number of imported malaria cases.[32] Babesia is a growing transfusion risk in the United States and has been implicated in 10 of 28 deaths from blood products between 2005 and 2008.[27–29,34,35] Hemoglobinopathy patients are at particular risk for severe hemolysis that has been associated with babesia.[15,36] The development of sensitive, specific assays for mass screening and a clear understanding of the risks of these infections is essential.

Almost half the transfused patients had experienced a transfusion reaction. Allergic reactions occurred in a third of patients, including at least two episodes of anaphylaxis. The frequency and severity of allergic reactions in chronically transfused thalassemia has not been well studied. It appears much higher than reported risk in the general population of approximately 1% for allergic reactions and 1:25,000 to 1:150,000 for anaphylaxis.[23,37–41] However, longitudinal studies are needed to confirm this. Although IgA deficiency is thought to be the most common cause of anaphylaxis, recently anti-haptoglobin antibody has been identified as a more common cause, particularly in people of Asian descent.[42] These deficiencies have not been studied in the thalassemia population.

Alloimmunization is a serious adverse consequence of transfusion therapy. The overall proportion of alloimmunized patients in our study was 19%, with almost half the patients

having multiple antibodies and several hemolytic transfusion reactions. Understanding the predictors of alloimmunization would enable the implementation of a cost-effective extended matching program for at-risk patients. In our study, logistic regression analysis found that transfusion exposure was the strongest predictor of alloantibody formation.[43] While there are genetic and immunologic differences between patients that affect alloimmunization rate, it is likely that alloimmunization will continue to increase with age and transfusion burden in this thalassemia cohort.[44–52] Transfusion exposure is the major factor in cumulative antibody risk.[9,12] E, Kell, and C antigens accounted for the majority of hemolytic antibodies identified in this U.S. cohort of patients. Matching for these antigens has reduced alloimmunization and complications in other studies.[6,9–12,53] Newer technology is making such preventative alloimmunization policies more cost-effective and supports their widespread implementation.[51,53,54]

Certain antibodies are unique to the Asian population and are likely to become an emerging transfusion-related complication in the United States.[4,5,7] Our Chinese patient with an Anti-Mi^a is one of the first North American thalassemia patients reported to have this antibody. In contrast, it accounts for over 30% of antibodies in thalassemia patients in China. The Mi^{a+} antigen is almost uniquely found in Asian donors.[4,5,7] In China, blood banks routinely screen donors for Mi^{a+} red cells. As the Asian donor population increases in the United States, anti-Mi^a antibodies are likely to increase and donor screening may become necessary.

Our study supported the concept of immune tolerance developing in very young children under one year of age. The alloimmunization rate in children who began transfusion before one year of age was only 11%, in contrast to 27% who began transfusion after one year of age. Immune tolerance as a factor in the rate of red cell alloimmunization has previously been suggested.[11,43,50] Recently, genetic factors influencing immune tolerance and alloimmunization have been identified.[50]

The effects of splenectomy on alloimmunization are unclear.[9,12] Splenectomy markedly increases antigen and microparticle exposure in hemolytic anemias.[55,56] This splenectomy-induced antigen overload likely increases alloimmunization rate. Thompson, et al. found on multivariate analysis that duration of transfusion and splenectomy were risk factors for alloimmunization; however, they found splenectomy was not a significant risk factor in the older, chronically transfused patients.[12] In our study, we observed splenectomy to be a risk factor on univariate analysis, but on multivariate analysis, only transfusion exposure was an independent predictor of alloimmunization. Differences between the two study populations and statistical modeling may account for the divergent findings. A large percentage of the Thalassemia Clinical Research Network included patients from international sites with differences in the percent of thalassemia diagnostic categories as well as age of onset and duration of transfusions.[3,12] Clearly, both studies underscore transfusion exposure as a key predictor of alloimmunization.[43]

Autoantibodies are a serious problem, occurring in 6.5% of this population. This is much higher than in the general population.[9,38,41,57] Their presence makes serologic cross-matching difficult and often masks an undetected alloantibody, which if not recognized, can

result in a hemolytic transfusion reaction. Eighty-one percent of patients with an autoantibody had been alloimmunized. Multivariate analysis confirmed alloimmunization as the only significant independent predictor of autoimmunization. This data suggests that the control of alloimmunization may help to minimize autoantibody formation.

