Optimizing Blood Stock Management for Efficient Usage of O-negative Blood in the Mid-West Area of Ireland

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Abstract

O-negative blood is a valuable asset as it can be transfused into any patient regardless of blood group and is therefore used in emergencies. However, O-negative blood is comparatively rare and therefore it must be carefully rationed. The Irish blood transfusion service is concerned that O-negative donors are being asked to donate too often and would like to reduce the amount of O-negative blood used, and in particularly reduce the usage of O-negative blood for the cases where it is not clinically necessary.

The study group considered possibilities for a reduction of the O-negative blood usage in the Mid-West Area, where the current situation is particularly alarming. With the aim to quantify and minimize risks to patients in the Limerick region under a new regime in which less O-negative blood is stored at any one time, the study group explored the consequences of reducing the amount of O-negative blood stored at six local hospitals. The study group also explored the possibility of achieving a reduction of the inappropriate usage of O-negative blood by optimizing current routine practice and worked out practical recommendations for an improvement of O-negative blood management that can potentially reduce inappropriate use of O-negative blood to zero.

1 Introduction

1.1 Background

Owing to its status of "universal donor", O Rh (D) negative blood is a labile and very valuable commodity that can be transfused to any patient regardless of his/her blood group. This is particularly essential in cases of emergency, when there is no time for careful examination of a patient's blood group. For this reason, O negative blood is usually stored for emergency use in on-site and off-site fridges. However, as only about 8% of the Irish population are O Rh (D) Negative, O-negative blood is comparatively rare and must be carefully rationed.

The high demand for O-negative blood in combination with its rarity puts a rather heavy burden on O-negative donors: high total demand for blood, which is caused by inappropriate use and the high emergency stocks (high security standards), results in overbleeding of donors. The Irish blood transfusion service is concerned that O-negative donors are being asked to donate too often and would like to reduce the amount of O-negative blood used. This heavy stress on the donors is further increased by a high level of inappropriate usage of the O-negative blood (that is usage of O-negative blood for patients for whom blood of other groups can be used; see Figure 1). In particular, the Irish Blood Transfusion Services Board has repeatedly highlighted that O Rh (D) Negative usage is deemed excessive in Hospitals of the Mid-Western Region, where the average usage for July – Dec 2010 was at 18.6% of all blood used, whereas the expected usage rate should be approximately 10%. Closer study revealed ineffective use of O-negative blood in the Limerick region: up to 42% of the total blood is given to non-O negative patients because of a shortly approaching expiration date. Of this, 22% of O Rh (D) Negative red cells were issued to non-O Rh (D) Negative patients with more than 3 days to expiry, which is considered inappropriate use. A further 16% of O Rh (D) Negative red cells were issued to non-O Rh (D) Negative patients with less than 3 days to expiry. A total of 38% of O Rh (D) Negative red cells were issued to avoid outdating.

1.2 Current practice in Mid-West Area

The Mid-West Regional Hospital, Limerick, (MWRHL or MWRH) currently receives two weekly routine deliveries from the Munster Regional Technical Centre (IBTS). In turn, the MWRHL supplies cross-matched blood to 6 hospitals in the region and stocks blood to 2 off-site laboratories (see Figure 2). Currently each of the six hospitals in the group holds a fixed number, between two and five, of units of O-negative blood at any one time. A total of nineteen O Rh (D) Negative units (for emergency use alone) are stored in satellite fridges at all times which impacts significantly on inventory levels, outdates and running costs. Blood is stored in units of about 250ml and can be stored for 35 days; however, in practical terms, the blood provided to Limerick generally has at most 21 days of storage life left on it. The problem is further complicated as MWRHL acts as a hub in the region and collects all the O-negative blood from the other hospitals 10 days before its expiry date.
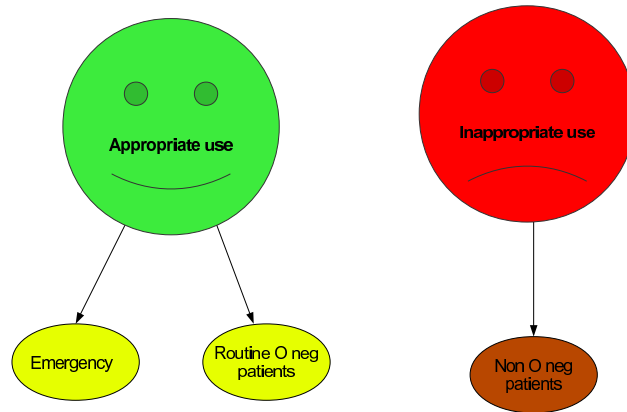
Figure 1: Terminology: Appropriate and inappropriate usage of O-negative blood

