International Journal of Technology Assessment in Health Care, **18:1** (2002), 81–93.

TO REUSE OR NOT TO REUSE?

An Economic Evaluation of Hemodialyzer Reuse Versus Conventional Single-use Hemodialysis for Chronic Hemodialysis Patients

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Abstract

Objectives: To evaluate the cost-effectiveness of reusing hemodialyzers for patients with kidney failure on dialysis employing either a heated citric acid or formaldehyde sterilization method, in comparison to the standard practice of single-use dialysis.
Methods: A meta-analysis of all relevant studies was performed to determine whether hemodialyzer reuse was associated with an increased relative risk of mortality or hospitalization. A decision tree was constructed to model the effect of three different dialysis strategies (single-use dialysis, heated citric acid, and formaldehyde dialyzer reuse) on the costs and quality-adjusted life expectancy of "typical" hemodialysis patients. The cost of heated citric acid reuse was estimated from a center experienced with the technique. The cost of end-stage renal disease (ESRD) care, survival data, and patient utilities were estimated from published sources.
Results: There was evidence of a higher relative risk of hospitalization (but not mortality) for hemodialyzer reuse compared with single-use dialysis. Depending on the assumptions used, the cost savings that could be expected by switching from single-use dialysis to heated citric acid reuse were small, ranging from CAN $0–739 per patient per year.
Conclusions: ESRD programs can incorporate the results of this study based on their individual situations to determine whether hemodialyzer reuse is appropriate in their setting.

Keywords: Costs, Decision analysis, Economic evaluation, End-stage renal disease, Hemodialyzer reuse, Hemodialysis

The authors wish to thank Jan Armstrong and Michael Laing for their help in the preparation of this study. Dr. Manns is supported by a combined Kidney Foundation of Canada/Alberta Heritage Foundation for Medical Research Clinical Fellowship. Dr. Donaldson holds the Svare Chair in Health Economics at the University of Calgary, where he is CIHR Senior Investigator, AHFMR Senior Scholar, and professor in the Departments of Community Health Sciences and Economics.

End-stage renal disease (ESRD) is a condition that receives a disproportionately large amount of resources relative to its prevalence in the population. For instance, despite the fact that only 0.07% of the population suffers from ESRD, it has been estimated that 1% to 2% of overall healthcare budgets are spent on the care of ESRD patients (1;18;27;39). Moreover, treatment of patients with ESRD using hemodialysis has long been criticized by economists as inefficient since it is associated with an unfavorably high cost per quality-adjusted life year (QALY) ratio (11;40) when compared with other commonly used medical interventions such as the treatment of hypercholesterolemia (29). Without renal replacement therapy (i.e., dialysis or kidney transplantation), patients with ESRD face certain death. Hence, although healthcare providers have traditionally not questioned funding for dialysis, there is a need to identify ways in which the efficiency of hemodialysis can be improved.

Patients on hemodialysis receive treatments, usually on a thrice weekly basis, whereby blood is pumped from a surgically created blood vessel through a hemodialyzer to cleanse the blood of toxins that accumulate as a result of kidney failure. Since hemodialyzers are generally used only once and discarded after each treatment (*single-use dialysis*), 10% of an outpatient hemodialysis program's budget is often spent on hemodialyzers. As such, many ESRD programs have focused on this area as a target for financial constraint. In an attempt to save money, some dialysis units clean, resterilize, and reuse a dialyzer 10 to 30 times prior to their disposal (*hemodialyzer reuse*).

In 1996, 81% of dialysis units in the United States practiced reuse (2;12). Over roughly the same time period, only 10% of European (varying widely by country) (33) and 15% of Canadian units employed reuse (1). This lower rate of reuse in Canada and Europe may have been due to reported adverse health effects associated with dialyzer reuse, including a reduction in survival and an increase in hospitalization rates (9;14;15;16;17;21;22;23). This data has predominantly come from U.S. centers practicing reuse with formaldehyde, glutaraldehyde, and peracetic acid. As such, Canadian programs practicing reuse have typically used less noxious sterilants such as heated citric acid (25).

