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Web interface–supported transmission risk assessment and cost-effectiveness analysis of postdonation screening: a global model applied to Ghana, Thailand, and the Netherlands

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BACKGROUND: The goal of our research was to actively involve decision makers in the economic assessment of screening strategies in their region. This study attempted to accomplish this by providing an easy-to-use Web interface at http://www.bloodsafety.info that allows decision makers to adapt this model to local conditions.

STUDY DESIGN AND METHODS: The cost-effectiveness was compared of 1) adding antigen screening to antibody screening for hepatitis C virus (HCV) and human immunodeficiency virus (HIV); 2) adding nucleic acid amplification testing (NAT) on hepatitis B virus (HBV), HCV, and HIV in minipool (pool of 6 [MP6] and 24 [MP24]) to antibody screening and hepatitis B surface antigen (HBsAg) screening; and 3) individual-donation NAT on HBV, HCV, and HIV to antibody screening and HBsAg screening for Ghana, Thailand, and the Netherlands.

RESULTS: The combination of HCV antibody-antigen combination (combo) and HIV combo added to antibody screening in Ghana and Thailand was cost-effective according to the WHO criteria. MP24-NAT screening in Ghana was also cost-effective. MP24-NAT on HBV, HCV, and HIV was not cost-effective compared to the other screening strategies evaluated for the Netherlands. Large regional differences in cost-effectiveness were found for Thailand.

CONCLUSION: The young transfusion recipient population of Ghana in combination with a high risk of viral transmission yields better cost-effectiveness for additional tests. The advanced age of the transfused population of the Netherlands and a small risk of viral transmission gives poor cost-effectiveness for more sensitive screening techniques. It was demonstrated that a global health economic model combined with a Web interface can provide easy access to risk assessment and cost-effectiveness analysis.

Economic evaluations of interventions to enhance blood transfusion safety have appeared since the 1980s and mainly concern blood donor screening.[1,2] The type of analysis underlying such economic evaluation generally employs mathematical modeling to simulate the health consequences and associated costs of transfusion-transmitted infections.

The local conditions of a region strongly determine the outcome of such a model. The most appropriate screening strategy will depend on factors such as the incidence of infections in the donor population, the resources available to allocate to screening, and the health care infrastructure.

Therefore, for these models to play a useful role in the decision-making process, they must be adapted to local conditions. However, up-to-date regional data are often only available to local decision makers and the exact information requirements of these decision makers are frequently unknown.

The goal of our research is to actively involve medical professionals and decision makers in the economic assessment of blood donor screening strategies in their region. We attempt to accomplish this by providing an easy-to-use Web interface that allows users to adapt our global model to local conditions and perform customized transmission risk assessments and cost-effectiveness analyses of several postdonation blood donor screening strategies.

In this article, we present the results of this model applied to Ghana, Thailand, and the Netherlands, using the Web interface that we developed for this health-economic model. We have chosen these countries to illustrate the potential impacts of large difference in local conditions and corresponding model outcomes between a typical developing, transitional, and developed country. Incident rates for hepatitis B virus (HBV), hepatitis C virus (HCV), and human immunodeficiency virus (HIV) in blood donors are high in Ghana, intermediate in Thailand, and relatively low in the Netherlands.[3-6] Also, the population of blood transfusion recipients in Ghana, as an example for sub-Saharan Africa, is on average much younger than blood transfusion recipients in the developed world.[7] Young patients with malaria and iron deficiency–related pediatric anemia represent a large share in the patient population. In contrast, in the developed world more than 50% of the units are transfused to patients aged 65 and older.[8,9]

Antibody screening is universally and widely applied in many countries. The residual viral transmission after antibody screening for HCV and HIV and screening for hepatitis B surface antigen (HBsAg) can be further reduced by adding more sensitive tests. For instance, antigen screening or nucleic acid amplification testing (NAT) reduces the time between the development of infectious viremia and the possible detection (i.e., the window period) and thus lower the residual transmission risk.[10] The objective of our study and the Web interface is to weigh the extra costs of adding more advanced screening techniques against savings in reduced health care costs for HBV, HCV, and HIV and corresponding health gains in these infections being averted. The approach is illustrated by performing incremental cost-effectiveness analyses of adding additional testing to existing screening strategies:

1. Adding antigen screening to antibody screening for HCV[11] and HIV (HCV antibody [Ab] and HIV-Ab);
2. Adding NAT to HCV-Ab and HIV-Ab screening; and
3. Adding NAT to antigen testing for HBV (HBsAg).

NAT can be evaluated in minipools (MPs) with various pool sizes or on each individual donation (ID). Both options are investigated below.

As is common in health-economic research, we explicitly distinguish the base case analysis from sensitivity and scenario analyses. All results of the base case and additional analyses presented below were calculated using the Web interface that is publicly accessible at http://www.bloodsafety.info. In the discussion, we will further address the potential role that Web-based interaction with health-economic models could play in supporting future decision making.

MATERIALS AND METHODS

Model overview

Cost-effectiveness of transfusion safety was simulated for Ghana, the Netherlands, and Thailand in a cohort of 10,000 donations to 1) illustrate the use of a Web interface to perform an economic evaluation and 2) to actually provide up-to-date estimates of cost-effectiveness of enhanced screening methods for blood transfusion safety in these three countries. In the base case the residual risk of transmission and the cost of screening were estimated for five postdonation screening strategies:

1. HBsAg, HCV-Ab, and HIV-Ab;
2. HBsAg, HCV-Ab + Ag (HCV combo), and HIV-Ab + Ag/p24 (HIV combo);
3. MP24-NAT (pool of 24 donations on HBV, HCV, and HIV) + HIV-Ab, HCV-Ab, and HBsAg;
4. MP6-NAT (pool of 6 donations on HBV, HCV, and HIV) + HIV-Ab, HCV-Ab, and HBsAg; and
5. ID-NAT (on HBV, HCV, and HIV) + HIV-Ab, HCV-Ab, and HBsAg.

From the estimated HBV, HCV, and HIV transmission risks the number of infected transfusion recipients was estimated using country-specific processing characteristics for donation, regarding the whole process from the donor to the patient. The burden of disease and arising treatment cost as a result of transfusion-acquired infections was modeled in country-specific patient cohorts. All costs were expressed in US$ (2006 price levels).

Using the Web interface, the user can change the variables of several predefined scenarios that we describe in this article: one for developing countries in Africa (in this case Ghana), one for transitional countries in Asia (three regions in Thailand), and one for the developed world (the
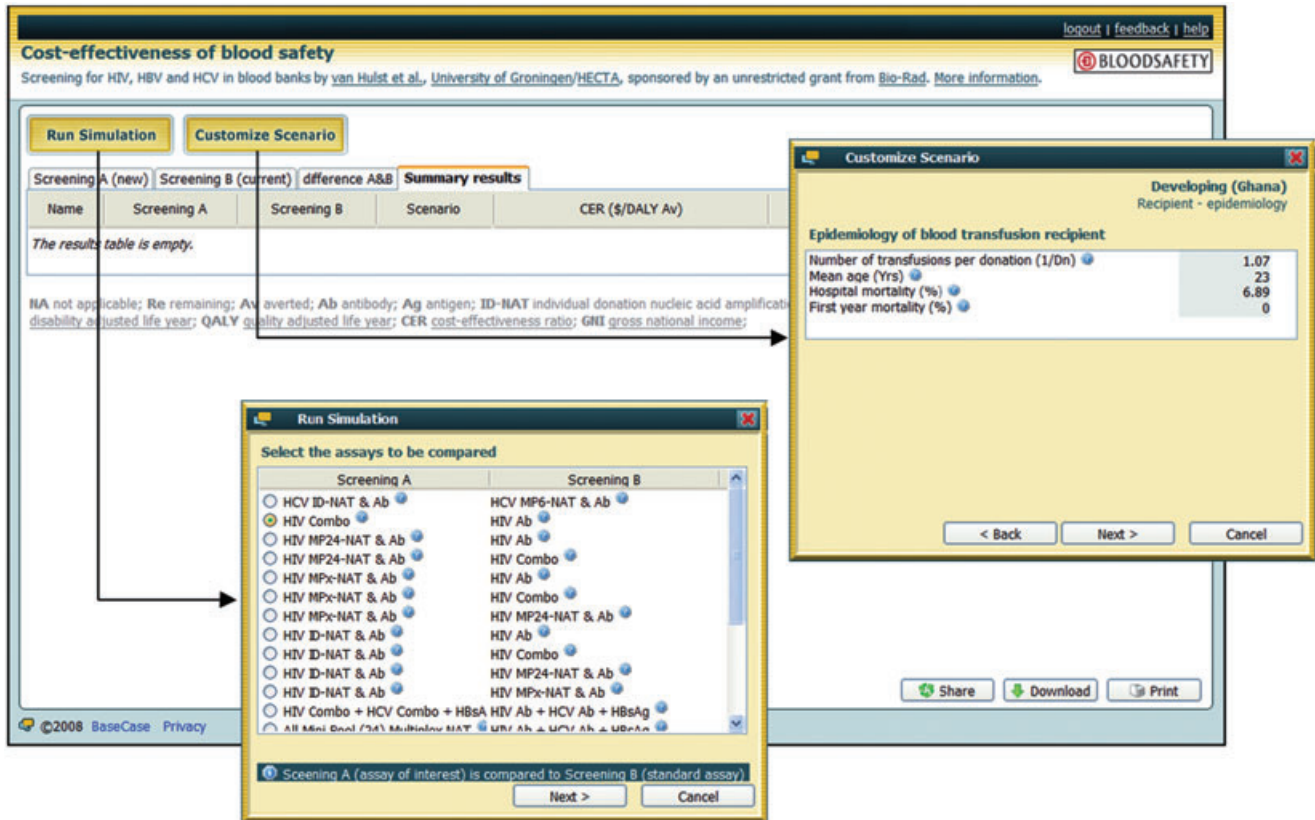
Fig. 1. Selecting the assays to be compared for the transmission risk assessment and cost-effectiveness analysis. Users can also customize available scenarios to their local situation.

