Changing Treatment Patterns

Practice Patterns, Case Mix, Medicare Payment Policy, and Dialysis Facility Costs

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Objective. To evaluate the effects of case mix, practice patterns, features of the payment system, and facility characteristics on the cost of dialysis.

Data Sources/Study Setting. The nationally representative sample of dialysis units in the 1991 U.S. Renal Data System's Case Mix Adequacy (CMA) Study. The CMA data were merged with data from Medicare Cost Reports, HCFA facility surveys, and HCFA's end-stage renal disease patient registry.

Study Design. We estimated a statistical cost function to examine the determinants of costs at the dialysis unit level.

Principal Findings. The relationship between case mix and costs was generally weak. However, dialysis practices (type of dialysis membrane, membrane reuse policy, and treatment duration) did have a significant effect on costs. Further, facilities whose payment was constrained by HCFA's ceiling on the adjustment for area wage rates incurred higher costs than unconstrained facilities. The costs of hospital-based units were considerably higher than those of freestanding units. Among chain units, only members of one of the largest national chains exhibited significant cost savings relative to independent facilities.

Conclusions. Little evidence showed that adjusting dialysis payment to account for differences in case mix across facilities would be necessary to ensure access to care for high-cost patients or to reimburse facilities equitably for their costs. However, current efforts to increase dose of dialysis may require higher payments. Longer treatments appear to be the most economical method of increasing the dose of dialysis. Switching to more expensive types of dialysis membranes was a more costly means of increasing dose and hence must be justified by benefits beyond those of higher dose. Reusing membranes saved money, but the savings were insufficient to offset the costs associated with using more expensive membranes. Most, but not all, of the higher costs observed in hospital-based units appear to reflect overhead cost allocation rather than a difference in real resources devoted to treatment. The economies experienced by the largest chains may provide an explanation for their recent growth in market share. The heterogeneity of results by chain size implies that characterizing units using a simple chain status indicator variable is inadequate. Cost differences by facility type and the effects of the ongoing growth of large chains are worthy of continued monitoring to inform both payment policy and antitrust enforcement.

Key Words. End-stage renal disease, dialysis, costs, Medicare, chain

BACKGROUND AND SIGNIFICANCE

U.S. healthcare providers increasingly face an environment characterized by capitation and stringent cost controls. Little is known about the long-run effects of these incentives on cost, quality of care, and the adoption of innovative technologies. Studying dialysis units provides a unique opportunity to observe a segment of the U.S. healthcare system that has already faced stringent cost controls under a capitated payment system for well over a decade. The purpose of this article is to estimate a statistical cost function for dialysis units and to analyze its implications for payment policy and quality of care.

Because many aspects of the economic and policy environment of dialysis are similar to those of other segments of the healthcare industry, this analysis can provide insights into a variety of managerial and policy issues. Issues that are common to both dialysis facilities and other healthcare providers include being asked to implement costly practice guidelines under capitation; consolidating providers into large, investor-owned chains; relating the cost of care to facility ownership (profit-status) or location (hospital-based versus freestanding); and adjusting payment policies—whether and how it should be done—for differences in case mix, input costs, or quality of care.

Medicare's Dialysis Payment System

More than 300,000 patients were treated for end-stage renal disease (ESRD) in the United States during 1995, at an aggregate cost of more than $13 billion

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(U.S. Renal Data System [USRDS] 1997). Because patients are Medicare-eligible 90 days after the onset of chronic renal failure, the vast majority of these costs were borne by Medicare's ESRD program and other public sources. On a per capita basis, Medicare ESRD patients are more than six times as costly as the average for all Medicare patients. The ESRD population more than doubled between 1986 and 1995 (USRDS 1997), and it continues to grow rapidly.

Medicare's end-stage renal disease program pays for outpatient hemodialysis on a prospective, per treatment basis with partial adjustment for geographic variation in labor costs. The payment rate has remained nearly fixed with a national average of approximately $125 per treatment for the past decade. This payment system does not account for differences among facilities in treatment practices, dose of dialysis, or case-mix severity.