Studies in Canada (3) and elsewhere (30) have examined how hemodialyzer reuse affects costs. One study published in 1993 suggested potential cost-savings of CAN $3,629 per patient per year (3) (CAN $1 = £0.45 = US $0.64). The cost-savings may no longer be as great since single-use hemodialyzers have become significantly less expensive. Further, these studies did not consider the potential negative health effects of dialyzer reuse. In fact, no previous prospective clinical trials or economic evaluations have examined the *health and resource* implications of hemodialyzer reuse when compared with single-use dialysis. Since our local renal program recently considered switching from single-use hemodialysis to hemodialyzer reuse, we performed a cost-utility analysis using a decision analytic approach, addressing the study question: what are the implications for costs and health outcomes of treating hemodialysis patients with hemodialyzer reuse using either the heated citric acid or formaldehyde sterilization methods compared with single-use dialysis?

METHODS

Population

We evaluated a simulated cohort of hemodialysis patients whose characteristics were representative of local patients seen in a Canadian dialysis center in terms of age (mean age, 60), sex (57% male), and comorbidity (40% diabetic, 40% with ischemic heart disease) (1;28). For the baseline analysis, we assumed that reuse would be performed for a dialysis unit containing 320 patients (i.e., the number of patients who receive hemodialysis at the Foothills Medical Centre in Calgary, Canada).

Treatment Alternatives

The treatment alternatives considered in this analysis consist of all of the treatment options that are currently used for hemodialysis patients in Canada (1): a) single-use dialysis with a typical synthetic dialyzer; b) hemodialyzer reuse with heated citric acid and a synthetic dialyzer designed for reuse; and c) reuse with formaldehyde and a synthetic dialyzer designed for reuse. All dialyzers have a surface area of 1.8 m^2 and nearly equivalent *in vitro* urea clearance (an important distinction since urea clearance is associated with mortality for chronic hemodialysis patients [26]). The only dialyzers that are available for reuse (in Canada) have a higher flux (i.e., remove more middle molecular weight substances) than the typical dialyzer for single-use dialysis. At present, there is no evidence from prospective clinical trials that use of such high-flux dialyzers (compared with typical synthetic hemodialyzers) is associated with significant clinical benefits, such as a lower mortality (20;37). Due to the higher cost of high-flux dialyzers, the standard of care for most ESRD programs (including our own) that practice single use is to use typical dialyzers. Therefore, this is the type of dialyzer assumed in the single-use option for our study (38).

Decision Analytic Model

A decision tree was constructed to model the effect of three different hemodialysis options on the costs and quality-adjusted life expectancy of "typical" hemodialysis patients (Figure 1). A Markov process (35) was used to model yearly transitions between the three possible clinical states: a) alive on hemodialysis; b) alive with a renal transplant; and c) dead. A 5-year time horizon was considered in the base-case analysis since a minority of patients remain on hemodialysis at 5 years. This horizon was extended in sensitivity analysis. The model outputs were quality-adjusted life-years (QALYs) and costs. QALYs were estimated by multiplying the number of cycles spent by the average patient in each clinical state by the utility associated with the state. (Although the number of expected QALYs ends up being very similar among the three different strategies, we report the results of the full decision analysis rather than a cost-minimization analysis, since it permitted thorough sensitivity analyses and calculation of lifetime costs.)

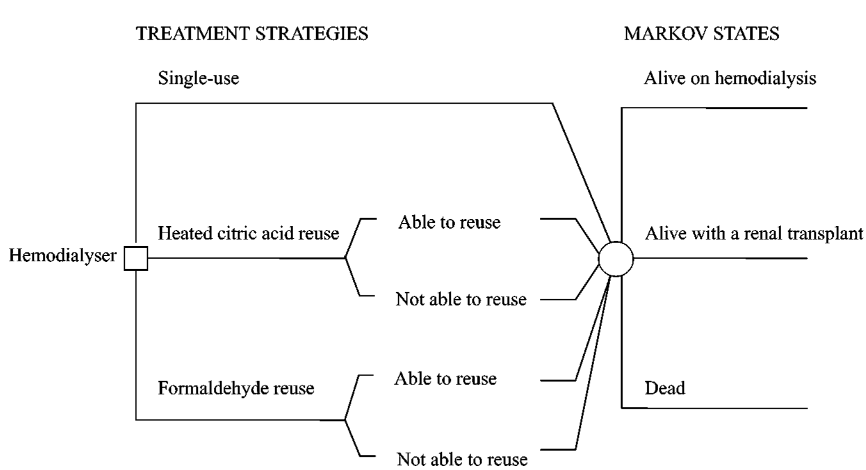

Figure 1. Decision tree showing hemodialysis patients can either be treated with single-use dialysis or hemodialyzer reuse using citric acid or formaldehyde sterilization. For the reuse strategies, a proportion of patients will be unable to reuse due to contraindications and will be treated with single-use dialysis.

