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Optimizing the Hospital Blood Bank Stock in Korea: A Comparative Analysis of the Uniform 5-Day Stock Index and a Novel Blood Stock Index

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Background: Maintaining optimal blood inventory levels in hospitals is important to prevent blood shortage and wastage. We aimed to provide an efficient blood inventory management strategy for hospital blood banks nation-wide by comparing the current use of 5-day issuable stock (IS) with Lim's IS as a novel target IS.

Methods: The average and CV of daily usage (DU) were calculated from information entered into Korea's Blood Management System by 194 participating hospitals in 2019 and 2020. Using these data, Lim's IS was calculated by determining the simulated annual average blood shortage day nearest to 1 for each blood group in each hospital. The 5-day IS (5IS) was estimated by multiplying the average DU in 2018 by five to count the shortage days in 2019.

Results: The average DU (0.3–231.3 units) and corresponding CV (0.33–7.14) in the participating hospitals were inversely proportional ($r = -0.699$ to -0.695). The hypothetical averages of 5IS and Lim's IS were 27.0 ± 41.2 and 24.7 ± 20.8, respectively ($P = 0.006$). The shortage days for 5IS and Lim's IS were 8.9 ± 22.7 and 1.0 ± 1.9, respectively ($P < 0.001$).

Conclusions: While 5IS was unacceptable for universal application, Lim's IS remained near one shortage day and is considered more efficient than 5IS. Hospitals should implement indicators that consider DU and its variations. This is the first study to introduce Lim's IS as an indicator of optimal blood inventory, and the data are expected to provide guidance for effective blood inventory management nationwide, particularly during blood shortages.

Key Words: Blood bank, Blood inventory management, Blood shortage day, Issuable stock

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INTRODUCTION

Adequate blood daily issuable stock (IS) levels should be maintained for hospitals to be able to provide blood transfusion services to patients in need within the required time frame. On the one hand, when inventories are insufficient, patients may not be able to receive timely transfusions. On the other hand, when the ISs of hospitals exceed the target IS, the risk of blood product wastage increases, which may negatively affect blood inventory levels in hospitals, particularly during nationwide blood shortages [1]. Therefore, establishing a target IS according to the ABO blood groups is important for efficient blood management in hospitals and reliable blood management on a national level.

It is recommended that the IS be established for each hospital separately, as conditions vary among hospitals. However, most hospitals in Korea arbitrarily apply a uniform 5-day IS (5IS) based on the average IS index (ISI) of a subset of hospitals [2, 3]. The ISI is calculated by dividing the IS by the average daily usage (DU) and is used to determine the daily blood demand [4]. The ISI can also be used to indicate the number of days of available blood stock in a blood bank inventory [1].

Unfortunately, hospitals occasionally have had difficulties in maintaining the existing target uniform 5IS, as documented in the monthly reports on blood supply and demand issued by the National Institute of Organ, Tissue and Blood Management (NIOTBM) of the Ministry of Health and Welfare. In addition to the rapidly declining fertility rate and aging population in Korea, the coronavirus disease (COVID-19) outbreak that struck in 2020 has been problematic for the national blood supply [5, 6]. Crisis levels according to the actual ISI during blood shortages in Korea are defined as follows: blue phase, <5 days; yellow phase, <3 days; orange phase, <2 days; and red phase, <1 day [7]. These crisis level definitions reflect blood inventory levels in blood supply centers at a national level; however, their application in the hospital setting and their impact on the actual inventory levels have not yet been investigated. Moreover, whether the use of 5IS is acceptable as the target IS in hospitals has not been properly investigated.

To resolve these issues, we established a novel IS (termed Lim's IS) using daily input data from participating hospitals in the Blood Management System (BMS), which monitors the blood supply and demand in Korea, and compared it with the currently used 5IS. Lim's IS and ISI were analyzed to establish a target IS for red blood cell (RBC) products in each hospital nationwide.

MATERIALS AND METHODS

Materials and data collection

The BMS was founded in 2008 as a pilot project in 28 hospitals in Korea and is equivalent to the national blood supply monitoring system in Korea governed by the NIOTBM of the Ministry of Health and Welfare. Prior to the enactment of new provisions of the Blood Management Act in December 2019, BMS participation was voluntary. Participation has since become mandatory depending on each hospital's previous year's blood supply, and the number of participating hospitals has soared to 1,174 as of October 31, 2023. In the BMS, blood product information (e.g., product type, serial number, blood group, and expiration date) of the previous day is entered or uploaded as a CSV file once a day by the participating hospitals [8].