Relative to a system in which particular technologies and techniques are centrally mandated, the flexibility inherent in allowing dialysis facilities to choose their treatment practices may have desirable dynamic properties (e.g., encouraging innovation) and efficiency properties (e.g., allowing facilities facing high labor costs to substitute more efficient dialysis for longer treatment times in achieving a target dose of dialysis). However, this flexibility has been accompanied by concern about quality of care. Facilities, particularly those in less competitive markets, have an incentive to deliver a lower dose of dialysis and to use less costly technologies in order to raise their profits. Inadequate dialysis dose has been linked to higher mortality rates, and Medicare's payment policy for dialysis has often been cited by dialysis units as a barrier to increasing the dose of dialysis. The Health Care Financing Administration (HCFA) is considering requiring facilities to adhere to practice guidelines in order to receive Medicare payment (Gardner 1997). It is not known how much, if any, adjustment to the payment schedule would be necessary to cover the costs of complying with these mandates.

Likewise, little is known about whether certain types of patients are more costly than others to treat. Because payment is generally independent of patient characteristics,[1] access to care may be compromised for patients with high-cost characteristics, in areas where high-cost characteristics are more prevalent than average, or in uncompetitive markets where facilities may have greater discretion over which patients to accept for treatment (Farley 1996). Knowing if costs are systematically related to case mix would be useful in determining the need for further research to document restricted access to care for high-cost patients. If such problems are documented, a case could be made for developing a case mix–adjusted payment system to prevent discrimination against high-cost patients and to provide equitable compensation to facilities bearing a disproportionate burden of high-cost patients.

Specific Aims

This study attempts to answer several policy-relevant questions in the dialysis industry:

1. Does an empirical basis exist for a case mix–adjusted payment system?
2. How costly are alternative methods of adhering to private guidelines or possible federal mandates to increase the dose of dialysis?
3. Does Medicare's policy of only partially adjusting for variations in healthcare wage rates create "windfalls" or "shortfalls" for facilities in low-wage or high-wage areas?
4. What are the costs of dialysis in facilities that differ on the basis of ownership (for-profit versus nonprofit), location (hospital-based versus freestanding), and system status (chains of various sizes versus independent)?

DATA AND METHODS

Data Sources

Data on facility characteristics, the number of dialysis treatments provided, and Medicare allowable costs were obtained from the HCFA Facility Survey File and the Medicare Cost Reports, which dialysis units are required to file annually. The age, race, sex, primary cause of end-stage renal disease, and length of time on dialysis were summarized at the facility level using data from HCFA's ESRD Program Medical Management and Information System (PMMIS), the national registry of ESRD patients. These data sets are described in greater detail elsewhere (USRDS 1997). Information about dialysis practices and patients' comorbid conditions were derived from the United States Renal Data System's 1990–1991 Case Mix Adequacy Special Study (CMA). The CMA is a nationally representative random sample containing approximately 25 percent of the dialysis facilities in the United States. Within each sampled facility, detailed information was collected for a random sample of patients. Additional information on the CMA is available elsewhere (USRDS 1992).

Chain status was determined using both publicly reported lists from the chains themselves and examinations of facility names following electronic searches for common character strings. These searches included all known U.S. dialysis facilities, not just those in our representative sample. Nonetheless, we believe that not all units that were members of a multifacility chain were identified using these procedures. Thus, our estimates of the effects of chain ownership on costs are likely to be conservative.

METHODS

We estimate a statistical cost function for dialysis units using ordinary least squares (OLS) and two-stage least squares techniques (2SLS). The model is based on the "flexible" multiproduct cost function of Dor, Held, and Pauly (1992). The dependent variable is the natural log of total Medicare allowable dialysis costs. The logarithmic transformation reduces the skewness of the distribution, preventing a few very large facilities from driving the results. The products are different types of dialysis treatments. For hemodialysis and several types of training treatments, the output measure is the number of treatments provided. For continuous ambulatory peritoneal dialysis (CAPD) and continuous cycling peritoneal dialysis (CCPD), each patient-week of treatment was converted to hemodialysis-equivalent treatments by multiplying by three. Other explanatory variables include facility characteristics, descriptors of the facility's case mix and dialysis practice patterns, and Medicare payment parameters.