Netherlands). To compare transmission risks and cost-effectiveness of two screening strategies, the user selects the appropriate comparison, chooses the scenario that resembles the region of interest most, optionally adapts variables, and performs the simulation (Fig. 1).

Donation; screening; and residual risk of HBV, HCV, and HIV transmission

Data on donations and subsequent processing for Ghana were obtained during 2004 from the National Blood Transfusion Service located at the Korle Bu Teaching Hospital (Accra, Ghana). Data on donating and processing for Thailand were retrieved from the information systems of the blood banks of the Prince Songkla University (Songkla, Thailand) and the Siriraj Hospital (Bangkok, Thailand). For the Netherlands data on donating and processing was obtained from the 2006 annual report of the Sanquin Blood Supply Foundation and a cost-effectiveness analysis of pathogen inactivation that was previously performed[5,12] (see Table 1 for the input variables for the base case).

In the Web interface the user has two options to estimate the residual transmission risk of a screening strategy. The preferred method is the incidence window period model, which is to be used if the incidence is known.[13,14] In the incidence window period model the residual risk of infection after testing is estimated by multiplying the window period (Table 2) for the particular test with the incidence of the infection (Table 1).[14-16] This method can certainly be used for the Netherlands. However, most blood banks in middle human development index (for example, Thailand) and low human development index (for example, Ghana) countries rely (in part) on one-time replacement donors to provide an adequate blood supply. Prevalence estimates can be obtained, but incidence rates are not readily available for these countries because these replacement donors are not followed up.[17] In these circumstances the detuned assay is an option to estimate the incidence; however, this is yet seldom available.[18] If the incidence is not known, the user can estimate the residual risks of transmissions with an adapted version of the window period model using the prevalence (see Appendix A, available as supporting information in the online version of this paper). The adapted version of the window period model is also used for the risk of transmission by first-time donors.

As HBV infection resolves, HBsAg titers decline to undetectable levels that can yet still be detected by ID-NAT.[19] The incidence of HBsAg positivity in repeat

	Base case values		
TABLE 1. Variable estimates for blood donation and screening			
Model variable	Ghana	Thailand	The Netherlands
Blood donation			
Number of donations per transfusion	1.07	1.66	1.66
Viral marker screening	Prevalence (%)	Prevalence (%)	Incidence (per 1×10^6 donor years)
HBsAg	15	2.51	11
		B1.20;C4.71;S1.61	
Anti-HCV	4	0.72	2.6
		B0.50;C1.31;S0.36	
Anti-HIV	2.49	0.39	5.5
		B0.20;C0.81;S0.16	
Cost of screening (US$/donation)			
HIV Ab	0.6	0.6	0.8
HIV combo (Ab, p24)	0.8	0.8	0.9
HIV MP24-NAT + HIV Ab	6.6	6.6	10.8
HIV MP6-NAT + HIV Ab	9.2	9.2	10.9
HIV ID-NAT + HIV Ab	17.4	17.4	20.8
HBsAg	0.4	0.4	0.5
HBV MP24-NAT + HBV Ab	6.4	6.4	10.5
HBV MP6-NAT + HBV Ab	9	9	10.8
HBV ID-NAT + HBV Ab	17.2	17.2	20.5
HCV Ab	2.6	2.6	4
HCV combo (Ab, p24)	4.0	4.0	5
HCV MP24-NAT + HCV Ab	8.6	8.6	14.0
HCV MP6-NAT + HCV Ab	11.2	11.2	14.3
HCV ID-NAT + HCV Ab	19.4	19.4	24.0
Multiplex MP24-NAT + HIV Ab, HBsAg, HCV Ab	9.6	9.6	15.3
Multiplex MP6-NAT + HIV Ab, HBsAg, HCV Ab	12.2	12.2	15.6
Multiplex ID-NAT + HIV Ab, HBsAg, HCV Ab	20.4	20.4	25.3

All costs in 2006 US$.
Ab = antibody; Ag = antigen; B = Bangkok; C = Chiang Mai; S = Songkla.

donors therefore underestimates the incidence of HBV infection. As a transient marker of infection, HBsAg can be cleared before the follow-up donation. In the incidence-based transmission risk estimation a correction factor was used to compensate for the transient nature of HBsAg. The incidence of HBsAg positivity is multiplied by a correction factor, 2.38 for Thailand and Ghana[20] and 3 for the Netherlands.[5] In the prevalence-based transmission risk estimation an extra window period was included for late-stage HBV infection.

Country-specific incidence; prevalence; estimated transmission risks for HBV, HCV, and HIV; and costs are presented in Table 1. The screening costs were estimated by multiplying the country-specific cost of the screening strategies with the number of donations in the cohort. Currently, only the costs of the tests and the reagents are included since labor costs, training costs, and amortized costs of equipment were not available.

Patient population; HBV, HCV, and HIV infections; and costs

Data on the clinical use of blood transfusion and the blood transfusion recipient were collected for each of the included countries. Because costs and outcomes of transfusion-acquired infectious diseases vary with age,

the exact age of recipients is important and the mean age of the transfused patient for each of the included countries was specifically estimated (Table 3). Also, the risk of receiving an infected unit was calculated from the blood transfusion utilization and the number of blood products processed from one donation for each country. Hospital mortality due to causes unrelated to transfusion was estimated at 6.89% for Ghana. Hospital mortality included patients dying during admission. Long-term excess mortality of blood transfusion recipients was not included in the model for Ghana and Thailand since it is only described for the developed world, where patients transfused are older and suffer from different underlying diseases.[8,21,22] For the Netherlands long-term excess mortality was estimated at 20% at 1 year posttransfusion.[8]

Health consequences of HBV and HCV infection were modeled with previously reported Markov models.[23-25] In 2003, vaccination for HBV started in Ghana and 85% of transfused patients born after 2003 were assumed to be vaccinated.[26] The effectiveness of the HBV vaccine was assumed to be 98%.[27,28] The susceptibility to HBV infection in patients not vaccinated against HBV was modeled at 20% for patients aged more than 10 years and 70% for those aged less than 10 years.[29] The susceptibility to HBV for the average patient was estimated at 20%. The treatment costs for cirrhosis and hepatocellular carcinoma

TABLE 2. Transmission risk estimation: window period of screening strategies and incubation time