Data on all RBC products from hospitals that participated in the BMS between January 2019 and December 2020 were provided by the NIOTBM in Excel worksheet format (Microsoft 2019; Microsoft, Redmond, WA, USA). Only hospitals that participated in the BMS prior to 2018 were selected. The rhesus (RhD) blood type was not specified since hospitals most likely do not keep RhD-negative blood products in their inventory because of the very low frequency of the RhD-negative blood type in Koreans (0.1%–0.24%) [9]. The data received included DU and inventory levels for each ABO blood group in 2019 and 2020, and the average DU in 2018 (calculated as annual blood usage/365, unconditionally rounded up) for each hospital, but excluded the hospital names. Data on transfused and wasted blood products were both included in the daily DU data from each hospital. The data were organized and analyzed using Microsoft Excel (Microsoft 2019; Microsoft, Redmond, WA, USA).

Hospitals were arbitrarily divided into seven groups according to their summed average DU of all blood groups, as follows: 1) ≥70 DU, 2) 30–69.9 DU, 3) 20–29.9 DU, 4) 10–19.9 DU, 5) 4–9.9 DU, 6) 2–3.9 DU, and 7) 1–1.9 DU. The data in the ≥70 DU group were further divided to analyze differences in blood consumption between weekdays and weekends (Saturday and Sunday).

Analysis of daily IS and ISI in 2019 and 2020

For each hospital, the IS and ISI (ISI = IS/DU) for 2019 and 2020 were calculated for each blood type from the acquired BMS data (N = 730 days). In addition, the average, SD, and CV (CV = SD/average DU) of DU for 2019 and 2020 were calculated. The 3SD IS, defined as the unconditionally rounded up sum of average DU and 3SD of DU (indicative of 99.7% of DU), was determined for each hospital. Lim's IS was calculated by multiplying the 3SD IS by the optimal multiplying factor (described in detail in the following section). 3SD ISI and Lim's ISI were calculated by dividing the 3SD IS or Lim's IS by the average DU of the corresponding hospital.

Simulation of 5IS and Lim's IS for 2019

The 5IS was calculated by multiplying the average DU of 2018 for each hospital by five. As the novel target IS, Lim's IS was estimated by multiplying the 3SD IS for 2018 by the optimal multiplying factor. The 3SD IS for 2018 was estimated by calculating the SD (= 2018 average DU × CV), assuming that the CV of DU in 2018 was identical to that in the period 2019–2020. The value of the optimal factor was determined as the value that lowered blood shortage days to around 1 day/yr for each of the seven groups in this study. To find the most optimal point of 3SD IS at which the number of shortage days in 2019 was nearest to 1, the 3SD IS was multiplied by one-tenth intervals between 1- and 2-fold levels and whole-number intervals from 2- to 7-fold levels for all blood groups at each hospital. For example, a 1.2-fold 3SD IS was selected for blood group O in the ≥70 DU group because the calculated annual average blood shortage days was 1.4 days for a 1.1-fold 3SD IS and 0.9 days for a 1.2-fold 3SD IS. However, Lim's ISI could not be calculated for some hospitals because the received DU data for 2018 were rounded to the nearest whole number, and therefore, included DU values of 0. If more than half of the hospitals had a 2018 DU value of 0 in the corresponding consumption level-based group, Lim's ISI data were excluded because they were not calculable (reported as "not available" ["NA"]).

Analysis of simulated annual average blood shortage days in 2019

The annual average blood shortage days were simulated using only the 2019 data because blood consumption was presumed to have decreased in 2020 due to COVID-19, which was expected to show a different pattern from 2018. The 2019 shortage days were defined and counted when the simulated IS was lower than the actual DU of each hospital in 2019. The IS and shortage days were calculated not only for 5IS and Lim's IS, but also for 3-day IS, 2-day IS, and 1-day IS, which were calculated by multiplying the average 2018 DU for each hospital with 3, 2, and 1, respectively, which corresponds to the yellow, orange, and red blood shortage crisis phases.

The shortage days per blood group for each hospital were counted using the CountIF function in Microsoft Excel. To eliminate hospitals with deviations in annual blood usage caused by factors unrelated to blood usage (e.g., hospital expansions), hospitals that met both of the following exclusion criteria were excluded: ≥10% difference in average DU for 2018 versus 2019–2020 in two or more ABO blood groups, and average DU ≥4 units.