Several key differences exist between the function estimated by Dor, Held, and Pauly and the present research. First, our data are for the year 1991, whereas Dor, Held, and Pauly used 1986 data. Second, the focus of Dor et al. was on economies of scale and scope with respect to various dialysis modalities, whereas we use data unavailable to them to investigate the costs of hemodialysis practices and case-mix severity. Third, we investigate ways in which the Medicare payment formula, which partially adjusts the labor component of costs for geographic variation in healthcare wages, is related to the actual costs incurred by facilities. Fourth, Dor and colleagues chose not to include hospital-based dialysis units because of the difficulty of separating dialysis unit costs from hospital overhead costs. We included hospital-based facilities, using a binary variable to indicate if a facility was hospital-owned. The difficulty of allocating costs primarily affects fixed and joint costs, making it a more important problem for Dor, Held, and Pauly's research questions relating to economies of scale and scope than for our research questions. Variable costs directly associated with providing dialysis, such as dialyzer membranes, solutions, and staffing of the dialysis unit are quite likely to be allocated to the dialysis unit regardless of whether the unit is based in a hospital or elsewhere. To test this assumption, the model was re-estimated without hospital-based units to determine if the results were robust to their exclusion.

RESULTS

The CMA sample included 523 facilities. Missing data resulted in the exclusion of ten facilities. In addition, the analysis was limited to facilities that delivered at least 3,000 hemodialysis treatments during 1991, after preliminary analysis indicated that a number of small facilities were outliers on several dimensions. This excluded an additional 76 facilities, leaving a final estimation sample of 437 facilities (84 percent of the CMA facilities). Descriptive statistics for the estimation sample appear in Table 1.

Results for the multivariate cost function appear in Table 2. The association between costs and the number and types of dialysis treatments were consistent with those found in Dor, Held, and Pauly's 1992 research. Thus, the discussion will focus on areas in which this study provides new insights into the cost of dialysis.

Case-Mix Severity

The model controls for clinical and demographic descriptors of the facility's patient mix, including age, number of years treated for ESRD, sex, race, cause of ESRD, presence of a cardiac comorbidity, presence of pulmonary disease, inability to ambulate independently, and bilirubin levels. These measures give a broad picture of the health status and demographic characteristics of the patients within each facility and are much more inclusive than the case-mix measures available to the Dor group (age and race).

Most of these case-mix measures were not associated with facility costs. Only bilirubin and the percentage of Hispanic patients in the unit were significantly related to costs. A 0.1 unit increase in bilirubin was associated with a 0.8 percent higher cost. Conversely, a 10 percentage point increase in the proportion of Hispanic patients dialyzed in a unit was associated with 1.3 percent lower costs.

Table 1: Descriptive Statistics

Dialysis Unit Characteristics (n = 437)	*Mean or Percent*	*s.d.*
Patient Demographics		
Age at SSD (*mean in years*)	58.43	7.10
Years on dialysis	3.25	1.50
Female %	49	0.07
African American %	34	0.27
Other race %	5	0.11
Hispanic %	11	0.21
Primary Cause of ESRD (percentage of patients)		
Diabetes	30	0.10
Hypertension	29	0.12
Glomerulonephritis	15	0.07
Other/unknown	21	0.08
Missing disease	5	0.04
Cormorbid Conditions / Lab Values (percentage of patients)		
Cardiac condition	77	0.18
Unable to ambulate independently	9	0.13
Pulmonary disease	12	0.14
Bilirubin *mg/dl* (*mean*)	0.50	0.31
Dialysis Treatments		
Total HD treatments	9,449	5,642.46
Total HD equivalent of CAPD/CCPD treatments	868	1,950.04
Total home HD treatments	163	1,167.15
Training HD treatments	18	196.40
Training CAPD and CCPD treatments	58	209.77
Region		
Ln of the population density (POP/MI^2)	7.28	1.97
Missing population	0.08	0.28
Dialysis Unit		
For-profit, freestanding unit %	67	0.47
Hospital unit %	22	0.41
Nonprofit, freestanding unit %	11	0.32
Chain status (1993) Not part of a chain %	62	0.48
Chain status (1993) Chain with 2–10 units %	13	0.34
Chain status (1993) Chain with 11–72 units %	7	0.26
Chain status (1993) Large national chain 1 %	11	0.32
Chain status (1993) Large national chain 2 %	6	0.23
Offers peritoneal dialysis %	27	0.44
Reuses dialyzers %	75	0.37
Cellulose membranes %	67	0.37
Synthetic membranes %	14	0.28
Modified cellulose %	16	0.30
Prescribed treatment time (*minutes*)	194	22.24

continued

Table 1: Continued

Dialysis Unit Characteristics (n = *437)*	*Mean or Percent*	*s.d.*
HCFA Reimbursement Parameters		
Market-adjusted reimbursement rate	$125.00	8.33
Price index predictions		
Below the floor %	16	0.37
Above the ceiling %	4	0.19

Notes: SSD = Study start date, HD = Hemodialysis, CAPD = Continuous ambulatory peritoneal dialysis, CCPD = Continuous cycling peritoneal dialysis.