Screening strategy	Window period (days)
HIV Ab[14]	20.3
HIV combo (Ab, p24)[14]	15
HIV MP24-NAT + HIV Ab[14]	9
HIV MP6-NAT + HIV Ab[15]	7.4
HIV ID-NAT + HIV Ab[14]	5.6
HBsAg[16]	38.3
Late-stage HBsAg[19]	24.0
HBV MP24-NAT* + HBsAg[16]	38.3
Late-stage HBV MP24-NAT + HBsAg[19]	24.0
HBV MP6-NAT + HBsAg[15]	22.6
Late-stage HBV MP6-NAT + HBsAg[15,19]	14.1
HBV ID-NAT + HBsAg[15,16]	20.6
Late-stage HBV ID-NAT + HBsAg[15,19]	12.9
Incidence correction factor for transient HBsAg infection in repeat donors[20]	2.38 (Netherlands 3[5])
HCV Ab[14]	58.3
HCV combo (Ab, Ag)[14]	12.5
HCV MP24-NAT + HCV Ab[14]	7.4
HCV MP6-NAT + HCV Ab[14]	6.1
HCV ID-NAT + HCV Ab[14]	4.9
Duration of disease stages without apparent clinical signs, i.e., incubation time (year)	
HIV (WHO Stages 1 and 2)	5
HBV	22
HCV	22

* No difference in window period between HBsAg and MP24-NAT.

Ab = antibody; Ag = antigen.

were included in the model for HBV and HCV and were obtained from the Korle Bu Teaching Hospital (Accra, Ghana). In Thailand, universal vaccination of newborn infants for HBV was introduced in 1992.[30] Vaccination coverage reached 92% in 1995 and has remained more than 95% ever since.[31] Currently, 33% of the blood transfusion recipients are assumed to be still susceptible to HBV infection.[30] Treatment costs associated with HBV and HCV disease states were obtained from diagnosis-related group costs from the Prince Songkla University Hospital (Table 3). Since March 2003, 15% of all newborns belonging to high-risk groups in the Netherlands have received vaccination for HBV.[32] Approximately 4% of the Dutch population aged between 40 and 75 years were estimated to be carriers of anti-HBc in 1995.[33] The susceptibility of Dutch blood transfusion recipients was accordingly assumed at 95%. In the absence of Dutch data, costs of treatment associated with HBV and HCV were derived from German cost data.[34,35] HBV transmission from donors with occult HBV infection was not included in this evaluation.

HIV infection was simulated using a two-stage Markov model.[36] Patients from Ghana were assumed to progress faster to the AIDS stage compared to patients from Thailand and the Netherlands. These progression rates are actually confined to the predefined scenarios in

the Web interface, the user cannot change this. To model the extension of the HIV stage and longevity by antiretroviral therapy (ART), it was assumed that antiviral drugs would be available for 7.5% of the patients in the base case, representing the current situation in Ghana.[37,38] All infected patients were assumed to receive standard care for sequelae of HIV infection. ART was assumed to be initiated at HIV WHO Stage 3 (clinical symptoms and CD4 count of $<200 \times 10^6$ cells/L), continued life-long and estimated to yield an additional 12 life-years in the base case.[39-42] The accessibility to ART for Thai transfusion recipients was assumed at 60%.[43] In the Netherlands all patients contracting HIV from blood transfusion were assumed to receive ART. Annual costs of ART and standard care for HIV patients are displayed in Table 3.

As a measure of burden of disease, the disability-adjusted life-year (DALY) was estimated by adding the years of life lost and the adjusted years lived with disease. The years of life lost per patient from transfusion-acquired infections were determined as the difference between the patient-specific life expectancy and the life expectancy after HBV, HCV, or HIV infection. The life expectancy after HBV, HCV, or HIV infection was estimated from the respective Markov models described in the preceding section. Country- and age-specific remaining life expectancies were taken from the WHO and directly applied to patients receiving blood transfusions.[44] Years lived with disease was reflected by the total time per patient in the HBV, HCV, HIV disease states multiplied by the appropriate disability weight.[45]

Cost-effectiveness

The cost-effectiveness of the screening strategies was evaluated from the health care perspective. We estimated the cost-effectiveness ratio (CER), that is, the costs divided by the additional health gains of a screening strategy (intervention), compared with doing nothing. Additionally, we estimated the incremental cost-effectiveness ratio (ICER), that is, the additional costs of a screening strategy divided by the additional health gains of a screening strategy, compared with the next least expensive screening strategy (comparator). Figure 2 illustrates these comparisons. Screening strategies that cost more and result in less health gains than other screening strategies were excluded (dominated). Next to dominated strategies, we labeled "extended dominated" alternatives. Extended dominated strategies are those strategies for which we can find another strategy that is more costly and provides more health gains, but at a more favorable (lower) CER.

The estimated (I)CERs were compared with the per-capita Gross National Income (GNI) of the respective countries. According to WHO guidelines, strategies that show a (I)CER below the per-capita GNI are regarded as cost-effective, whereas strategies with a (I)CER above

TABLE 3. Key variable estimates for patients receiving a blood transfusion*			
	Base case values		
Model variable	Ghana	Thailand	The Netherlands
Epidemiology			
Mean age (year)	23[7]	45.46	65
Hospital mortality (%)	6.89	0	0
First-year mortality (%)	0	0	20
Number of secondary HIV transmissions (R0)	1	1	0
HIV			
Recipients infected with HIV before transfusion (%)	2.3[57]	1.4[58]	0.2[59]
HIV progression model[36]	Fast	Slow	Slow
Accessibility to ART (%)	7.5[37,38]	60[58]	100[59]
Duration of WHO Stages 1 and 2 (year)	5	5	5
Extension of WHO Stage 3 by ART (year)	12	12	12
Disability weight HIV[45]	0.136	0.136	0.136
Disability weight AIDS[45]	0.505	0.505	0.505
Cost of basic care for PLWHA (US$/year)	35	35	12,500
Cost of ART for WHO Stages 3 and 4 (US$/year)	380	1,158	12,500
HBV			
Recipient susceptibility to HBV infection (%)	20	33	95
Progression to chronic hepatitis (%)	5	5	5
HCV			
Recipients infected with HCV before transfusion (%)	4	4.8[60]	0
Spontaneous remission (%)	31	31	31
HBV and HCV			
Access to liver transplantation (%)	0	0	100
Disability weight cirrhosis	0.18	0.18	0.18
Disability weight decompensated cirrhosis	0.49	0.49	0.49
Disability weight HCC	0.45	0.45	0.45
Cost of cirrhosis (US$/year)	485	310.82	918
Cost of decompensated cirrhosis (US$/year)	485	13,973.10	17,091
Cost of HCC (US$/year)	360	6760.11	22,514
Cost of liver transplantation (US$ in the first year)	NA	NA	159,952

* All costs in 2006 US$.
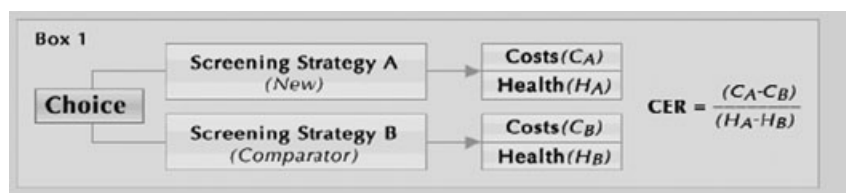HCC = hepatocellular carcinoma; NA = not applicable; PLWHA = persons living with HIV or AIDS.

Fig. 2. Calculation of the CER.

three times the per-capita GNI are regarded as not cost-effective.[46,47] The health gains were expressed as DALYs averted, that is, the reduction in premature death and morbidity due to averted transfusion-transmitted infections by the specific screening strategy. The DALYs associated with each screening strategy were determined by multiplying the residual risk of HBV, HCV, or HIV transmission for the specific screening strategy with the DALYs caused by transfusion-acquired diseases. In line with health-economic guidelines (http://www.ispor.org), DALYs were discounted at 3% and weighted for age in the base case; an evaluation without age weighing was also performed.[45] The costs per screening strategy were estimated by adding the costs of screening and health care costs of transfusion-acquired infections. Future costs were also discounted at 3% annually.