Statistical analysis

A paired *t*-test was used to compare the average DU between 2019–2020 and 2018 (unconditional rounding up used for all data). Pearson's correlation coefficients (r) were calculated to analyze the relationship between the average DU and CV of DU of participating hospitals by ABO blood type. To evaluate Lim's ISI, the simulated average IS and shortage days were calculated based on 5IS and Lim's IS and compared using a paired *t*-test for each blood group. Statistical analysis was performed using Microsoft Excel, and $P<0.05$ was considered statistically significant.

RESULTS

Characteristics of participating hospitals

In total, 194 hospitals were included in the study. During the 2-yr period (2019–2020), these hospitals used 3,049,811 units of RBC blood products, accounting for 82.4% of the total 3,703,178 units supplied. The daily parameters of the RBC products varied depending on the hospital and ABO blood group. The average DU was 0.3–231.3 units (mean±SD, 21.5±28.8 units), average IS was 0.1–1,215.7 units (mean±SD, 105.6±140.8 units), and ISI was 0.0–35.3 days (mean±SD, 5.4±2.7 days). When comparing the 2-yr (2019–2020) and 2018 average DU data for each ABO blood group, the average DU was significantly lower in the former group, which included the COVID-19 outbreak period ($P<0.001$ for blood groups B, O, AB, and $P=0.018$ for blood group A).

The average DU and corresponding CV per ABO blood type in 2019–2020 were inversely proportional, with r=–0.696 for blood groups O and A, r=–0.699 for B, and r=–0.697 for AB. After excluding three hospitals with an average DU <1 unit but markedly increased CVs (2.43–7.14), the 2-yr CV for DU of the remaining 191 hospitals ranged from 0.33 to 3.97 (Fig. 1). In nine hospitals with a total DU ≥70 units, the average DU accounted for 25.8% (1,080.3 out of 4,177.8 units) of the average DU of the participating hospitals. The proportion of weekend DU compared to weekday DU ranged from 52.9% to 69.2%, with similar percentages among blood groups within each hospital.

Daily inventory levels and inventory indices in 2019 and 2020

The average DU was the highest for blood group A, followed by blood groups O, B, and AB. However, the ISI was the lowest in blood group A. During 2019–2020, the actual ISI of the participating hospitals was maintained at 5.4 days (3.8–11.9), without significant differences according to their DU. In contrast, the 3SD ISI (2.2–22.3) and Lim's ISI (2.4–10.0 excluding NA data) showed more diversity, with an inversely proportional relationship to average DU, as it was calculated by factoring in for variations in the DU of each hospital (Table 1).