Dialysis Technologies and Practices

The costs associated with three hemodialysis technologies/practices were analyzed in this study: prescribed treatment times, membrane type (cellulose, modified cellulose, and synthetic), and dialyzer reuse. Each of these technologies and practices was significantly associated with costs.

Longer treatment times were more costly, with a ten-minute (approximately 5 percent) increase in treatment time leading to a 1.4 percent increase in costs. This increase represents about $1.75 per treatment. Holding all other covariates constant, a facility using only synthetic dialyzer membranes had costs 11.2 percent higher than a facility using only cellulose membranes.[2] Similarly, a facility using only modified cellulose dialyzer membranes had costs 14.9 percent higher than a facility using only cellulose membranes. These differences represent approximately $14–$18 per dialysis treatment. Finally, a facility reusing dialyzers for all of its patients was found to have costs 6.8 percent below those of a facility that never reuses dialyzers. This translates into savings of approximately $9 per treatment.

Wage-Adjusted Payment

Medicare payment varies across facilities depending on location. HCFA applies its area wage index to adjust payment to account for geographic differences in labor costs (the largest single component of costs), subject to a "floor" and a "ceiling" (payments to facilities in areas where labor costs fall below 90 percent of the national average or exceed 130 percent of the national average are not adjusted beyond the 90 percent or 130 percent level). For freestanding facilities the floor payment was $117 and the ceiling was $139. Hospital-based units had a $4 higher base rate, raising their floor payment to $121, but they had the same $139 ceiling as freestanding facilities. Effectively,

Table 2: Regression Results
(Dependent Variable = Log Total Dialysis Cost for Entire Unit, 1991)

Dialysis Unit Characteristics	*PE*	p-*value*
Intercept	11.3387	<.001
Patient Demographics (average or proportion of patients)		
Age at SSD (per 1 year)	−0.0013	.455
Years on dialysis	−0.0073	.396
Female (proportion yes)	0.0989	.546
African American (proportion yes)	0.0412	.482
Other race (proportion yes)	−0.0650	.612
Hispanic (proportion yes)	−0.1399	.036
Primary Cause of ESRD (proportion of patients)		
Diabetes (proportion yes)	−0.1173	.575
Hypertensive (proportion yes)	−0.1977	.304
Other/unknown (proportion yes)	0.3160	.195
Missing disease (proportion yes)	−0.0494	.885
Cormorbid Conditions / Lab Values (average or proportion of patients)		
Cardiac condition (proportion yes)	−0.0831	.224
Unable to ambulate independently (proportion yes)	0.0971	.293
Pulmonary disease (proportion yes)	0.1311	.118
Bilirubin *mg/dl*	0.0761	.034
Dialysis Treatments		
Total HD treatments ($\times 10^{-3}$)	0.205	<.001
Total HD treatments *squared* ($\times 10^{-3}$)	−7.27E-06	<.001
Total HD treatments *cubed* ($\times 10^{-3}$)	9.69E-11	<.001
Total HD equivalent of CAPD/CCPD treatments ($\times 10^{-3}$)	0.092	<.001
Total HD equivalent of CAPD/CCPD treatments *squared* ($\times 10^{-3}$)	−4.06E-06	.050
Total home HD treatments ($\times 10^{-3}$)	0.044	.034
Training HD treatments ($\times 10^{-3}$)	0.631	.059
Training CAPD and CCPD treatments ($\times 10^{-3}$)	0.094	.368
Region		
Ln of the population density (POP/MI^2)	0.0377	<.001
Missing population (yes compared to no)	0.0686	.096
Dialysis Unit (average or proportion of patients)		
Hospital unit (compared to freestanding for-profit)	0.2769	<.001
Nonprofit, freestanding unit (compared to freestanding for-profit)	0.0308	.442
Chain status (1993) 2–10 units (compared to not part of a chain)	0.0096	.781
Chain status (1993) 11–72 units (compared to not part of a chain)	0.0830	.089
Chain status (1993) Large national chain 1 (compared to not part of a chain)	−0.0483	.211
Chain status (1993) Large national chain 2 (compared to not part of a chain)	−0.1458	.003
Offer peritoneal dialysis (yes compared to no)	0.0557	.038
Reusing dialyzers (proportion yes)	−0.0707	.036
Synthetic membranes (proportion yes)	0.1058	.031