Using the Web interface the user can evaluate combinations of 19 screening strategies (of which five are described is this article) in three countries. It contains more than 80 model variables that can be changed. Within the limited space of an article we present only the sensitivity of the outcomes to test costs; mean age of the blood transfusion recipient; incidence (or prevalence) of the viral markers in donors; and treatment costs for HBV, HCV, and HIV.

RESULTS

Base case analysis

HCV antigen screening prevented more transfusion-transmitted infections than HIV p24 antigen screening, both in addition to antibody screening. Ghana was the country with the greatest number of cases prevented by adding antigen screening for HIV and HCV to antibody screening (Table 4). Ghana also had the highest prevented disease burden (in DALYs) by additional antigen screening for HIV and HCV. HIV antigen screening contributed to 82% of the prevented disease burden in this region.

TABLE 4. Transmission risk assessment and cost-effectiveness analyses of the base case*

Screening A (new)	Screening B (current)	Scenario	Cases averted, effects and costs per 10,000 donations					A compared to B—summary results	
			HIV+† (Av)	HCV+† (Av)	HBV+† (Av)	Effects (DALY Av)	Total costs ($)	CER (US$/DALY Av)	Ratio CER/GNI
HIV combo + HCV combo + HBsAg	HIV Ab + HCV Ab + HBsAg	Ghana	1.4068	2.1805	0.0000	34.0249	20,689	608	1.4
All MP24 multiplex NAT	HIV combo + HCV combo + HBsAg	Ghana	1.5926	0.2428	0.0000	32.1790	37,140	1,154	2.6
All MP6 multiplex NAT	All MP24 multiplex NAT	Ghana	0.4247	0.0619	0.9522	10.4398	25,766	2,468	5.5
All ID multiplex NAT	All MP6 multiplex NAT	Ghana	0.4778	0.0571	0.1190	9.8423	81,746	8,306	18.5
HIV combo + HCV combo + HBsAg	HIV Ab + HCV Ab + HBsAg	Thailand	0.3705	0.6515	0.0000	3.2088	18,500	5,765	2.1
All MP24 multiplex NAT	HIV combo + HCV combo + HBsAg	Thailand	0.4194	0.0726	0.0000	2.7182	35,147	12,930	4.7
All MP6 multiplex NAT	All MP24 multiplex NAT	Thailand	0.1119	0.0185	0.5303	1.3373	25,189	18,836	6.8
All ID multiplex NAT	All MP6 multiplex NAT	Thailand	0.1258	0.0171	0.0663	0.8857	81,145	91,617	33.3
HIV combo + HCV combo + HBsAg	HIV Ab + HCV Ab + HBsAg	Thailand (Bangkok)	0.1900	0.4504	0.0000	1.8054	20,011	11,084	4.0
All MP24 multiplex NAT	HIV combo + HCV combo + HBsAg	Thailand (Bangkok)	0.2151	0.0502	0.0000	1.4117	36,515	25,865	9.4
All MP6 multiplex NAT	All MP24 multiplex NAT	Thailand (Bangkok)	0.0574	0.0128	0.2538	0.6694	25,580	38,214	13.9
All ID multiplex NAT	All MP6 multiplex NAT	Thailand (Bangkok)	0.0645	0.0118	0.0317	0.4558	81,557	178,939	65.1
HIV combo + HCV combo + HBsAg	HIV Ab + HCV Ab + HBsAg	Thailand (Chiang Mai)	0.7695	1.1800	0.0000	6.4263	15,019	2,337	0.8
All MP24 multiplex NAT	HIV combo + HCV combo + HBsAg	Thailand (Chiang Mai)	0.8711	0.1314	0.0000	5.6190	32,106	5,714	2.1
All MP6 multiplex NAT	All MP24 multiplex NAT	Thailand (Chiang Mai)	0.2323	0.0335	0.9964	2.6492	24,334	9,185	3.3
All ID multiplex NAT	All MP6 multiplex NAT	Thailand (Chiang Mai)	0.2613	0.0309	0.1245	1.8181	80,234	44,130	16.0
HIV combo + HCV combo + HBsAg	HIV Ab + HCV Ab + HBsAg	Thailand (Songkla)	0.1520	0.3243	0.0000	1.3948	20,469	14,675	5.3
All MP24 multiplex NAT	HIV combo + HCV combo + HBsAg	Thailand (Songkla)	0.1721	0.0361	0.0000	1.1239	36,819	32,760	11.9
All MP6 multiplex NAT	All MP24 multiplex NAT	Thailand (Songkla)	0.0459	0.0092	0.3406	0.6932	25,653	37,005	13.5
All ID multiplex NAT	All MP6 multiplex NAT	Thailand (Songkla)	0.0516	0.0085	0.0426	0.3832	81,645	213,054	77.5
HIV combo + HCV combo + HBsAg	HIV Ab + HCV Ab + HBsAg	Netherlands	0.0013	0.0054	0.0000	0.0031	17,912	5,819,518	158.9
All MP24 multiplex NAT	HIV combo + HCV combo + HBsAg	Netherlands	0.0015	0.0006	0.0000	0.0014	81,925	59,127,509	1,614.6
All MP6 multiplex NAT	All MP24 multiplex NAT	Netherlands	0.0004	0.0002	0.0224	0.0098	2,950	300,925	8.2
All ID multiplex NAT	All MP6 multiplex NAT	Netherlands	0.0004	0.0001	0.0028	0.0016	96,974	60,502,453	1,652.2

* All costs in 2006 US$. The CER and the ratio to the GNI per capita are shown. GNI for Ghana, Thailand, and The Netherlands was US$450, US$2750, and US$36,620 per capita.
Antigen (combo) and NAT were in addition to HBsAg, HCV-Ab, and HIV-Ab.
† Infected blood transfusion recipients.
Ab = antibody; Ag = antigen; Av = averted.

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Compared to Ghana, the disease burden prevented by adding antigen screening for HIV and HCV was lower for Thailand. HIV contributed to 72% of the prevented disease burden by additional antigen screening in Thailand. The prevented disease burden and the number of cases of HIV and HCV prevented by additional antigen screening was the lowest for the Netherlands. In contrast to the disease burden, the difference in the total costs between the combo tests for HIV and HCV and the HIV and HCV antibody screening strategy was similar among the different countries. Prevented treatment costs contributed to a small share of the difference in costs between combo and antibody screening; only 18.9%, 6.3%, and a negligible percentage were found for Thailand, Ghana, and the Netherlands, respectively. The CER of combo tests for HIV and HCV compared to the respective antibody tests was consistently lower than the other evaluated screening strategies. For Ghana, this CER was below the three times GNI threshold of cost-effectiveness. Adding antigen testing to antibody screening in the Netherlands is expected to yield a CER more than three times the GNI. In Thailand large regional differences were seen. In Chiang Mai the CER for HIV and HCV combo assays was below the GNI threshold of cost-effectiveness. For the whole of Thailand, the CER for using HIV and HCV combo assays instead of antibody assays was below the three times GNI per-capita threshold.

MP24-NAT prevented less disease burden in addition to HCV and HIV combo at higher costs than HCV and HIV combo relative to antibody screening. Therefore, the cost-effectiveness of MP24-NAT is lower (higher costs-to-benefit ratio, CER) than for HIV and combo screening (lower CER). The greatest number of infections and disease burden was prevented in Ghana, followed by Thailand. The number of HBV, HCV, and HIV infections prevented was very low for the Netherlands. Of the evaluated countries, Ghana displayed the lowest (most favorable) CER for MP24-NAT screening relative to combo tests which was just below the three times the GNI per capita of cost-effectiveness. Thailand and the Netherlands showed CERs more than four and 1600 times the per-capita GNI.

In line with the previous observations, the more sensitive and more expensive MP6-NAT screening strategy gave less health benefit compared to the next least expensive strategy (MP24-NAT) and thus higher costs-to-benefit ratios (CERs), except for the Netherlands. The small difference in expected test costs between MP24-NAT and MP6-NAT together with more transfusion-infected cases prevented resulted in relatively low costs-to-benefit ratio for MP6-NAT screening. The reduction of disease burden in Thailand and the Netherlands can for the larger part be attributed to the prevention of HBV transmission. The CER was more than three times GNI for all evaluated countries. ID-NAT added to antibody screening gave the highest ratio of the CER to the GNI.