1.3   Objectives of the Study Group

The study group was ask to quantify and minimise risks to patients in the Limerick region under a new proposed regime for blood management, in which less O-negative blood is stored within the region at any one time, and to model the consequences of reducing the amount of O-negative blood stored at a group of six local hospitals. In particular, the following tasks were stated:

1. Estimate the level of risk to patients associated with a proposed new blood storage scheme, where a reduced amount of blood is stored.

2. Determine whether a lower level of risk can be achieved without increasing the number of units of blood.

The ultimate goal of the study was, however, to explore possibilities to reduce the use of O-negative blood, and in particularly inappropriate use of blood, by improving the existing blood management protocol and without jeopardizing patient welfare. In order to achieve this objective, the group investigated the consequences of reducing the amount of O-negative blood stored at a group of six hospitals in the Limerick region, and worked out practical recommendations for an improvement of O-negative blood management.

2   Problem Formulation

2.1   Current Use of O-negative Blood: Data analysis

In the order to address this problem, the study group started with an analysis of the databases on blood use provided by MWRH. The results of this analysis are summarized
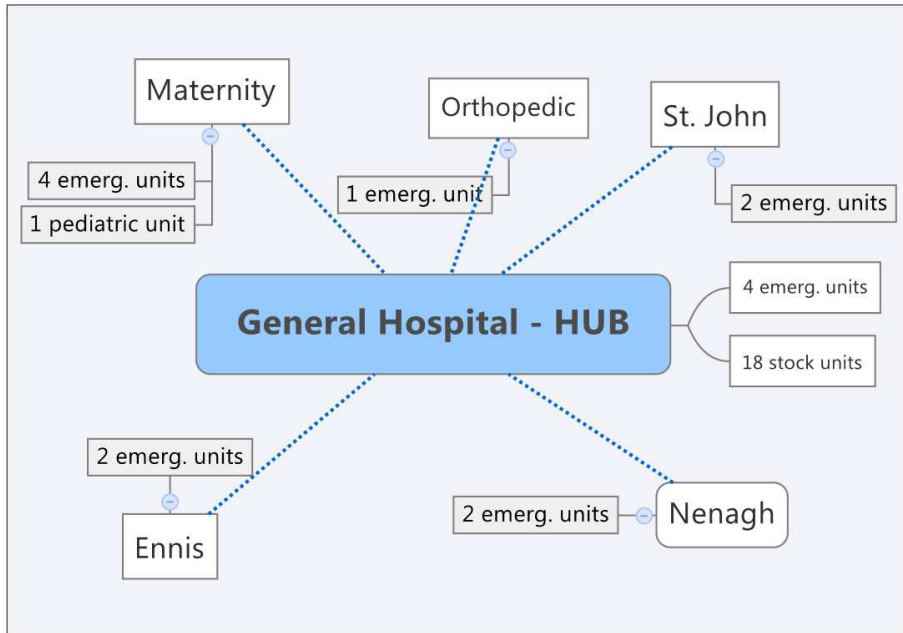
Figure 2: Current allocation of O-negative blood in Mid-Western hospitals.

below. Tables 1 and 2 give use of O-negative blood for three periods; the use is measured in units per day (Table 1) and in percents of all blood used (Table 2). Figure 3 shows the shelf-life of blood that was used inappropriately (upper diagram) and appropriately (lower diagram).

Table 1: Average Daily Usage; units per day

Period	App. Use	Emerg. Use	Inapp. Use	Total
2009–2011 (881 days)	1.722	0.112	1.187	3.022
2009–2010 (760 days)	1.534	0.122	1.220	2.876
2011 (151 days)	2.325	0.040	0.788	3.152

Tables 1 and 2 demonstrate that a significant reduction in inappropriate use of blood was achieved in the first five months of 2011. However the levels of inappropriate use remain high and further reduction is necessary. Figure 3 leads to a conclusion that the major reason for inappropriate use of blood is approaching expiry day; this indicates that simple practical measures can lead to a significant reduction in inappropriate use.