Simulations of average daily IS and annual average blood shortage days in 2019

The simulated average IS and shortage days were calculated for

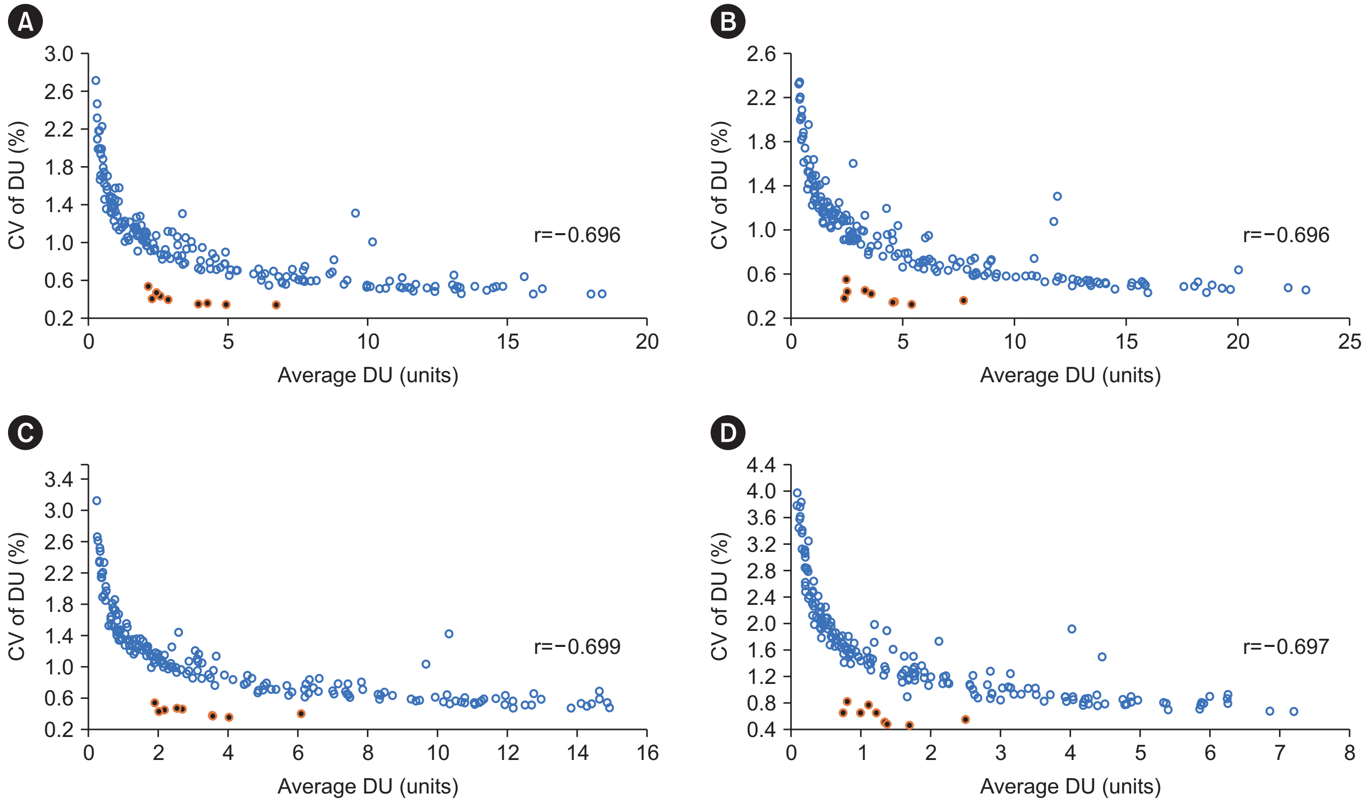

Fig. 1. Correlation between the average and CV of daily DU for blood groups: (A) O, (B) A, (C) B, (D) AB over a 2-yr period (2019–2020). The average DUs of nine hospitals with the highest DUs are shown as one-tenth of their original values (black circles).
Abbreviation: DU, daily usage.

170 hospitals, after eliminating 21 hospitals that met the exclusion criteria and three hospitals with an average DU <1 (Table 2). Overall, the simulated average IS was significantly lower when Lim's IS was applied than when 5IS was used in hospitals with an average DU of ≥20 units, whereas opposite findings were observed for hospitals with an average DU of <10 units. Similarly, the simulated average IS by blood groups revealed significantly lower levels of Lim's IS for group O and A in hospitals with DU ≥20 units. In contrast, group AB had significantly lower 5IS in all groups, except the DU ≥70 group (Table 2). There was no significant difference in the simulated average IS when 5IS or Lim's IS was applied to hospitals in the 10–19.9 DU group, except for blood group AB.

The total shortage days were significantly shorter for all blood groups when Lim's IS was applied (Table 3). The various ISIs correspond to the blood shortage crisis levels and are reported as 3-day IS, 2-day IS, and 1-day IS. The number of shortage days increased with decreasing IS, particularly in hospitals with a low average DU, except for 1-day IS (Table 3). Among the seven DU groups, hospitals with an average DU of ≥70 units showed the lowest impact on inventories until 2-day IS (orange phase) but had the worst impact on their inventories at the 1-day IS (red phase).

DISCUSSION

Our results indicate that a different standard may need to be implemented to set the target ISI according to the average DU of each hospital to maintain an efficient and adequate blood supply at the national level. In Korea, the average ISI was reported for 5 days in most hospitals and for 4.2 days in four hospitals with a DU of >30 units [2, 3, 8, 10]. In the UK, the National Health Service recommends 3–4 days of stock, but hospitals reportedly hold an average of 5.9 days of stock [11]. A questionnaire review regarding inventory management showed that the target ISI varies among countries: 7 days in Austria, 5–12 days in Belgium, 5–8 days in Canada, 3–5 days in Germany, <5 days in Hong Kong, 3–5 days in Israel, 6–12 days in the Netherlands, 10–14 days in Norway, 4 days in Portugal, 7 days in South Africa, 3–7 days in Spain, 2.5–3 days in the US (Wisconsin), and

Table 1. DU (units) and associated ISI (days) of 194 participants in the BMS in Korea for 2 yrs (2019 and 2020)