Figure 3 shows that for Ghana and Thailand all evaluated screening strategies are on the cost-effectiveness frontier. None of the evaluated strategies were more effective and less costly than another screening strategy for these countries. When ordered from least effective to most effective, as in Fig. 3, the estimated CERs resembled the ICERs because none of the strategies can be eliminated in the evaluations for Ghana and Thailand. With the given variables and assumptions, the disease burden prevented and costs associated with MP24-NAT screening added to antibody screening for the Netherlands are below the line that connects combo tests to MP6-NAT added to antibody screening. The CER of MP24-NAT relative to combo tests is higher than the CER of MP6-NAT relative to combo tests. In this case, MP24-NAT added to antibody screening is eliminated and only antibody screening, combo tests, MP6-NAT, and ID-NAT must be considered. The ICER of ID-NAT versus MP6-NAT was US$60.5 million per DALY prevented which is more than 1600 times higher than the GNI per capita for the Netherlands. At US$7.6 million per DALY prevented, the ICER of MP6-NAT versus HCV and HIV combo test is considerably lower.

Conventional sensitivity analysis

Figure 4 shows the sensitivity of the CER to changes in test costs; mean age of the blood transfusion recipient; the incidence rates (or prevalence) of viral markers in blood donors; and treatment costs for HBV, HCV, and HIV. The CER is very sensitive to changes in test costs. In particular, comparisons of antibody and combo tests are very sensitive to changes in costs because of the small difference in costs between both screening methods. A test cost reduction of 25% yielded a 65% to more than 90% lower (more favorable) CER. Reducing the costs of MP24-NAT in combination with antibody screening by 25% lowered the CER of MP24-NAT relative to combo tests below the three times GNI per-capita threshold Thailand. The cost-effectiveness of screening strategies is sensitive to changes in the prevalence or incidence of transfusion-transmissible infection in donors. In particular, the expected costs and benefits of MP6-NAT compared to MP24-NAT are very sensitive to the estimation of the HBV transmission risk. The influence of the mean age of the blood transfusion recipient was the greatest for the Netherlands. Changes in treatment costs for HBV, HCV, and HIV were of little consequence for all countries and screening strategies included (data not shown). However, projecting future improvement of treatment options for Thailand negatively impacted the cost-effectiveness of screening strategies. An expected 100% access to ART combined with a higher survival (an extended survival of 24 instead of 12 life-years) and 100% access to liver transplantation increased the CER more than twofold for MP-NAT versus combo tests. This was
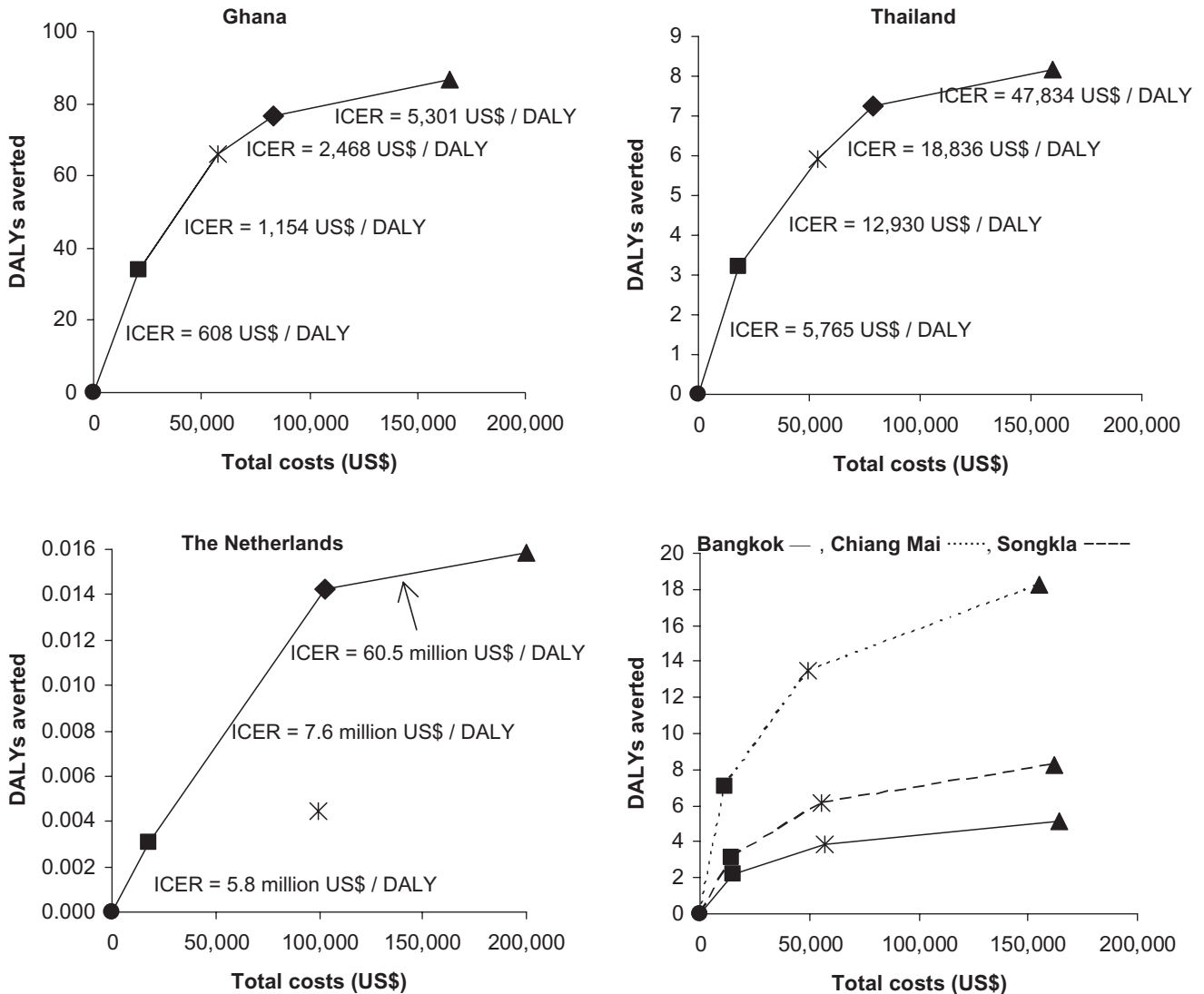
Fig. 3. Prevented disease burden (DALYs) and total costs of postdonation screening per 10,000 donations in Ghana, Thailand, the Netherlands, and regional scenarios for Thailand (Bangkok, Chiang Mai, and Songkla). Strategies on the right of the line are dominated by the strategies on the line because these strategies are less effective or cost more than the strategies on the line. This line also represents the ICER. ICER estimates are not shown for the regional scenarios for Thailand (Bangkok, Chiang Mai, and Songkla). All costs in 2006 US$. (●) antibody; (■) combo = antibody + antigen; (*) MP24-NAT; (◆) MP6-NAT; (▲) ID-NAT.

mainly caused by the reduction in disease burden caused by HIV, HCV, and HBV.