2.2 Optimal Problem Formulation

In order to explore a possibility of reduction of the inappropriate use, we formulate the following mathematical optimization problem. For the purpose of mathematical analysis, we divide the whole blood stock in the region into two parts: the emergency stock and

Table 2: Blood Usage; percentage of blood used

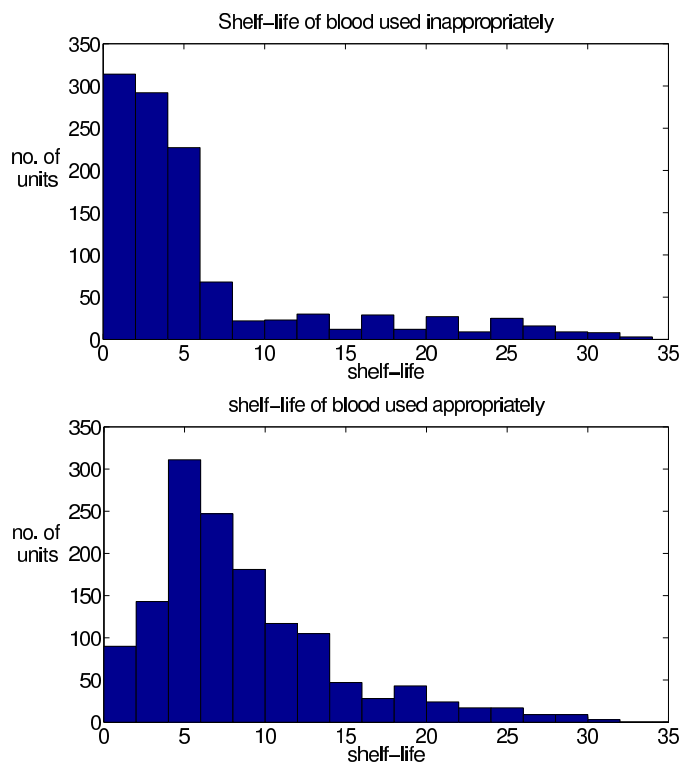| Period	App. Use	Emerg. Use	Inapp. Use	Total
2009–2011 (881 days)	56.99%	3.72%	39.29%	100%
2009–2010 (760 days)	53.34%	4.25%	42.41%	100%
2011 (151 days)	73.74%	1.26%	25%	100%

Figure 3: Shelf life of O-negative blood

the stock in the hub. (We assume that the latter is for routine use only.) We assume that the emergency stock is fixed at a preset level S_E; the stock in the hub is fixed at a level S_H. The current blood allocation between the hospitals and storages in the region is given in Figure 2. We assume that blood is ordered and delivered at a constant rate, and that we can move blood between the storages without constraints. In addition, we assume that

- Blood is delivered into the emergency stock and the hub stock from the blood bank (the "source") at constant rates, a_E and a_H respectively.

- Blood is used in the emergency rooms and in the hub (the routine appropriate use) at constant rates μ_E and μ_H, respectively.

- The emergency stock is replenished with blood coming directly from the source

(the blood bank);

- The blood units in the hub are used in the order that the oldest blood go first, and these are replenished by transferring the oldest dated units from the emergency stock into the hub and by direct delivery from the blood bank, whereas the emergency stock is replenished by delivery from the blood bank.

Using this notation, the inappropriate use of O-negative blood ("wastage" W) can be defined as

$$W = a_E + a_H - \mu_E - \mu_H; \tag{2.1}$$

that is, "wastage" is all blood that was not used either for emergency, or for routine patients who require O-negative blood transfusion. Our objective is to minimize "wastage" under the constraint that the total storage time (shelf life) of blood in the region L is less than a certain preset time L_{max} (currently $L_{max} = 21$ days). Assuming that the blood spent some time in emergency storage and then moved to the hub storage, we find that the total shelf life is

$$L = \frac{S_E}{a_E} + \frac{S_H}{a_E + a_H - \mu_E} \leq L_{max} \tag{2.2}$$

(here S_E/a_E is storage time in emergency departments, and $S_H/(a_E + a_H - \mu_E)$ is storage time in the hub). The parameter values that we are using further in this study are summarized in Table 3 (compare these with data in Tables 1 and 2).