continued

Table 2: Continued

Dialysis Unit Characteristics	*PE*	p-*value*
Modified cellulose (proportion yes)	0.1398	<.001
Prescribed treatment time (*minutes*)	0.0014	.020
HCFA Reimbursement		
Market-adjusted reimbursement rate	0.0058	.026
Spline at floor	−0.0012	.890
Spline at ceiling	0.0369	.010
R^2	0.8816	
n	437	

facilities at the floor are paid more than they would receive if HCFA fully adjusted for area wage differences. Conversely, facilities at the ceiling are paid less than they would receive if HCFA fully adjusted payment for wage differences. Overall, 15.8 percent of the study facilities were at the payment floor and 3.7 percent were at the ceiling.

To test the response of costs incurred by facilities to this wage-adjusted payment formula, we constructed the payment that would prevail if HCFA (hypothetically) did not impose the floor and ceiling levels on the adjustment (we refer to this hypothetical rate as the "fully adjusted payment"). The fully adjusted payment was entered in the cost function as a spline, with knots at the floor and ceiling levels. Thus, the model allows the slope of the relationship between the wage-adjusted payment and costs to change at those two points. The slope in the region between the floor and ceiling serves as the reference region. The slope below the floor represents the effect on costs when a facility's fully adjusted payment rate is one dollar closer to the floor (facilities at the floor are paid more than they would receive if the floor were not imposed; the closer the fully adjusted payment is to the floor, the less the "overpayment"). The slope between the floor and ceiling represents the effect of a one dollar increase in *actual* payment to account for higher local healthcare wages (because HCFA does adjust the payment rate to account for higher area wages over this range). Finally, the slope above the ceiling represents the effect on costs of a one dollar increase in the shortfall between the fully adjusted payment rate and the ceiling (facilities at the ceiling are paid less than they would receive if the ceiling were not imposed).

For facilities whose payment fell between the floor and the ceiling, a one dollar (0.8 percent) increase in payment led to a 0.6 percent increase in costs.

The hypothesis that a one percent increase in payment led to a one percent increase in costs could not be rejected at conventional levels of significance. For facilities at the floor, the spline variable is not significantly different from zero. Thus, the effect on costs of having a fully adjusted payment one dollar closer to the floor did not differ from the 0.6 percent increase in costs per one dollar increase in payment observed in the region between the floor and ceiling. However, facilities at the ceiling had a significantly steeper slope. Each additional dollar by which the fully adjusted payment exceeded the ceiling was associated with 4.3 percent higher costs.

Facility Characteristics

Facility ownership was associated with costs. Hospital-based units, which were almost exclusively nonprofit in our sample, had 31.9 percent higher costs than for-profit freestanding facilities. Nonprofit freestanding units did not have significantly higher costs than for-profit freestanding units. Chain units were classified into four groups. Costs for members of the smallest chains (two–ten units) were not significantly different from the costs of independents. Members of midsize chains (11–72 units) had costs 8.7 percent above those of independents ($p = .089$). Only the two largest national chains showed any evidence of savings. Members of large national chain 1 had costs 4.7 percent lower than independents, but this difference was not significant ($p = .21$). Costs of facilities in large national chain 2 were 13.6 percent lower than independents ($p = .003$).

In addition, the natural log of the population density was included as a proxy for input prices that were not directly observable in the data (particularly real estate prices, because the payment variables account for area wage rates). A doubling in population density was associated with 3.8 percent higher costs.