Variable	Blood group	Groups by total DU (N hospitals) ≥70 (N=9)	30–69.9 (N=39)	20–29.9 (N=20)	10–19.9 (N=31)	4–9.9 (N=49)	2–3.9 (N=28)	1–1.9 (N=15)	<1 (N=3)	Total (N=194)
DU	O	34.9±15.5	12.2±2.5	7.0±0.6	4.1±0.8	1.9±0.5	1.1±1.7	0.4±0.1	0.1±0.1	6.1±8.4
	A	40.3±17.3	14.9±3.2	8.4±0.8	5.2±0.9	2.3±0.6	1.5±2.1	0.5±0.1	0.2±0.1	7.4±9.7
	B	31.6±13.5	11.4±2.0	6.9±0.7	4.0±0.9	1.8±0.4	1.1±1.8	0.4±0.1	0.2±0.1	5.8±7.6
	AB	13.1±5.5	4.8±1.0	2.8±0.4	1.7±0.3	0.8±0.2	0.5±0.7	0.2±0.0	0.1±0.0	2.4±3.1
	All	30.0±16.7	10.8±4.4	6.3±2.2	3.7±1.5	1.7±0.7	1.0±1.7	0.4±0.1	0.1±0.1	21.5±28.8
ISI	O	4.3±0.8	4.9±1.7	5.0±1.4	5.4±1.9	5.8±2.0	6.0±2.6	6.3±3.3	11.9±20.3	5.4±2.2
	A	3.8±0.8	4.2±1.5	4.4±1.0	4.4±1.4	4.8±1.7	5.2±2.1	6.2±2.7	6.8±9.2	4.7±1.8
	B	4.7±0.9	5.2±1.8	5.1±1.2	5.6±1.8	5.8±2.1	5.9±2.5	5.9±3.6	6.3±9.9	5.6±2.3
	AB	6.3±0.8	6.1±1.5	5.6±1.4	6.3±2.5	5.4±2.0	5.2±2.7	5.7±5.6	11.0±18.9	5.8±3.2
	All	4.8±1.2	5.1±1.8	5.0±1.3	5.4±2.0	5.5±2.0	5.6±2.5	6.0±3.8	9.0±13.4	5.4±2.7
3SD ISI	O	2.3±0.2	2.8±0.3	3.0±0.2	3.6±0.4	4.4±0.4	5.6±0.5	7.6±1.0	15.4±8.3	4.3±2.2
	A	2.2±0.2	2.6±0.3	2.9±0.2	3.4±0.4	4.2±0.4	5.2±0.6	7.0±0.7	10.3±3.5	4.0±1.6
	B	2.3±0.2	2.8±0.3	3.1±0.2	3.6±0.5	4.5±0.4	5.8±0.6	7.9±1.1	11.2±5.2	4.3±1.9
	AB	2.8±0.4	3.6±0.4	4.1±0.4	4.9±0.7	6.1±0.7	8.3±1.2	10.9±1.4	22.3±7.6	6.0±3.2
	All	2.4±0.4	2.9±0.5	3.3±0.5	3.9±0.8	4.8±0.9	6.2±1.5	8.4±1.8	14.8±7.4	4.7±2.4
Lim's ISI (optimal multiplying factor)	O	2.7 (1.2)	3.5 (1.3)	4.3 (1.4)	5.3 (1.4)	6.6 (1.4)	7.2 (1.2)	NA (4.0)	-	NA (2.0)
	A	2.4 (1.1)	3.4 (1.3)	3.9 (1.3)	4.8 (1.4)	6.2 (1.4)	7.1 (1.3)	NA (3.0)	-	NA (2.0)
	B	2.8 (1.2)	3.5 (1.3)	4.5 (1.4)	5.2 (1.4)	8.3 (1.7)	NA (2.0)	NA (4.0)	-	NA (2.0)
	AB	4.9 (1.7)	5.4 (1.5)	6.5 (1.5)	10.0 (1.9)	NA (3.0)	NA (4.0)	NA (3.0)	-	NA (3.0)
	All	2.9 (1.3)	3.9 (1.4)	4.5 (1.4)	6.0 (1.6)	NA (2.0)	NA (3.0)	NA (4.0)	-	NA (2.0)

Data are expressed as mean±SD.
The ISI was calculated by dividing daily IS by the DU. The 3SD IS was determined as the unconditionally rounded up sum of average DU and 3SD of DU. Lim's IS was calculated by multiplying the 3SD ISI by the optimal factor.
Abbreviations: DU, daily usage; ISI, issuable stock index; BMS, Blood Management System; SD, standard deviation; NA, not available.