Table 3: Notation and parameter values

Average usage rate, μ_H	– 2.34 units per day
Average emergency rate, μ_E	– 0.11 units per day
Required emergency stock, S_E	– 16 units
Target hub stock, S_H	– 18 units
Blood unit lifetime, L_{max}	– 21 days

Let us consider the a_E, a_H plane (Figure 4); each point of this plane corresponds to the rates of supply a_E and a_H. Equation (2.1) defines a family of straight lines in a_E, a_H plane; these straight lines are depicted in blue in Figure 4. Equality (2.2) defines a family of hyperbolas in a_E, a_H plane (these are depicted in black in Figure 4). For all a_E, a_H which are located in the area (a triangle) that is colored in orange in Figure 5, L is lower than L_{max} (and is equal to L_{max} on the left-hand boundary of the area), whereas $W \leq 0$ in the orange area. The condition $W < 0$ means that there is no wastage, but the supply is insufficient; equality $W = 0$, which implies that the supply exactly balances the appropriate use, holds on the right-hand boundary of the orange area. The optimal solution, where wastage $W = 0$ while the shelf life is the lowest possible, is at the lower right-hand corner of the triangle. This point corresponds to

$$a_H = 0, \qquad W = 0, \qquad a_E = \mu_H + \mu_E.$$

The condition $a_H = 0$ implies that the best policy is to never supply the hub storage from the source, but to put all newly delivered blood to the emergency storage, which
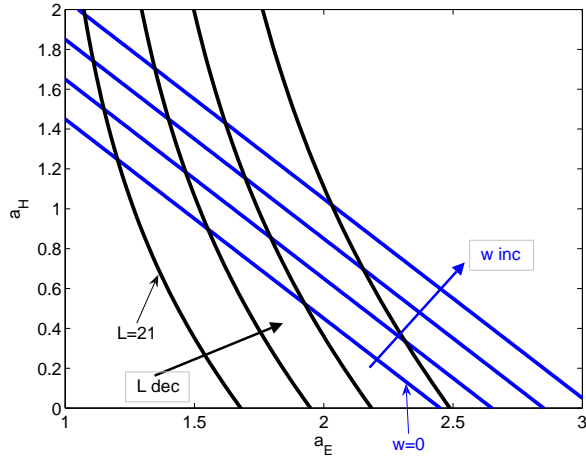
Figure 4: a_E, a_H plane

replaces the oldest-dated blood. The oldest-dated blood, in turn, should go to the hub. Of the blood stored in the hub, the oldest should be used first. This optimal solution gives us also the optimal times for keeping blood in emergency and the hub:

$$L_E = \frac{S_E}{\mu_H + \mu_E} = 6.53, \qquad L_H = \frac{S_H}{\mu_H} = 7.7.$$

This leads to a shelf life of $L = 14.3$ days on average (which is considerably shorter than the current 21 days).
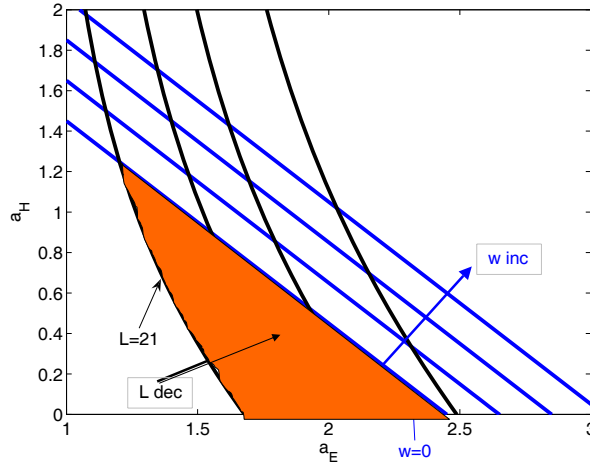

Figure 5: a_E, a_H plane and the optimal region.

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2.3 Delivery Management Protocol Proposal

The mathematical formulation and analysis decisively demonstrates that an optimization of the existing blood management practice can ensure a complete elimination of the inappropriate use of O-negative blood and a 33% reduction of the blood shelf life. The study group suggests the following protocol (see Figure 6):

1. All new arrivals from the source go exclusively to the emergency stock; no newly arrived blood should go to the hub stock.

2. The units of blood in emergency are replenished and replaced (the oldest first) with units coming directly from the source.