There is no national standardized procedure for preparation of red cells and no consensus among participating thalassemia centers. Transfusion policy for thalassemia is determined by generalized blood banking policies within each institution.[58] The risk/benefit of extended red cell antigen matching for transfusions in hemoglobinopathies is debated.[51,53,59,60] Prospective studies indicate that antigen matching for Cc, Ee, D, and K reduces alloimmunization.[6,51,53,61]

Molecular red cell phenotyping of donors and recipients may increase the efficacy and efficiency of red cell matching and decrease blood inventory requirements.[37,51,62] Prospective outcome studies, including cost analysis, are needed.

The routine policy to radiate all blood products received by thalassemia patients at four of the participating centers is controversial.[37,63] Radiation adds monetary cost and alters red cell metabolism, causing accelerated cellular potassium loss, elevated free plasma hemoglobin levels, and shortened red cell survival.[37,64,65] The British Blood Transfusion Task Force and the Serious Hazards of Transfusion Program (SHOT), a United Kingdom hemovigilance effort, do not recommend radiated red cell units for hemoglobinopathies.[64] However, some centers with large populations of immunocompromised patients, cancer patients, and premature infants use universal radiation as a local policy. The overall best policy for use of radiated red cells in hemoglobinopathy patients needs to be addressed.

This study has several limitations. Data collected at enrollment was retrospective and not all of the information could be verified. While not the focus of this report, analysis of iron-induced tissue injury is limited by a lack of actual tissue iron concentrations and specific vital organ functions as well as incomplete information regarding initiation and maintenance of chelation regimens. The intake forms did not quantitate the number of transfusion reactions per patient unit of exposure, which limits the determination of actual transfusion complication rates. Also, the laboratory testing for immune reactions was not centralized.

In summary, the thalassemia population in the United States is a multi-ethnic community including many recent immigrants who have a high rate of transfusion-related complications that exceeds that of other transfused populations.[14,23,39,40,43] Transfusion reactions (including allo- and auto-immunization, hemolytic, and anaphylactic) are serious problems. Despite advances in iron chelation and blood safety, major improvements in hemosiderosis and transfusion-acquired infections are still needed. There is no standard practice among thalassemia centers on blood product preparation designed to limit transfusion reactions. This longitudinal surveillance project will enable the development of recommendations for interventions to prevent transfusion morbidity and evaluate long-term effectiveness. Ultimately, this will improve the safety of the national blood supply and its delivery.

ACKNOWLEDGEMENTS

The authors would like to thank the staff at Clinical and Translational Science Institute (CTSI), Shanda Robertson, and Kristen Giambusso for administrative support. This study was supported by the Centers for Disease Control and Prevention (CDC): 5U01DD000310-05 to Children's Hospital & Research Center Oakland, U01-DD00306 to Children's Hospital Philadelphia, U01-DD00309 to Children's Hospital Los Angeles, U01-DD000308-05 to Boston Children's Hospital, U01-DD0003075 to Ann & Robert H. Lurie Children's Hospital of Chicago, and U01-DD000311-05 to Weill Medical College of Cornell University, as well as NCRR grant M01-RR02172 to Boston Children's Hospital.

Appendix I: Site and Staff Information

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Appendix 2 – Procedures for Laboratory Testing of Infections by the CDC

Patients who consented were surveyed clinically and 5ml of blood was collected by established phlebotomy methods. Specimens were prepared and mailed using the appropriate packaging to the CDC Serum Bank and Epidemic Response Laboratory in Lawrenceville, Georgia. Specimens received at the Serum Bank were assigned a specimen accessioning number and processed. Central testing for infectious disease was conducted at the CDC for the presence of hepatitis A, B, and C viruses, and HIV (appendix 2). After testing, the remainder of each serum specimen is used by the CDC to contribute to a serum bank for possible future use in evaluating the safety of blood products used by these patients.