7–10 days in Venezuela [12]. Our results suggest that hospitals with low blood consumption levels (<10 units/day) would need a higher ISI and to increase their blood supply compared to hospitals with higher blood consumption (>20 units/day) to reduce their shortage days to approximately 1 day. In addition, 25.8% of the national blood supply was used by the nine hospitals with the highest blood consumption rate (≥70 DU group), which accounted for only 4.6% of hospitals participating in the BMS. This suggests that the amount of blood stocked in the inventories of these hospitals greatly impacts the national blood supply. If these hospitals were to apply the proposed Lim's IS to their blood inventory and maintain their shortage days close to 1 day, the IS would be reduced and most hospitals would be able to efficiently manage their blood supply, which would greatly help with the supply of RBC products in Korea.

Fig. 2 shows a flow chart of the procedure used to establish Lim's IS (and ISI) for each hospital according to each ABO blood group. Lim's IS (or ISI) can be applied when the blood usage amount and variation of the current year are expected to be similar to those of the previous year. Lim's IS was obtained by determining the most optimal multiplying factor in which the shortage days became nearest to 1 for each blood group, which may prevent blood shortages on a national level. The target blood shortage days can be used in a flexible manner and applied differently according to a hospital's specific situation; for example, 0–1 day for ideal IS or normal blood supply status, and 1–2 days for minimal IS or blood shortages on a national level. If the blood supply is sufficient on a national level, the shortage day to determine the target IS does not need to be maintained as high as 1.

Lim's ISI was calculated by dividing Lim's IS by the DU of the corresponding hospital, which enabled comparison among daily

Table 2. Five-day IS and Lim's IS according to total blood usage and ABO blood groups

Blood group	IS	Groups by total DU (N hospitals)							Total (N=170)
		≥70 (N=9)	30–69.9 (N=28)	20–29.9 (N=17)	10–19.9 (N=26)	4–9.9 (N=47)	2–3.9 (N=28)	1–1.9 (N=15)	
O	5-day	180.6±71.5	62.9±11.2	34.4±3.5	20.2±4.8‡	10.0±3.3	6.8±8.5†	2.0±2.5	30.5±44.2
	Lim's	95.5±30.5	44.1±7.3	29.8±3.3	20.9±4.2	12.9±3.8	8.6±5.4	15.7±14.9	24.9±22.5
A	5-day	205.6±85.3	77.9±15.8	42.4±5.0	25.8±5.8‡	12.6±4.2	8.4±10.4*	4.0±2.1	37.1±51.2
	Lim's	97.7±34.8	51.8±9.3	33.1±3.2	24.8±5.7	15.3±5.0	10.4±6.8	18.8±8.4	28.4±23.6
B	5-day	162.8±75.0	57.7±9.1	34.1±4.4	21.2±4.8‡	9.5±4.1	6.4±8.7	3.0±2.5	28.7±40.7‡
	Lim's	88.3±36.7	40.8±6.5	30.4±4.1	21.6±3.7	15.1±5.9	13.9±9.1	22.7±16.1	26.2±20.6
AB	5-day	62.8±24.6‡	25.5±4.6	14.7±2.1	8.5±2.4	4.6±1.8	1.8±4.1	NA	11.9±15.9
	Lim's	59.9±18.9	27.2±4.6	17.9±3.0	16.7±4.7	18.4±6.1	11.7±14.7	NA	19.3±14.2
All	5-day	152.9±85.3	56.0±22.0	31.4±11.0	18.9±7.9	9.1±4.5	5.8±8.5	3.0±2.5	27.0±41.2†
	Lim's	85.3±33.4	41.0±11.4	27.8±6.8	21.0±5.4	15.4±5.6	11.1±9.7	19.1±13.6	24.7±20.8

Data are expressed as mean±SD (in units).
NA was due to the exclusion of more than half of the hospitals with a 2018 DU value of 0 in their corresponding consumption level-based group.
The 5-day IS was determined by multiplying the DU by five. Lim's IS was calculated by multiplying the 3SD ISI with the optimal factor.
All data show a significant difference between 5-day IS and Lim's IS ($P<0.001$; *$P<0.05$, †$P<0.01$), except data indicated by ‡(not significant).
Abbreviations: DU, daily usage; IS, issuable stock; NA, not available.

average consumption levels (Table 1). Theoretically, 3SD ISI should include 99.7% of DU, but was not considered a suitable variable for calculating the shortage days for every hospital because of its wide variation (2.2–22.3 days, Table 1); therefore, a multiplying factor was needed.