https://doi.org/10.1017/S0266462302108087 Published online by Cambridge University Press

As mentioned above, previous studies have shown that reduced urea clearance through dialysis is associated with an increased mortality risk (26). Studies of chemical sterilization have shown that urea clearance is stable up to 10 reuses but then decreases progressively after 10 dialyzer reuses (5;34). It is controversial whether urea clearance decreases significantly with heated citric acid reuse; some studies show no change (25;32), although the largest study showed a trend toward a reduction in urea clearance, but only after ten reuses (5). To take this uncertainty into account and to avoid modeling the effect of a linear reduction in urea clearance on increased mortality for patients treated with reuse (which would have reduced the transparency of our model), in two of the reuse scenarios considered below, we assumed that only 10 reuses per dialyzer would be performed.

Costs and QALYs were both discounted at an annual rate of 5% (4). All analyses were performed using DATA software, version 3.5 (TreeAge Software, Inc., Williamstown, MA).

DATA SOURCES

Mortality

The annual mortality of hemodialysis patients on synthetic dialyzers was estimated using the mean annual mortality risk reported for all Canadian hemodialysis patients by the Canadian Organ Replacement Register (CORR) (Table 1) (1).

In order to determine the relative risk (RR) of mortality for patients being treated with hemodialyzer reuse, a standard fixed effects meta-analytic method (36) was used to combine the RR of mortality as reported in all relevant studies. Studies were identified through a comprehensive MEDLINE search, 1968 to present, using the search terms "reuse" and "hemodialysis," as well as a hand-search of the bibliographies of all relevant identified articles. All included studies met the following criteria: data not previously reported,

Table 1. The Baseline Risk of Mortality and Hospitalization for Patients Treated with Single-use Synthetic Hemodialysis and the Relative Risk of Mortality and Hospitalization for Hemodialyzer Reuse Compared with Single-use Synthetic Hemodialysis

Variable	Baseline estimate	Range (95% CI)	Data source
Annual mortality risk for hemodialysis patients treated with synthetic single use	0.152	0.145–0.159	1
Annual number of hospital days for hemodialysis patients treated with synthetic single use	7.4 days	4.2–10.7	SARP[a]
Average utility score for in-center hemodialysis patients	0.43	0.35–0.51	8
Average utility score for patients with a renal transplant	0.84	0.79–0.89	8
Annual rate of transplantation	0.0835		1
Annual mortality risk for transplant patients	0.045		23
RR of mortality for patients treated with any method of hemodialyzer reuse[b] vs synthetic single use	1.01	0.996–1.027	9;14;15;17;21;22
RR of mortality for patients treated with formaldehyde reuse vs synthetic single use	1.002	0.99–1.016	9;14;15;17;22
RR of hospitalization for patients treated with any method of hemodialyzer reuse[b] vs synthetic single use	1.10	1.06–1.15	15;16;22
RR of hospitalization for patients treated with formaldehyde reuse vs synthetic single use	1.08	1.03–1.14	15;16;22

[a] Southern Alberta Renal Program.
[b] Used as the estimate of RR for patients treated with heated citric acid reuse.

prospective data collection, follow-up of 70% of patients, and adjustment of RR for at least age and the presence of diabetes, two factors likely to confound the risk of mortality. Six (9;14;15;17;21;22) of 240 screened studies met all stated inclusion criteria and were included. The RR of mortality for formaldehyde was estimated by combining the RR of mortality for studies reporting separately on patients using formaldehyde reuse compared with single use (9;14;15;17;22). Since heated citric acid reuse was not a common reuse strategy in these studies, the baseline RR of mortality that was used in our model for heated citric acid reuse was determined by combining the RR of mortality for patients treated with all types of reuse compared with single use (Table 1) (9;14;15;17;21;22).

Risk of Hospitalization

The annual risk of hospitalization for patients using single-use synthetic dialyzers was estimated using information from an administrative and research database in place in the Southern Alberta Renal Program (SARP) (Table 1) (unpublished data, 2001). The RR of hospitalization for patients being treated with hemodialyzer reuse was calculated as above. To be included in this meta-analysis, all studies had to meet the above-noted inclusion criteria and had to report the RR of hospitalization. Three studies were identified (15;16;22). The baseline RR of hospitalization for formaldehyde was estimated by combining the RR of hospitalization for studies reporting separately on patients using formaldehyde reuse compared with single use (15;16;22). As above, the baseline RR of hospitalization for heated citric acid reuse was estimated by combining the RR of hospitalization for patients on all types of reuse compared to single use (Table 1) (15;16;22).