DISCUSSION

We investigated the cost-effectiveness of screening blood donations for HBV, HCV, and HIV in Ghana, Thailand, and the Netherlands using a Web interface to a global model comprising country and patient population–specific survival, blood product utilization, and direct cost data. We found that adding tests to HBsAg and antibody screening for HIV and HCV would prevent the most disease burden in Ghana, followed by Thailand, and finally the Nether-

lands. Given the variables and underlying assumptions of our model, introducing HIV and HCV combo tests instead of antibody screening was estimated to be cost-effective for Ghana and Chiang Mai (Thailand). In both scenarios the base case ICER was below the three times GNI per-capita threshold that has been suggested by both the WHO and the World Bank for very cost-effective interventions. The averted disease burden could mainly be attributed to prevention of HIV transmission. ID-NAT was not cost-effective in any of the explored scenarios. For all evaluated regions the ICERs of ID-NAT relative to the next least expensive screening strategy were well over three times the GNI per-capita threshold for cost-effectiveness over
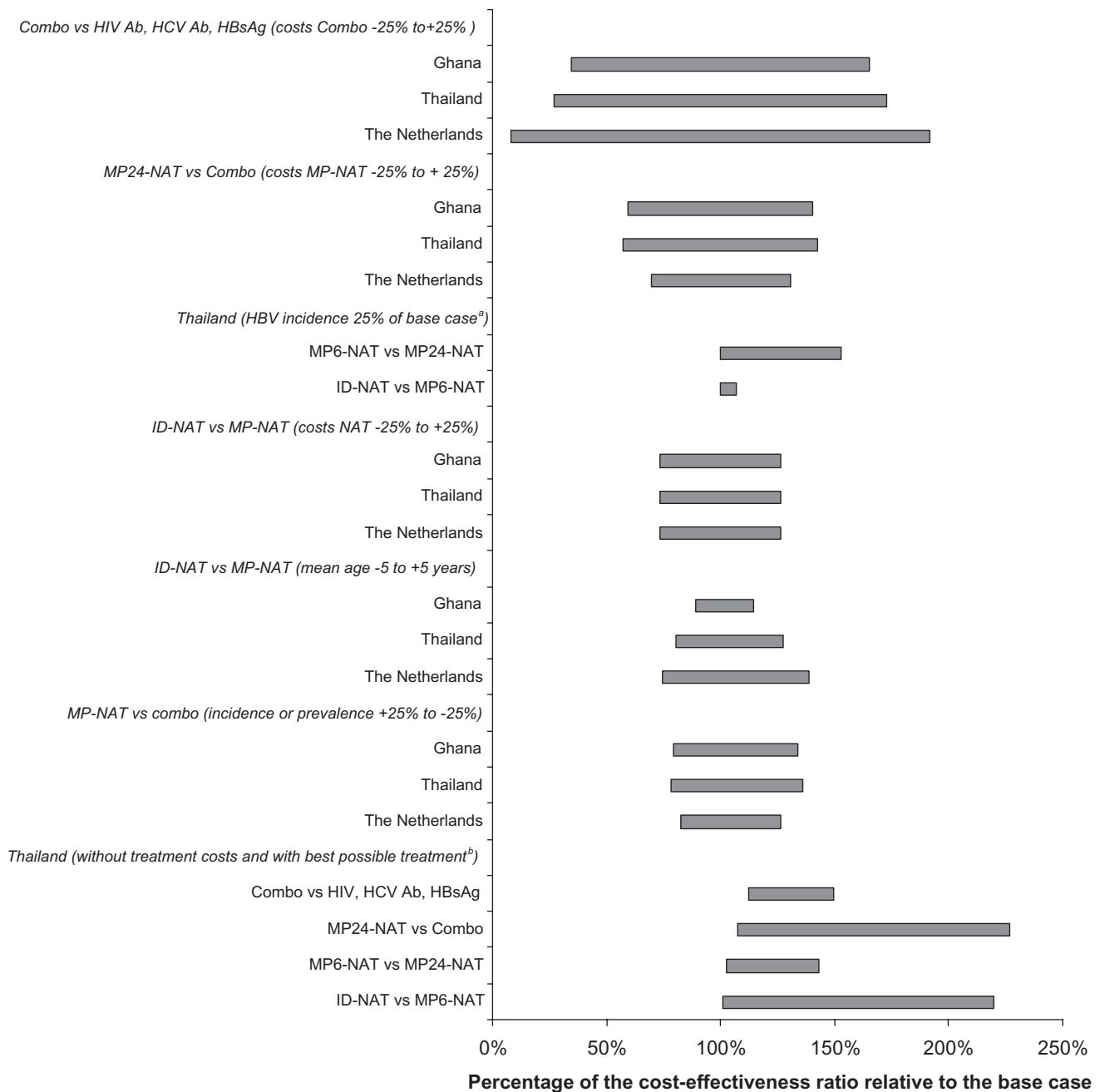
Fig. 4. Sensitivity analysis of selected variables. Antigen (Ag; combo) and NAT were in addition to HBsAg, HCV antibody (Ab), and HIV Ab. [a]MP24-NAT versus HBsAg is not evaluated because the window periods are the same;[16] [b]possible treatment comprises 100% access to ART for HIV with a duration of effect of 24 years and 100% access to liver transplantation.

which interventions are regarded not cost-effective. MP24-NAT was cost-effective for Ghana, Bangkok (Thailand), and Chiang Mai (Thailand) because in these scenarios the ICER was one to three times the GNI per capita. Interestingly, for the Netherlands, MP24-NAT added to antibody screening was dominated by a screening strategy comprising HIV and HCV combo tests and also by MP6-NAT added to antibody tests. MP48-NAT for HIV and HCV in combination with HBsAg and antibody screening for

HIV and HCV is the current screening strategy in the Netherlands. In Thailand blood donations are generally screened for HBsAg and antibodies to HIV and HCV. Some blood centers in Thailand are currently implementing ID-NAT for HBV, HCV, and HIV in combination with serology. In Ghana blood donations are mainly screened for HBsAg and antibodies to HIV and HCV.

Health care interventions in sub-Saharan Africa targeted at communicable diseases are associated with CERs

ranging from US$121 per DALY averted for malaria control and US$310 per DALY averted for prevention of mother-to-child HIV transmission up to US$542 to $1280 per DALY averted or US$1180 per life-year gained for providing highly active ART.[48-50] Expanding blood donations screening with HIV-antigen tests does not compare favorably with these specific interventions. Compared to CERs for expanding HIV screening in the more developed world, which easily exceed US$1 million per DALY averted (I)CERs found for introducing additional screening in Ghana and Thailand represent much greater value. The rank order in the value for money is mainly determined by two variables: 1) the risk of viral transmission and 2) the mean age of the transfusion recipient. Due to the incubation time of HBV, HCV, and HIV, the younger transfusion recipient population in Ghana will experience more disease burden than the older transfusion recipient population of the Netherlands. Obviously, the much higher risk of viral transmission in Ghana relative to the Netherlands will provide better cost-effectiveness for more sensitive screening strategies.

One limitation of our evaluation is the determination of the residual risk of viral transmission by using the prevalence instead of the preferred incidence window-phase approach or the application of a detuned assay.[13,51] However, our estimated residual risk may be a good approximation, since the risk of 2.76 per 10,000 donated units after HIV antibody screening in the present study falls well within the range from a previously reported direct determination. In this study, performed in Kumasi (Ghana) with a comparable HIV prevalence, 0.6 to 3.9 infective units per 10,000 donated units were found.[52] Also transmission risks estimated for HIV, HCV, and HBV infection in Thailand, 1:80,000, 1:230,000, and 1:9600 per donation, respectively, compare reasonably well to a recent study conducted in Thailand. In this study the combined ID-NAT/MP6-NAT yield rates for HIV, HCV, and HBV were 1:97,000, 1:490,000, and 1:2800 per donation, respectively.[53] As was shown by our analysis, the estimation of HBV transmission risk is critical for taking an informed decision to adopt either MP6-NAT or MP24-NAT screening in Thailand. A further limitation of this evaluation is that only window period HIV transmissions are considered, disregarding transmissions due to technical or human failure, which could also potentially be reduced by additional screening tests.[54] At first glance, users can only use the mean age of the transfused population. This certainly has drawbacks since the course of infection with HBV, HCV, and HIV is age dependent. However, the disease models accessed from the Web interface are age dependent. Therefore, more experienced users can estimate the cost-effectiveness based on an age distribution of the transfused population by performing evaluations for each age group in that specific population. Labor costs, training costs, and amortized costs of equipment were not included in the screening costs. This is a potential favorable bias toward labor and capital intensive screening strategies, such as NAT. The estimation of labor costs, training costs, and amortized costs of equipment is left for further work.

We note several problems regarding the usability of economic studies on blood transfusion screening strategies to support decision making. For model developers, local data for the many regions a model could theoretically be applied to is frequently unavailable. Moreover, the number of possible screening strategies is very large and the exact information requirements of decision makers are very difficult to anticipate. As science progresses and new evidence comes available, economic studies need to be updated, but such updates are rarely reported in literature. When updates appear, it is mainly as letters, and no complete overview is provided.[55,56]

We believe that a solution to these problems lies in the development of global economic models that are transferable to many regions. Local researchers, medical professionals, and decision makers could be more actively involved in applying these models to their own settings. This approach could 1) lower the barrier of entry to economic evaluation, 2) advocate cost-effectiveness analysis to support policy decisions, and 3) increase the transparency of economic studies.