SENSITIVITY ANALYSES

Several variants of the model were estimated to assess the robustness of the results. In one version, the dependent variable was redefined as the natural log of Medicare hemodialysis costs rather than the natural log of Medicare costs for all dialysis modalities. Differences between this and the primary specification were minor, as would be expected given that hemodialysis costs constituted 92.7 percent of total costs. Likewise, restricting the sample to facilities that provided no dialysis modalities other than in-center hemodialysis did not substantially affect the results. Finally, dropping hospital-based facilities also resulted in only minor differences compared to the primary model. This is particularly reassuring given the qualitatively large difference in costs between hospital-based and freestanding facilities.

In place of the four binary variables indicating the chain size (2–10 units, 11–72 units, large national chain 1, and large national chain 2), the model was reestimated using a single binary variable to represent chain status. In this alternative specification, chain facilities did not have costs significantly different from independents. One other change in the results emerged when chain status was captured by a simple binary variable: the association between nonprofit ownership and costs became stronger and more significant ($p = .086$), with nonprofit freestanding facilities having costs 6.8 percent above those of their for-profit counterparts. The fact that both large national chains were for-profit might account for the change in the coefficient for nonprofit freestanding facilities.

Several of the explanatory variables, particularly the variables describing the dialysis treatment (treatment time, membrane type, and membrane reuse), are endogenous choices of the facility. As such, the parameter estimates may be biased if facilities adopting certain technologies and practices also have different propensities to use other cost-saving or cost-increasing practices that we did not observe in our data set. To address this possibility, we constructed a two-stage least squares estimator (Greene 1993) in which predictions of the use of these technologies and practices were constructed in the first stage and these predictions were entered into the model in the second stage in place of the potentially endogenous variables. Variables such as the presence of certificate-of-need regulation and socioeconomic characteristics of the general (nondialysis) population in the facility's county were used as predictors in the first-stage equations. Unfortunately, these predictors yielded imprecise estimates of the costs associated with dialysis technologies and practices, and this approach had to be abandoned.[3]

Given this limitation, the coefficients should be interpreted as reflecting the change in costs directly *and* indirectly associated with a technology or practice in the observational data. For example, the estimate of the cost of using a synthetic membrane potentially captures three types of cost differences between units using synthetic membranes and units using cellulose membranes. First, the extra cost of the synthetic membrane would be captured. Second, the coefficient would capture cost differences directly related to using synthetic membranes (but not captured by other variables in the model), such as any extra cost of the dialysis machines capable of using synthetic membranes. Third, if facilities adopting synthetic membranes also have a higher than average propensity to use other cost-saving or cost-increasing practices that are unrelated to the decision to use a particular membrane or to the other practices that were included in the model, the parameter estimate also captures the costs of these separate but correlated decisions.

If only the first type of effect (the extra cost of purchasing a synthetic membrane) were captured, the coefficient would be properly interpreted as the cost of changing to synthetic membranes holding all else about the treatment constant (staffing, machine, etc.). Because this should equal the accounting estimate of the extra cost of synthetic membranes, a statistical cost function estimate of only the first effect would be uninteresting. If both the first and second types of effects were captured, the coefficient would be properly interpreted as the extra costs of changing from a pattern of care that uses cellulose membranes to a pattern of care that uses synthetic membranes (holding treatment time and reuse constant because they are entered into the model separately). This is a useful piece of information as it would be generalizable to facilities that have not yet adopted synthetic membranes and thus could guide their decisions or the decisions of those setting payment policy. Only adding the third effect (practice patterns unrelated to membrane type) creates bias. If effects in this category are large, the cost function results would not generalize to facilities that have not yet adopted synthetic membranes. Assuming that facilities using the more expensive synthetic membranes would tend to be more likely to use other cost-increasing techniques, the parameter estimate can be interpreted as an upper bound on the additional costs of using synthetic membranes.

Finally, to test the plausibility of the associations found in the cost function, we estimated a separate set of regressions that disaggregates costs into labor, supplies, depreciation/maintenance, and other overhead costs. These estimates generally appeared plausible. For example, labor was the only component of costs that increased with the duration of the dialysis treatment.