Transplantation

The yearly rate of transplantation for dialysis patients was estimated using data from CORR (1), while the yearly mortality risk for transplant patients was estimated from a Canadian study (Table 1) (24).

Health-related Quality of Life

Information on the average utility score for patients treated with hemodialysis or renal transplantation was estimated from a study using the time-trade off technique (Table 2) (8).

Table 2. Cost Estimates (in Canadian Dollars Where CAN $1 = £0.45 = U.S. $0.64)

Variable	Baseline estimate	Range	Data source
Cost of synthetic hemodialyzer per run (assuming all patients are treated with single-use)	$18	$16–20	[a]
Cost of synthetic hemodialyzer per run (for patients who are unable to reuse)	$28	$22–30	[b]
Cost of heated citric acid reuse per run	See Table 3	$12.66–17.68	Appendix 1
Cost of formaldehyde reuse per run	See Table 3	$15.47–20.66	Appendix 2
Yearly cost of outpatient dialysis per patient[c]	$62,289	$55,535–69,043	19
Yearly cost of hospitalization per hemodialysis patient treated with synthetic single-use dialysis	$5,862	$3,234–8,489	SARP[c]
Yearly cost of transplantation[d]			24
Year 1	$66,290		
Years 2 and on	$27,875/year		

[a] Pricing based on local volume-based discount rate for synthetic dialyzer (1.8 m^2 surface area).
[b] Estimate of price considering lower volume of sales.
[c] Southern Alberta Renal Program.
[d] Assumed to be equal for all strategies.

The average quality of life of hemodialysis patients treated with single-use dialyzers and dialyzer reuse was assumed to be equal, since several studies have shown no difference in condition-specific quality of life or intradialytic symptoms for patients treated with single-use dialysis or hemodialyzer reuse (6;13;31).

Costs

This study took the perspective of the healthcare payer. All cost estimates are shown in Table 2 in Canadian dollars. Dialyzer pricing was determined by local contract-negotiated prices. Actual dialyzer identities are not released due to contractual agreements. The cost per session for heated citric acid and formaldehyde reuse was determined as described in detail in Appendices 1 and 2, respectively.

There is controversy as to which costs should be included in a cost analysis of hemodialyzer reuse (3). Different renal programs will vary in their initial set-up costs and with regard to their transportation costs. It is also controversial whether extra dialysis staff is needed in dialysis units that reuse (3). Some programs have hired extra staff for the purposes of dialyzer verification before dialysis as well as rinsing and disposition of dialyzers after dialysis, while for other programs these tasks have been performed by existing nursing staff. There is also controversy regarding potential health risks of hemodialyzer reuse. Therefore, we considered the implications on costs and QALYs of four potential scenarios. In scenario 1, we assumed that there were 320 patients, 85% were able to reuse, the average number of reuses was 13.3 (the current average number of reuses performed at the Toronto General Hospital), no extra time was required of dialysis staff in performing the reuse process, and the construction cost per session was $0.71 (Appendix 1). In scenario 2, the same assumptions were made except the average number of reuses was 10, and it was assumed that 10 extra minutes were required of dialysis staff per run. For scenarios 1 and 2, the RR of mortality and hospitalization associated with reuse were higher than 1, as reported in Table 1. Scenarios 3 and 4 are identical to scenarios 1 and 2 with respect to the costs considered, but the RR of mortality and hospitalization for reuse versus single use was assumed to be one.

The cost of yearly outpatient dialysis care (excluding the cost of the hemodialyzers) and the cost of renal transplantation were estimated from recent studies (19;24). The yearly cost of hospitalization was estimated from local patient-specific costing data (Manns et al., 2001).

Sensitivity Analysis

One-way and two-way sensitivity analyses were performed on all variables in our model to assess the effect of varying baseline estimates within clinically plausible ranges (see Tables 1 and 2) on our results.

RESULTS

Risk of Mortality and Hospitalization

Based on our meta-analysis, we found no statistically significant difference between hemodialyzer reuse and single-use dialysis in terms of the RR of mortality (Table 1). There was evidence of an association between excess hospitalization and treatment with hemodialyzer reuse when compared with patients treated with single-use hemodialysis, although this evidence came from studies using chemical sterilization (Table 1).