Particularly in regions with limited resources, where explicit trade-offs are necessary, cost-effectiveness analysis can contribute to a more optimal allocation of health-care resources. However, these regions often lack the financial resources to develop their own models. Our approach can lower the barrier to perform cost-effectiveness analysis and at the same time raise awareness of the usefulness of such analysis and provide background information on the method used.

To allow interaction with economic models, we believe that a Web interface offers several significant advantages. It avoids the need for nonexperts to interact with complex modeling technology directly. Additionally, it is an efficient way of distributing a model to a globally distributed audience. Finally, a Web-based system allows multiple users to share model data and this opens up new opportunities for remote communication and collaboration.

Directions of future research

We recommend the formation of an expert panel of health economists to guide and support local decision makers and researchers with the collection of reliable local data required for a correct assessment for their region. The Web interface can be further developed into a more advanced communication platform to support the dialogue and exchange of knowledge between an expert panel and local decision makers and researchers. Ideally, this platform

should allow the broader blood bank community to share regional scenario data and corresponding model outcome and benefit from each other's work.

This initiative was recently adopted by the subgroup on cost-utility analysis and risk assessment of the International Society Blood Transfusion working party on transfusion-transmitted infectious diseases and will be further developed within that framework.

CONFLICT OF INTEREST

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REFERENCES

1. Van Hulst M, De Wolf JT, Staginnus U, Ruitenberg EJ, Postma MJ. Pharmaco-economics of blood transfusion safety: review of the available evidence. Vox Sang 2002;83:146-55.

2. Custer B. Economic analyses of blood safety and transfusion medicine interventions: a systematic review. Transfus Med Rev 2004;18:127-43.

3. Sarkodie F, Adarkwa M, du-Sarkodie Y, Candotti D, Acheampong JW, Allain JP. Screening for viral markers in volunteer and replacement blood donors in West Africa. Vox Sang 2001;80:142-7.

4. Kitayaporn D, Bejrachandra S, Chongkolwatana V, Chandanayingyong D, Weniger BG. Potential deferral criteria predictive of human immunodeficiency virus positivity among blood donors in Thailand. Transfusion 1994;34:152-7.

5. Janssen MP, Van Der Poel CL, Buskens E, Bonneux L, Bonsel GJ, van Hout BA. Costs and benefits of bacterial culturing and pathogen reduction in the Netherlands. Transfusion 2006;46:956-65.

6. Nantachit N, Thaikruea L, Thongsawat S, Leetrakool N, Fongsatikul L, Sompan P, Fong YL, Nichols D, Ziermann R, Ness P, Nelson KE. Evaluation of a multiplex human immunodeficiency virus-1, hepatitis C virus, and hepatitis B virus nucleic acid testing assay to detect viremic blood donors in northern Thailand. Transfusion 2007;47:1803-8.

7. Van Hulst M, Sagoe KW, Vermande JE, van de Schaaf IP, van der Tuuk Adriani WP, Torpey K, Ansah J, Mingle JA, Smit Sibinga CT, Postma MJ. Cost-effectiveness of HIV screening of blood donations in Accra (Ghana). Value Health 2008;11:809-19.

8. Tynell E, Norda R, Shanwell A, Bjorkman A. Long-term survival in transfusion recipients in Sweden, 1993. Transfusion 2001;41:251-5.

9. Cobain TJ, Vamvakas EC, Wells A, Titlestad K. A survey of the demographics of blood use. Transfus Med 2007;17:1-15.

10. Schreiber GB, Busch MP, Kleinman SH, Korelitz JJ. The risk of transfusion-transmitted viral infections. The Retrovirus Epidemiology Donor Study. N Engl J Med 1996;334:1685-90.

11. Laperche S, Elghouzzi MH, Morel P, Asso-Bonnet M, Le Marrec N, Girault A, Servant-Delmas A, Bouchardeau F, Deschaseaux M, Piquet Y. Is an assay for simultaneous detection of hepatitis C virus core antigen and antibody a valuable alternative to nucleic acid testing? Transfusion 2005;45:1965-72.

12. Sanquin Blood Supply Foundation. Sanquin Annual Report 2006. Amsterdam: Sanquin Blood Supply Foundation; 2007.

13. Kleinman S, Busch MP, Korelitz JJ, Schreiber GB. The incidence/window period model and its use to assess the risk of transfusion-transmitted human immunodeficiency virus and hepatitis C virus infection. Transfus Med Rev 1997;11:155-72.

14. Busch MP, Glynn SA, Stramer SL, Strong DM, Caglioti S, Wright DJ, Pappalardo B, Kleinman SH. A new strategy for estimating risks of transfusion-transmitted viral infections based on rates of detection of recently infected donors. Transfusion 2005;45:254-64.

15. Assal A, Barlet V, Deschaseaux M, Dupont I, Gallian P, Guitton C, Morel P, van Drimmelen H, David B, Lelie N, De Micco P. Sensitivity of two hepatitis B virus, hepatitis C virus (HCV), and human immunodeficiency virus (HIV) nucleic acid test systems relative to hepatitis B surface antigen, anti-HCV, anti-HIV, and p24/anti-HIV combination assays in seroconversion panels. Transfusion 2009;49:301-10.

16. Kleinman SH, Busch MP. Assessing the impact of HBV NAT on window period reduction and residual risk. J Clin Virol 2006;36 Suppl 1:S23-9.

17. Field SP, Allain JP. Transfusion in Sub-Saharan Africa—does a Western model fit? J Clin Pathol 2007;60:1073-5.

18. Fang CT, Field SP, Busch MP, Heyns AP. Human immunodeficiency virus-1 and hepatitis C virus RNA among South African blood donors: estimation of residual transfusion risk and yield of nucleic acid testing. Vox Sang 2003;85:9-19.

19. Yoshikawa A, Gotanda Y, Itabashi M, Minegishi K, Kanemitsu K, Nishioka K. HBV NAT positive blood donors in the early and late stages of HBV infection: analyses of the window period and kinetics of HBV DNA. Vox Sang 2005;88:77-86.

20. Korelitz JJ, Busch MP, Kleinman SH, Williams AE, Gilcher RO, Ownby HE, Schreiber GB. A method for estimating

hepatitis B virus incidence rates in volunteer blood donors. National Heart, Lung, and Blood Institute Retrovirus Epidemiology Donor Study. Transfusion 1997;37:634-40.

21. Vamvakas EC, Taswell HF. Epidemiology of blood transfusion. Transfusion 1994;34:464-70.

22. Jackson BR, Busch MP, Stramer SL, AuBuchon JP. The cost-effectiveness of NAT for HIV, HCV, and HBV in whole-blood donations. Transfusion 2003;43:721-9.

23. Crowley S, Tognarini D, Desmond P, Lees M, Saal G. Introduction of lamivudine for the treatment of chronic hepatitis B: expected clinical and economic outcomes based on 4-year clinical trial data. J Gastroenterol Hepatol 2002;17: 153-64.

24. Bennett WG, Inoue Y, Beck JR, Wong JB, Pauker SG, Davis GL. Estimates of the cost-effectiveness of a single course of interferon-alpha 2b in patients with histologically mild chronic hepatitis C. Ann Intern Med 1997;127:855-65.

25. Borkent-Raven BA, Janssen MP, Van Der Poel CL, de Wit GA, Bonsel GJ, van Hout BA. Cost-effectiveness of additional hepatitis B virus nucleic acid testing of individual donations or minipools of six donations in the Netherlands. Transfusion 2009;49:311-9.

26. WHO. Ghana reported immunization coverage. [cited 2007 May 10]. Available from: http://www.who.int/immunization_monitoring/en/globalsummary/timeseries/tscoveragebycountry.cfm?C=GHA

27. Dentinger CM, McMahon BJ, Butler JC, Dunaway CE, Zanis CL, Bulkow LR, Bruden DL, Nainan OV, Khristova ML, Hennessy TW, Parkinson AJ. Persistence of antibody to hepatitis B and protection from disease among Alaska natives immunized at birth. Pediatr Infect Dis J 2005;24: 786-92.