Lim's IS implemented in this study was calculated assuming that the requested amount of blood products could be supplied at least once a day, considering the geographical characteristics of Korea. This is because during blood shortage periods, it would be preferable that hospitals received blood products every day instead of storing several days' worth of blood. However, it would be much more effective and realistic to maintain RBC inventory levels at the IS while receiving blood products once every few days or extend the calculated shortage day in hospitals with low blood consumption levels, such as the 1–1.9 DU group in Table 2. However, it is unclear whether 1 day as the shortage day for Lim's IS is suitable for hospitals with low blood consumption levels, because the IS can be overestimated, which may increase blood wastage. To clarify this limitation, further studies are required to determine the appropriate shortage day for applying Lim's IS to hospitals with low blood consumption levels.

In all ABO blood groups, the average and CV of DU showed an inverse correlation. In addition, the prediction of the average DU in hospitals with low blood consumption was particularly difficult because of the high CV values. As such, variation factors have been used along with other factors in algorithms of blood inventor models for minimizing blood shortage and outdating, such as the XGBoost and stochastic inventory models [13, 14]. The Australian Red Cross Blood Service developed an RBC safety stock calculation method using the Z score, average of lead time, variance of demand, variance of lead time, and average of demand in each period [15]. It is considered necessary to reflect the unique characteristics of each country when calculating the target ISI.

As our study included only hospitals participating in the BMS, which accounts for 82.4% of the RBC blood products supplied in Korea, it is not clear whether Lim's IS will in fact reduce the average IS and annual blood shortage days at the national level. Furthermore, based on the 2018 annual data on RBC products, as most hospitals not included in the BMS use <5,000 units/yr (average DU<13.7), the IS is expected to increase when using Lim's IS instead of the 5IS [10]. Therefore, additional studies including all hospitals offering transfusion services are required. In addition, in future, it would be helpful for hospitals if the NIOTBM provided the CV or SD in addition to the average DU of the previous year and used decimal numbers instead of integers when reporting the average DU.

In summary, Lim's IS, a novel IS, was calculated by multiplying the 3SD IS by the optimal factor at which the annual average blood shortage day was 1, reflecting the variation in blood consumption among hospitals. Additionally, Lim's ISI was found to be an effective index that not only lowered the average IS of the

Table 3. Simulated blood shortage days according to various IS levels, blood usage, and ABO blood groups in 2019

Blood group	IS	Groups by total daily usages (N hospitals)							Total (N = 170)
		≥70 (N = 9)	30–69.9 (N = 28)	20–29.9 (N = 17)	10–19.9 (N = 26)	4–9.9 (N = 47)	2–3.9 (N = 28)	1–1.9 (N = 15)	
O	5-day	0.1	0.1	0.5	1.7	4.3	3.4	56.5	7.1
	Lim's	0.9†	1.0‡	1.0*	1.2	1.0‡	0.7‡	0.9‡	1.0‡
	3 SD	4.1	7.9	7.6	8.4	8.9	2.2	57.5	11.5
	3-day	0.7	2.4	4.2	11.6	21.3	18.5	58.9	16.7
	2-day	6.4	17.4	25.2	43.1	48.9	37.3	63.3	37.6
	1-day	155.4	155.9	150.1	144.8	120.5	97.1	79.9	127.4
A	5-day	0.1	0.2	0.4	0.9	2.5	4.1	20.3	3.4
	Lim's	1.2	1.1‡	1.1‡	1.3*	0.9†	1.1‡	1.3*	1.1‡
	3 SD	4.6	7.1	6.9	7.6	7.4	4.5	21.6	8.0
	3-day	0.6	2.0	3.8	8.2	16.9	20.3	26.7	12.3
	2-day	4.9	14.5	23.0	34.8	46.4	42.4	36.5	33.3
	1-day	166.2	161.4	148.6	151.8	125.2	105.8	75.5	132.2
B	5-day	0.1	0.1	0.1	1.0	6.4	9.5	34.1	6.5
	Lim's	1.1	1.0‡	0.8*	0.9	1.0‡	1.1	0.5†	0.9‡
	3 SD	6.3	8.0	7.9	6.7	13.1	9.9	37.8	12.1
	3-day	1.0	2.1	5.1	9.1	25.2	23.0	38.5	16.4
	2-day	7.3	18.0	27.3	36.4	53.0	39.7	43.9	36.7
	1-day	160.4	154.0	143.4	133.4	125.4	95.4	67.9	125.0
AB	5-day	1.0	1.3	2.2	7.2	14.6	54.1	45.2	18.5
	Lim's	1.0	1.0	1.2/0.8‡	1.0‡	1.0†	0.8‡	0.9‡	1.0‡
	3 SD	10.3	8.2	8.9	10.6	16.4	46.1	34.6	19.6
	3-day	6.2	7.8	12.6	26.5	27.7	55.4	45.2	27.7
	2-day	23.8	30.9	36.0	52.6	43.9	58.6	45.2	43.8
	1-day	157.2	132.5	117.6	118.6	91.4	71.8	45.2	101.1
All	5-day	0.3	0.5	0.8	2.7	7.0	17.8	39.0	8.9
	Lim's	1.1†	1.0‡	1.0	1.1‡	1.0‡	1.0‡	0.9‡	1.0‡
	3 SD	6.3	7.8	7.8	8.3	11.5	15.7	37.9	12.8
	3-day	2.1	3.6	6.4	13.8	22.8	29.3	42.3	18.3
	2-day	10.6	20.2	27.9	41.7	48.0	44.5	47.2	37.8
	1-day	159.8	151.0	139.9	137.2	115.6	92.5	67.1	121.4