Cost of Each Strategy per Dialysis Session

The cost of the dialyzer for patients treated with a single-use synthetic dialyzer was CAN $18 (actual purchase price). Table 3 outlines the cost per dialysis session for heated citric acid

Table 3. Cost of Heated Citric Acid and Formaldehyde Reuse: Cost per Reuse Session and Average Cost per Session for All Patients Receiving Dialysis in a Facility Practicing Reuse (Taking into Account that a Proportion of Patients Will Be Unable to Reuse and Will Be Treated with a More Expensive Single-use Dialyzer)

Assumptions	Heated citric acid reuse: per reuse	Heated citric acid reuse: Average cost per patient per run	Formaldehyde reuse: Cost per reuse	Formaldehyde reuse: Average cost per patient per run
Scenario 1[a] (excluding construction costs)	$9.95	$12.66	$13.26	$15.47
Scenario 1	$10.66	$13.26	$13.97	$16.08
Scenario 1 plus extra 10 minutes staff time per run	$13.27	$15.48	$16.58	$18.29
Scenario 2[b]	$14.26	$16.32	$17.57	$19.14
Scenario 2 plus assumption of only 160 patients	$15.54	$17.41	$18.85	$20.22
Scenario 2 plus assumption that only 80% of patients able to reuse	$14.60	$17.28	$17.65	$19.72
Scenario 2 plus transportation expense $1.25 per session	$15.51	$17.39	$18.82	$20.20
Scenario 2 plus transportation expense $1.25, RO water machine $0.54	$15.86	$17.68	$19.36	$20.66

[a] Assumes 320 patients, 85% able to reuse, average number of reuses 13.3, no extra time required of dialysis staff, construction cost per session $0.71, transportation expense and RO water machine per session $0.
[b] Assumes 320 patients, 85% able to reuse, average number of reuses 10, extra 10 minutes of dialysis staff time required per run, construction cost per session $0.71, transportation expense and RO water machine per session $0.

and formaldehyde reuse for patients who actually reuse (*cost per reuse*) as well as the average cost per dialysis session for all patients, some of whom are treated with single-use dialysis due to a contraindication to reuse (*average cost per patient per run*). The average cost per patient per run represents a weighted average of the cost per reuse for those patients able to reuse and the cost per dialysis session for the *proportion* of patients unable to reuse (i.e., patients who are unable to reuse but who receive dialysis in units that practice reuse will be dialyzed with a more expensive, though identical, single-use dialyzer due to the fact that the dialysis unit is buying a smaller number of hemodialyzers). In scenarios 1 and 2, the average cost per patient per run for patients treated in a facility practicing heated citric acid reuse is $13.26 and $16.32, respectively. Depending on the assumptions used, the average cost per patient per run for heated citric acid reuse ranged from $12.66 to $17.68 (Table 3).

Cost-utility Analysis

In scenario 1, the incremental cost-utility ratio for single-use dialysis compared with heated citric acid reuse was CAN $299,739 per QALY. In scenario 2, the most cost-effective strategy was treatment with single-use synthetic dialyzers, since costs were slightly lower and the number of QALYs slightly higher compared with heated citric acid reuse (Table 4). In scenarios 3 and 4, there were small cost-savings associated with heated citric acid reuse (Table 4).

Sensitivity Analysis

The results of this analysis were only sensitive to the estimates used for the cost of heated citric acid reuse (or alternatively, on the cost difference between heated citric acid reuse and single-use dialyzers) and the RR of mortality and hospitalization for heated citric acid reuse.

Table 4. Expected Average per Patient Total Cost and Number of QALYs for Four Scenarios

Scenario	Strategy	Average cost per patient over 5-year time horizon	Average number of expected QALYs over 5-year time horizon	Incremental cost-utility ratio (single-use synthetic vs heated citric acid reuse)
Scenario 1[a]	Synthetic single use	$218,284	1.648	$299,739
	Heated citric acid reuse	$217,073	1.644	
	Formaldehyde reuse	$218,467	1.647	
Scenario 2[b]	Synthetic single use	$218,284	1.648	[e]
	Heated citric acid reuse	$218,321	1.644	
	Formaldehyde reuse	$219,718	1.647	
Scenario 3[c]	Synthetic single use	$218,284	1.648	[f]
	Heated citric acid reuse	$216,362	1.648	
	Formaldehyde reuse	$217,515	1.648	
Scenario 4[d]	Synthetic single use	$218,284	1.648	[f]
	Heated citric acid reuse	$217,615	1.648	
	Formaldehyde reuse	$218,768	1.648	