Performed on Ortho Vitros ECi (Ortho Clinical Diagnostics, Rochester, NY)

aHBc:	Anti-HBC (Ortho)
aHBs:	Anti-HBS (Ortho)
HBsAg:	HBsAG (Ortho)
aHBc IgM:	Anti-HBC IgM (Ortho)
aHIV:	Anit-HIV 1+2 (Ortho)

Performed on Abbot AxSYM (Abbott Diagnostics, Abbot Park, IL)

aHCV:	Abbott AxSYM Anti-HCV (Abbott Diagnostics)
aHAV:	Abbott AxSYM HAVAB 2.0 (Abbott Diagnostics)
aHAV IgM:	Abott AxSYM HAVAB-M 2.0 (Abbott Diagnostics)

Manual

RIBA: Chiron RIBA HCV 3.0 SIA (Ortho Clinical Diagnostics)

Performed on m1000 and Prism 7000 (Abbott Molecular)

HCV RNA: HCV RNA (Abbott Molecular)

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Table 1

Thalassemia Patient Characteristics in the CDC Hemovigilance Study

	Chronic Tx (n=327)	Intermittent Tx (n=38)	Never Tx (n=42)	Total (n=407)
Average Age (years)*	22.8 ± 13.1	21.9 ± 16.7	9.8 ± 10.2	21.3 ± 13.8
Diagnosis				
β-thalassemia Major	82% (267/327)	31% (11/38)	14% (6/42)	70% (284/407)
β-thalassemia Intermedia	6% (20/327)	21% (8/38)	21% (9/42)	9% (37/407)
α-thalassemia Syndromes†	6% (20/327)	39% (15/38)	55%(23/42)	14% (56/407)
E-β-thalassemia	6% (20/327)	11% (4/38)	10% (4/42)	7% (28/407)
Gender				
Female	53% (174/327)	76% (29/38)	48%(20/42)	55% (223/407)
Male	47% (153/327)	24% (9/38)	52%(22/42)	45% (184/407)
Race				
Asian	48% (157/327)	68% (26/38)	57%(24/42)	51% (207/407)
White	49% (159/327)	24% (9/38)	17% (7/42)	43% (175/407)
Other	3% (11/327)	8% (3/38)	26%(11/42)	6% (25/407)

*Median ages for ChronicTx (transfusion), IntermittentTx, and NeverTx, respectively: 31.3 (<1 – 58), 17.3 (1 – 61), and 7 (1–53)

†HbH, HbHCS

Table 2

RBC Antigen Specificity of Alloantibodies Detected

Alloantibody	Frequency
E	29
K	17
C	12
Jka	6
c	5
HLA	5
KP[a]	4
V	4
D	3
I	3
S	3
Bg[a]	2
Cw	2
e	2
Jkb	2
Lea	2
WA1	2
f	1
Fya	1
Fyb	1
G	1
HTLA	1
Js[a]	1
LU[a]	1
M	1
Mi	1
Sd[a]	1
York A	1

There were 10 antibodies without identified specificities. 47% of patients had multiple antibodies (see text for details).

Table 3

Age of Initiation of Transfusion Therapy and Alloimmunization (n=297)

Age Transfusion Start	Rate of Alloimmunization	P = .0021
<1	11% (10/91)	
1–10	28% (47/169)	
11–20	31% (4/13)	
21+	18% (3/17)	

On univariate analysis, infants initiating chronic transfusion therapy prior to one year of age had a lower rate of alloimmunization suggesting antigen tolerance as a mechanism.

Table 4

Univariate Predictors of Alloimmunization in *Chronically Transfused Patients* (n=299)

	Mean ± SD (n)	P-value
Current Age		P<.0001
With Alloantibody	29.5 ± 13.1 (64)	
Without Alloantibody)	20.5 ± 12.3 (235)	
Years of Transfusion		P<.0001
With Alloantibody	25.9 ± 13.0 (64)	
Without Alloantibody	16.4 ± 11.1 (226)	
	Alloimmunization %	
Gender		n.s
Male	23% (32/137)	
Female	20% (32/162)	
Race		P=0.001
White	30% (43/145)	
Asian	13% (19/144)	
Splenectomy		P<.0001
Yes	30% (48/158)	
No	11% (16/141)	

* In a stepwise multivariate logistic regression of alloantibody formation in chronically transfused patients -- which included age at study enrollment (left as a continuous variable), years of transfusion, race (Asian vs. White), and splenectomy status -- only years of transfusion remained a significant independent predictor of alloimmunization.