3. The units removed from the emergency stock go to the hub stock.

4. When units are used in the hub, the oldest units must be used first.

Thus, assuming that there are two deliveries per week (that is the existing practice) and 16 emergency units are required, it can be suggested that each week the first delivery of 8 units goes to Nenagh (2 units), Ennis (2 units) and MWRHL (4 units), while the second delivery of 8 units goes to St. John (2 units), Orthopaedic (1 unit) and Maternity (5 units) hospitals. Each time the whole stock in a hospital is completely replaced with the newly arrived blood, and the older blood goes to the hub. At the existing rate of the appropriate use of 2.325 units per day and the emergency use 0.1 units per day, the hub stock will be routinely used in less than a week. Figure 7 gives an example of the routine.
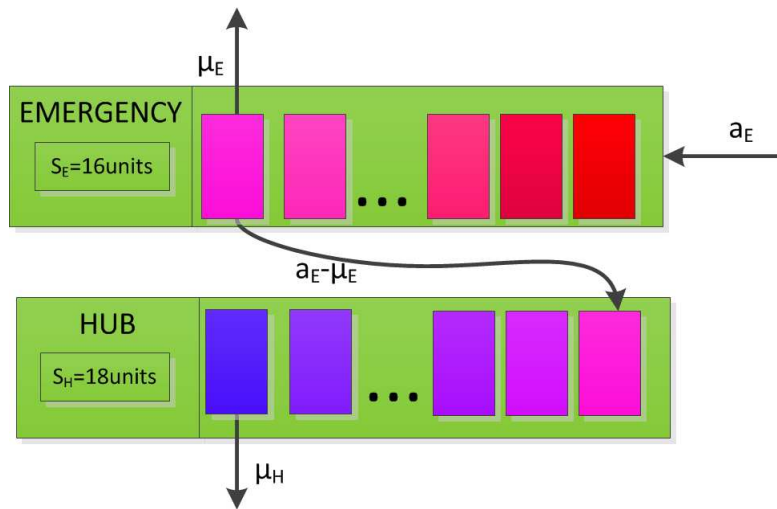

Figure 6: The flow chart for the proposed protocol.

Other arrangements are also possible. Thus, the above suggested routine is based on emergency stock of 16 units and hence on the supply rate of 16 units per week. This
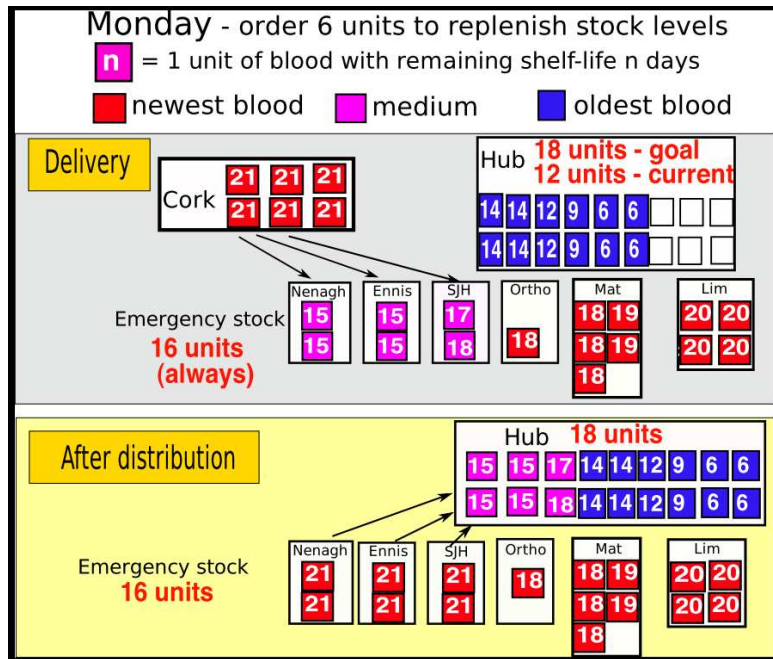
Figure 7: Example of the daily management using the proposed protocol.

can be insufficient, as the current appropriate use level, 16.55 units per week on average, is slightly higher. The deficit can be compensated by extra deliveries (when necessary), or by increasing the emergency stock to 17 units. We have to note, however, that the average appropriate use of O-negative blood during the last two and half years is lower than 2 units per day, which is lower than current. The delivery rate of 16 units per week is sufficient to maintain an average rate of the appropriate use of 2.28 units per day.

Stochastic simulations were performed in Matlab, in order to consider the effect of the discreteness of blood units. For each day, random variables representing the number of units used in emergency and in routine use were drawn from binomial distributions, with means corresponding to the parameters extracted from the data. The proposed protocol was simulated, and the resulting level of inappropriate use was shown to be almost zero, in agreement with the optimization analysis. The robustness of the protocol to variation in the parameters was also confirmed.