[a] Scenario 1 assumes 320 patients, 85% able to reuse, average number of reuses 13.3, no extra time required of dialysis staff, construction cost per session $0.71, transportation expense and RO water machine per session $0.
[b] Scenario 2 assumes 320 patients, 85% able to reuse, average number of reuses 10, extra 10 minutes of dialysis staff time required per run, construction cost per session $0.71, transportation expense and RO water machine per session $0.
[c] Scenario 3 is scenario 1 and in addition assumes that the RR of mortality and hospitalization for reuse vs single use is 1.
[d] Scenario 4 is scenario 2 and in addition assumes that the RR of mortality and hospitalization for reuse vs single use is 1.
[e] Incremental cost-utility ratio not reported since synthetic single-use strategy is dominant.
[f] Incremental cost-utility ratio not reported since heated citric acid reuse strategy is dominant.

Considering scenario 2, the costs of heated citric acid reuse and single-use synthetic dialysis were equal when either the cost of heated citric acid reuse per session was CAN $13.60 (cost difference of $4.40), the RR of hospitalization for patients treated with hemodialyzer reuse was 1.09, or the RR of mortality for hemodialyzer reuse was equal to 1.02.

Extending the time horizon of our analysis did not change the ranking of the alternative treatment strategies for any of the scenarios. However, if the time horizon for scenario 1 was extended to 10 years, the cost per QALY gained by performing single-use dialysis was reduced from CAN $299,739 to $212,035 because most of the survivors from 5 years onward were being treated with renal transplantation (which was less expensive).

Resource Implications

Considering the best-case scenario for reuse, scenario 3 (lower cost heated citric acid reuse and RR of mortality and hospitalization of unity for reuse compared with single use), a 320-patient hemodialysis unit could save CAN $236,621 ($739 per patient) per year by switching to heated citric acid reuse. Alternatively, if one considers scenario 4 (higher cost of heated citric acid reuse), then a 320-patient hemodialysis unit could be expected to save only $83,866 ($262 per patient) per year by switching to heated citric acid reuse. This does not take into account the extra costs that a program considering reuse would face if the reuse facility were located in a different site than the dialysis facility (Table 3). In addition, this saving may be more than offset by the extra expenditure resulting from an increased risk of hospitalization due to hemodialyzer reuse (scenario 2).

For programs that are currently practicing single-use dialysis with more expensive high-flux dialyzers, the expected cost-savings would be higher. For instance, a 320-patient hemodialysis unit could save CAN $536,000 ($1,675 per patient) per year (scenario 3) or

https://doi.org/10.1017/S0266462302108087 Published online by Cambridge University Press

$383,360 ($1,198 per patient) per year (scenario 4) by switching to heated citric acid reuse (based on our local cost of a high-flux dialyzer for *single use*, $24). Again, this saving may be significantly less if there is an increased risk of hospitalization due to hemodialyzer reuse (scenario 2).

DISCUSSION

When considering implementation of a new treatment such as hemodialyzer reuse, ESRD programs must consider both the effects on health outcomes and costs. We found no significant evidence of an increased RR of mortality due to hemodialyzer reuse. There was evidence of an association between treatment with hemodialyzer reuse and an increased risk of hospitalization. This result must be interpreted with caution. First, it was based on the results of our meta-analysis combining only three studies (15;16;22) and thus may have resulted from publication bias. Furthermore, since all studies were nonrandomized, there may have been selection bias, and the relationship between dialyzer reuse and excess hospitalization may have been confounded by the presence of unmeasured factors such as profit status of the dialysis unit.

Our study had several limitations that we have attempted to overcome through our analysis. First, our estimate of the RR of mortality and hospitalization for heated citric acid was derived from a meta-analysis of studies comparing hemodialysis reuse using formaldehyde, glutaraldehyde, and peracetic acid sterilization with single-use synthetic dialysis. This may not be a valid extrapolation, but few centers have historically used heated citric acid reuse (25), and therefore there have been no studies examining the RR of mortality and hospitalization comparing this option with single-use synthetic dialysis. To address this criticism, we considered two analyses (scenarios 3 and 4) where the RR of mortality and hospitalization were equal for heated citric acid reuse and synthetic dialyzer use. Another criticism is that we did not model the potential (although as yet unproven by clinical trials) clinical benefits that may be associated with the high-flux dialyzer that was used in our model for the reuse strategies (7). We do provide estimates, however, of the cost-savings that could be achieved for single-use programs that are currently using high-flux dialyzers. Finally, this study could be criticized as not having wide generalizability since cost estimates were based solely on Canadian data. However, while absolute costs (such as the cost of labor, hospitalization, dialyzers, etc.) will vary from country to country, the cost of reuse relative to single use is not likely to change significantly. In addition, we have provided enough information in the Appendices and in Table 3 for ESRD programs in other countries to determine the effect that local price differences would have on the cost of establishing a local reuse program.