Data are expressed as average simulated blood shortage days.
Statistical significance between 5-day and Lim's IS: $^{*}P < 0.05$, $^{\dagger}P < 0.01$, $^{\ddagger}P < 0.001$.
The 5-day IS was determined by multiplying the daily usage by five. Lim's IS was calculated by multiplying the 3SD ISI with the optimal factor. 3-day, 2-day, and 1-day ISs correspond to the yellow, orange, and red blood shortage crisis phases, respectively, and were calculated by multiplying the daily usage by 3, 2, and 1, respectively.
Abbreviation: IS, issuable stock.

hospitals participating in the BMS but also reduced the annual average blood shortage days when compared to the 5ISI. Furthermore, shortage days were proposed for all blood crisis phases for guidance during periods of blood shortage. To the best of our knowledge, this study was the first in Korea to report optimal blood inventory levels on a national level and blood shortage days according to various indices and to show the impact of blood inventories in hospitals on the national level ac-

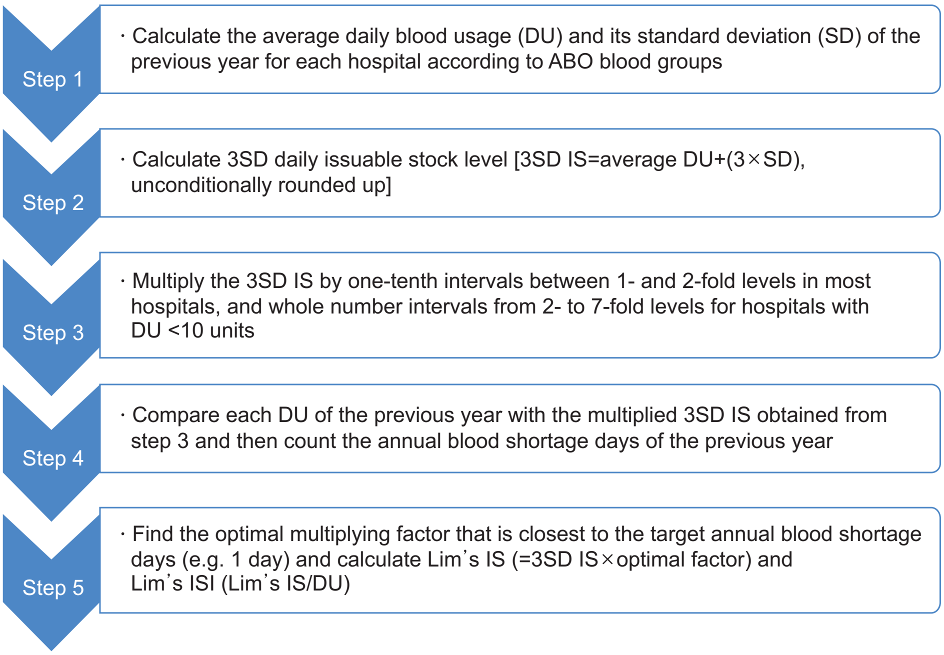

Fig. 2. Flow chart of the procedure used to obtain Lim's daily IS level and the ISI for each hospital according to the ABO blood group.
Abbreviations: IS, issuable stock; ISI, IS index.

cording to the crisis level during blood shortages. Our results are expected to provide guidance for efficient blood management on a national level and deepen our understanding of various scenarios that hospitals encounter in response to blood shortage crises.

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AUTHOR CONTRIBUTIONS

Lim YA designed and supervised the study. Lim YA and Park SJ wrote and revised the manuscript. Lim YA, Park SJ, and Kim KH contributed to data analysis and interpretation. All authors have read and approved the final manuscript.

CONFLICTS OF INTEREST

None declared.

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