28. Milne A, West DJ, Chinh DV, Moyes CD, Poerschke G. Field evaluation of the efficacy and immunogenicity of recombinant hepatitis B vaccine without HBIG in newborn Vietnamese infants. J Med Virol 2002;67:327-33.

29. Allain JP, Candotti D, Soldan K, Sarkodie F, Phelps B, Giachetti C, Shyamala V, Yeboah F, Anokwa M, Owusu-Ofori S, Opare-Sem O. The risk of hepatitis B virus infection by transfusion in Kumasi, Ghana. Blood 2003;101:2419-25.

30. Chongsrisawat V, Yoocharoen P, Theamboonlers A, Tharmaphornpilas P, Warinsathien P, Sinlaparatsamee S, Paupunwatana S, Chaiear K, Khwanjaipanich S, Poovorawan Y. Hepatitis B seroprevalence in Thailand: 12 years after hepatitis B vaccine integration into the national expanded programme on immunization. Trop Med Int Health 2006; 11:1496-502.

31. WHO. Thailand reported immunization coverage. [cited 2007 May 10]. Available from: http://www.who.int/immunization_monitoring/en/globalsummary/timeseries/tscoveragebycountry.cfm?C=THA

32. Boot HJ, Schouls L, Hahne S, Berbers GA, van de Laar MJ, Kimman TG. [Vaccination against pneumococci and hepatitis B in the Dutch National Immunisation Programme]. Ned Tijdschr Geneeskd 2007;151:172-6.

33. Veldhuijzen IK, Conyn-van Spaendoncka MA, Dorigo-Zetsmab JW. Seroprevalentie van hepatitis B en C in de Nederlandse bevolking [Seroprevalence of hepatitis B and C in the Dutch population]. Infect Bull 1999;10:182-4.

34. Wasem J, Sroczynski G, Aidelsburger P, Buchberger B, Hessel F, Conrads-Frank A, Peters-Blochinger A, Kurth BM, Wong JB, Rossol S, Siebert U. [Health economics of chronic infectious diseases: the example of hepatitis C]. Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz 2006;49:57-63.

35. Siebert U, Sroczynski G, German Hepatitis C Model (GEHMO) Group, HTA-Expertenpanels für Hepatitis C. Antivirale Therapie bei Patienten mit chronischer Hepatitis C in Deutschland. Medizinische und ökonomische Evaluation der initialen Kombinationstherapie mit Interferon/Peginterferon und Ribavirin. Köln: DIMDI; 2003.

36. UNAIDS Reference Group on Estimates, Modelling and Projections. Improved methods and assumptions for estimation of the HIV/AIDS epidemic and its impact: recommendations of the UNAIDS reference group on estimates, modelling and projections. AIDS 2002;16:W1-14.

37. Predicting the failure of 3 by 5. Lancet 2005;365:1597.

38. Ministry of Health/Ghana Health Service. HIV/AIDS in Ghana. Accra: National AIDS/STI Control Programme/Ghana Health Service; 2005.

39. Sterne JA, Hernan MA, Ledergerber B, Tilling K, Weber R, Sendi P, Rickenbach M, Robins JM, Egger M. Long-term effectiveness of potent antiretroviral therapy in preventing AIDS and death: a prospective cohort study. Lancet 2005; 366:378-84.

40. Beck EJ, Mandalia S, Gaudreault M, Brewer C, Zowall H, Gilmore N, Klein MB, Lalonde R, Piche A, Hankins CA. The cost-effectiveness of highly active antiretroviral therapy, Canada 1991-2001. AIDS 2004;18:2411-8.

41. Torpey EK. Estimating the cost of HIV related clinical care services. Accra: Family Health International; 2003.

42. Etard JF, Ndiaye I, Thierry-Mieg M, Gueye NF, Gueye PM, Laniece I, Dieng AB, Diouf A, Laurent C, Mboup S, Sow PS, Delaporte E. Mortality and causes of death in adults receiving highly active antiretroviral therapy in Senegal: a 7-year cohort study. AIDS 2006;20:1181-9.

43. UNAIDS/WHO. Thailand country profile. [cited 2007 Nov 22]. Available from: http://apps.who.int/globalatlas/predefinedReports/EFS2008/short/EFSCountryProfiles2008_TH.pdf

44. WHO Statistical Information System (WHOSIS). Life Tables for 191 Countries, Ghana, 2006. [cited 2007 Jun 1]. Available from: http://apps.who.int/whosis/database/life_tables/life_tables.cfm

45. Murray CJ, Lopez AD. The global burden of disease. A comprehensive assesment of mortality and disability for diseases, injuries and risk factors in 1990 and projected to 2020. Cambridge (MA): Harvard University Press; 1996.

46. WHO. Investing in health research and development: report of the ad hoc committee on health research

relating to future intervention options. Geneva: WHO; 1996.

47. World Bank. World Development Report 1993. New York: Oxford University Press; 1993.

48. Creese A, Floyd K, Alban A, Guinness L. Cost-effectiveness of HIV/AIDS interventions in Africa: a systematic review of the evidence. Lancet 2002;359:1635-43.

49. Hogan DR, Baltussen R, Hayashi C, Lauer JA, Salomon JA. Cost effectiveness analysis of strategies to combat HIV/AIDS in developing countries. BMJ 2005;331:1431-7.

50. Goldie SJ, Yazdanpanah Y, Losina E, Weinstein MC, Anglaret X, Walensky RP, Hsu HE, Kimmel A, Holmes C, Kaplan JE, Freedberg KA. Cost-effectiveness of HIV treatment in resource-poor settings—the case of Cote d'Ivoire. N Engl J Med 2006;355:1141-53.

51. Wang B, Schreiber GB, Glynn SA, Kleinman S, Wright DJ, Murphy EL, Busch MP. Does prevalence of transfusion-transmissible viral infection reflect corresponding incidence in United States blood donors? Transfusion 2005;45: 1089-96.

52. Candotti D, Sarkodie F, Allain JP. Residual risk of transfusion in Ghana. Br J Haematol 2001;113:37-9.

53. Phikulsod S, Oota S, Tirawatnapong T, Sakuldamrongpanich T, Chalermchan W, Louisirirotchanakul S, Tanprasert S, Chongkolwatana V, Kitpoka P, Phanuphak P, Wasi C, Nuchprayoon C; the Working Group for NAT Study in Thai Blood Donations. One-year experience of nucleic acid technology testing for human immunodeficiency virus Type 1, hepatitis C virus, and hepatitis B virus in Thai blood donations. Transfusion 2009;49:1126-35.

54. Moore A, Herrera G, Nyamongo J, Lackritz E, Granade T, Nahlen B, Oloo A, Opondo G, Muga R, Janssen R. Estimated risk of HIV transmission by blood transfusion in Kenya. Lancet 2001;358:657-60.

55. AuBuchon JP, Birkmeyer JD. Safety and cost-effectiveness of solvent-detergent-treated plasma. In search of a zero-risk blood supply. JAMA 1994;272:1210-4.

56. Jackson BR, AuBuchon JP, Birkmeyer JD. Update of cost-effectiveness analysis for solvent-detergent-treated plasma. JAMA 1999;282:329.

57. UNAIDS/WHO. Epidemiological fact sheets on HIV and AIDS for Ghana, 2008 update. [cited 2009 Jun 1]. Available from: http://apps.who.int/globalatlas/predefinedReports/EFS2008/full/EFS2008_GH.pdf

58. UNAIDS/WHO. Epidemiological fact sheets on HIV and AIDS for Thailand, 2008 update. [cited 2009 Jun 1]. Available from: http://apps.who.int/globalatlas/predefinedReports/EFS2008/full/EFS2008_TH.pdf

59. UNAIDS/WHO. Epidemiological fact sheets on HIV and AIDS for the Netherlands, 2008 update. [cited 2009 Jun 1]. Available from: http://apps.who.int/globalatlas/predefinedReports/EFS2008/full/EFS2008_NL.pdf

60. Vipa T, Weer P, Varu D, Duan S, Yupa W, Amna C, Pote A, Than S. Viral hepatitis infections among dialysis patients: Thailand registry report. Nephrology 2007;12:399-405.

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article:

APPENDIX A: Adapted version of window-period model using the prevalence.

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