We estimated the costs of heated citric acid reuse from a center experienced with the technique. As such, the costs reported are a conservative estimate. A new center learning the technique may have significantly higher costs per session for heated citric acid reuse. Nonetheless, the direct costs of heated citric acid reuse per dialysis session noted in our study were less than for formaldehyde reuse and, in general, heated citric acid reuse was also less expensive than the cost of single-use synthetic dialysis. The extent to which a renal program could save resources by switching to heated citric acid reuse was crucially dependent on the assumptions made. If the reuse facility is not located in the same geographic site as the dialysis units that it services, if an increase in nursing staff is required to implement hemodialyzer reuse, and if there is, in fact, an increased risk of hospitalization, then the cost-savings per patient resulting from hemodialyzer reuse is likely to be minimal or nonexistent. If no extra dialysis staff is needed for hemodialyzer reuse and there is no increased risk of hospitalization, then there may be a moderate cost-saving per patient resulting from hemodialyzer reuse (CAN $763 per patient per year). Finally, if a dialysis unit initially is using only more expensive high-flux, single-use dialyzers, then the cost-savings that could be achieved by switching to reuse would be greater.

Irrespective of the assumptions used, the cost-savings per patient that could be expected from switching to hemodialyzer reuse in our study did not approach the CAN $3,629 per patient annual savings reported by a previous Canadian study looking at formaldehyde reuse (3). In part, this is due to the current lower price of single-use hemodialyzers, but it also reflects our inclusion of additional costs (heparinized saline, rental and construction costs). We believe that the inclusion of these extra costs is justified since all dialysis units will incur some start-up costs relating to the construction of a reconditioning facility. Furthermore, even if a reconditioning unit is to be located in a hospital (and therefore no rental money is actually paid), one must consider what other use this valuable hospital space could be put to if a reconditioning unit was not built (i.e., the opportunity cost).

It is important to note that the price paid for single-use hemodialyzers has decreased by nearly 31% in the past 5 years. If that trend continues, then the cost-savings that could be expected by programs upon switching to hemodialyzer reuse may become negligible. For programs that are already practicing hemodialyzer reuse, continuation of such programs in the short term may result in moderate cost-savings with no significant risk to the patient.

POLICY IMPLICATIONS

Patients treated with hemodialyzer reuse do not appear to have a higher risk of mortality than those treated with single-use dialysis. The extent to which an ESRD program can expect to save resources by switching to reuse is highly dependent on local circumstances and the assumptions made. Local factors should be considered when determining whether to switch to hemodialyzer reuse. The factors that will increase the potential cost-savings associated with switching to reuse include: a) having a large number of hemodialysis patients ($>$160) located in the same site as the reuse facility (thereby minimizing transportation expense); b) current use by the local hemodialysis unit of more expensive high-flux hemodialyzers; and c) being able to switch to reuse without the need for extra nursing/unit aide staff. If there is in fact an increase in hospitalization required for patients who are treated with reuse, then the cost-savings that may be achieved with a switch to hemodialysis reuse will be minimized. In addition, a new center learning the reuse technique might have significantly higher costs per session in the short term.

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APPENDIX 1

THE COST OF HEATED CITRIC ACID REUSE PER SESSION (IN CANADIAN DOLLARS)

The following data were derived from a detailed microcosting study performed at the heated citric acid reconditioning unit, Toronto General Hospital, Canada. The estimates for staff costs were altered based on local wage scales. In addition, the cost of labor and capital equipment is based on a 320-patient dialysis unit with 85% of patients being able to reuse (212,160 reuse runs over 5 years). The following estimates were used to calculate the average cost per run for heated citric acid reuse for scenarios 1 and 2:

1. The cost of the F80 dialyser is $40. Assuming 10 reuses, the cost per run is $4.
2. The cost of reconditioning supplies is $0.80 per run (includes cost of blood lines and dialysate caps, citric acid solution, test kits, and chart recorders).
3. The cost of reverse osmosis water needed for the reconditioning process is $0.19 per run.
4. The cost of 500 ml of heparinized saline required to flush the dialyzer postdialysis is $1.11 per run.
5. Assuming that one reconditioning machine (Seratronics DS4 at $60,000 each, Fresenius, Lexington, MA), one oven ($5,000), and one refrigerator ($800) are required for 80 patients (four of each in total), then a conservative fixed cost per run estimate is $1.47, assuming that: a) an annuity factor of 4.2124 is used (Bank of Canada lending rate of 6% over 5 years); and b) machines are amortized over 5 years with no resale value. Maintenance costs for equipment are estimated at $0.15 per run.
6. Electricity charges are estimated at $0.02 per run.
7. Two full-time equivalent reconditioning technicians would be needed for 320 patients. The hourly wage of a technician is $24 per hour plus benefits. The estimated cost is $2.65 per run.

The following cost estimates were based on local cost projections assuming a reuse facility was set up locally:

1. Rental cost for the reconditioning unit is estimated at $2,000 per month ($0.57/run) based on average cost per square foot of industrial office space in Calgary.
2. The Calgary Regional Health Authority received estimates for the cost of construction on the dialysis units and the space that would be used for reconditioning. An estimate of $320,000 was tendered. If this fixed cost is amortized over 20 years at the Bank of Canada lending rate of 6% (annuity factor of 10.5940), then the construction cost is $0.71 per run.
3. Extra dialysis staff may be required for dialyzer verification predialysis as well as rinsing and disposition of dialyzers postdialysis. We estimated that unit aide-level staff would spend 10 minutes per run (an extra three full-time unit aides in total) and be paid $13 per hour plus benefits. This amounts to $2.61 per run.

4. If reuse were to be conducted for dialysis units at different sites, then transportation expenses would need to be included (these were not included in base-case analysis). Assuming that a van ($35,000 over 5 years) and driver would be needed (7 hours/day, 7 days/week at $14/hour plus benefits), the cost would be $1.25 per run.
5. If reuse is to be conducted at a site separate from the dialysis unit, then a reverse osmosis water machine may be needed in addition to the existing machine used for preparing the dialysate. The machine is $120,000 or $0.54 per run. This expense was also not included in the baseline analysis.

APPENDIX 2

THE COST OF FORMALDEHYDE REUSE PER SESSION (IN CANADIAN DOLLARS)

The following data were derived from a 1993 study by Baris and McGregor (3) that examined the costs of formaldehyde reuse. The costs for formaldehyde reuse were converted to 1999 Canadian dollars using the consumer price index for healthcare goods for Canada (10). The cost of labor and capital equipment is based on 320 patients, with 85% being able to reuse (212,160 reuse runs over 5 years). The following estimates were used to calculate the average cost per run for formaldehyde reuse for scenarios 1 and 2:

1. The cost of the F80 dialyser is $40. Assuming 10 reuses, the cost per run is $4.
2. The cost of formaldehyde reuse per run (assuming "medium costs") would be $8.58. This included the cost of reconditioning and rinsing machines, the cost of all solutions and supplies, and the cost of technician labor. It did not include the cost of rental, construction costs, extra dialysis staff, or the cost of the dialyzer.
3. The cost of 500 ml of heparinized saline required to flush the dialyzer postdialysis is $1.11 per run.

The following cost estimates were based on local cost projections assuming a reuse facility was set up here. The values used are the same as those used for heated citric acid in Appendix 1.

1. Rental cost for the reconditioning unit is estimated at $2,000 per month ($0.57/run) based on the local average cost per square foot for industrial office space.
2. The Calgary Regional Health Authority received estimates for the cost of construction on the dialysis units and the space that would be used for reconditioning. An estimate of $320,000 was tendered. If this fixed cost is amortized over 20 years at the Bank of Canada lending rate of 6% (annuity factor of 10.5940), then the construction cost is $0.71 per run.
3. Extra dialysis staff may be required for dialyzer verification predialysis as well as rinsing and disposition of dialyzers postdialysis. We estimated that unit aide-level staff would spend 10 minutes per run (an extra three full-time unit aides) and be paid $13 per hour plus benefits. This amounts to $2.61 per run.
4. If reuse were to be conducted for dialysis units at different sites, then transportation expenses would need to be considered (not included in baseline analysis). Assuming that a van ($35,000 over 5 years) and driver would be needed (7 hours/day at $14/hour plus benefits), the cost would be $1.25 per run.

If reuse is to be conducted at a site separate from the dialysis unit, then a reverse osmosis water machine may be needed in addition to the existing machine used for dialysate. The machine is $120,000 or $0.54 per run. This expense was also not included in the baseline analysis

https://doi.org/10.1017/S0266462302108087 Published online by Cambridge University Press