DISCUSSION AND LIMITATIONS

Case-Mix Severity

Although the finding that most case-mix measures were not significantly associated with facility costs may be surprising, it is also reassuring given the lack of case-mix adjustment in the payment formula. We had hypothesized that more severely ill patients would lead to higher facility costs because such patients would be more likely to require disproportionate attention from facility staff (e.g., for patients unable to ambulate independently) or to experience complications that would disrupt facility scheduling and result in missed treatments. Even the clinical/demographic factors that were statistically significant predictors of costs did not have qualitatively large effects.

Although a facility-level cost function cannot rule out the possibility that caring for certain types of patients is more costly, we were unable to find evidence that certain facilities bore a disproportionate burden of such costly cases. If severity varies across facilities in ways not captured by the available case-mix measures, it is still possible that certain facilities have a significantly more costly case mix. However, such variation would likely present a difficult policy dilemma because the clinical and demographic measures we use are likely to be sufficiently available and verifiable to use in a case mix–adjusted payment system. Adjusting payments on the basis of severity measures that were unobservable to us and uncorrelated with the measures included in our cost function is not likely to be feasible.

Dor, Held, and Pauly (1995) did not include the prevalence of Hispanic patients as an explanatory variable, but they did find a negative relationship of a similar magnitude between the prevalence of African American patients and costs. These relationships between race or ethnicity and costs could arise because of unmeasured racial/ethnic differences in case mix, because of racial/ethnic differences in attitudes toward medical care (e.g., the likelihood that a patient skips a treatment), or because minority patients disproportionately receive dialysis at lower-quality facilities. The latter explanation may be most compelling, but overt discrimination may not necessarily be the cause. Because minority patients have lower incomes on average than whites, they are less likely to have generous insurance coverage to supplement Medicare. This supplementary coverage can be quite important as non-Medicare obligations average more than $8,000 per year (USRDS 1997). As Dor and Farley (1996) found in the case of hospitals, costs may reflect the generosity of the facility's payer mix.

Another limitation arises because some of the case-mix variables (cardiac comorbidities, pulmonary disease, inability to ambulate, and bilirubin levels) are not derived from a census of patients within each facility. Hence, the proportion of a facility's patients in which these conditions were present is measured with error given that these measures were constructed using only the representative sample of patients drawn for the CMA study. Thus, the coefficient estimates may be biased toward zero. However, the lack of strong case mix/cost relationships even for patient descriptors drawn from the PMMIS (a census of patients) is consistent with the conclusion that case-mix differences across facilities do not result in large inequities in payment that may precipitate access problems for a costly subset of patients.

Dialysis Technologies and Practices

Several recent studies report that mortality declines with dialysis dose (Held, Port, Wolfe, et al. 1996; Hakim, Held, Stannard, et al. 1994; Owen, Lew, Liu, et al. 1993; Held, Levin, Bovbjerg, et al. 1991). While the dose beyond which further reductions in mortality do not occur has not been well established, the available studies indicate that any such threshold exceeds the treatment levels that prevailed in the United States during the early 1990s. In addition, dialysis patients in many other nations have lower mortality rates. Undoubtedly, this partially reflects inadequate adjustment for the more severe case mix found in the United States, but studies have also documented that practice patterns in low-mortality nations differ from practices prevailing in the United States. For example, Held, Wolfe, Gaylin, et al. (1994) reported that the dose of dialysis is lower in this country than in various European nations.

These findings have led to an effort (spurred in part by the HCFA Core Indicators Project [Vladeck 1995]) to increase the dose of dialysis to a target, measured by Kt/V, of at least 1.2.[4] This is the dose recommended by a National Institutes of Health Consensus Conference (Consensus Development Conference Panel 1994) and by a practice guideline developed by the Renal Physicians Association (1993). The proportion of facilities achieving this target increased from 30 percent in 1990 to 50 percent in 1993 (USRDS 1996). It is not known how costly it has been for facilities to achieve these increases in dialysis dose and, hence, how much the payment would have to be adjusted to compensate facilities for the costs of complying with the guideline or to induce the remaining facilities to comply.

Facilities influence the dose of dialysis through choice of dialyzer membrane, blood flow rate, dialysate flow rate, and prescribed duration of treatment. This study provides estimates of the cost increments, in actual practice, associated with longer treatments and with the use of synthetic and modified cellulose membranes. These estimates can be used to simulate the costs of increasing the dose of dialysis. Average delivered Kt/V was 1.01 in 1990 (USRDS 1997). The simulations will be based on a 10 percent (0.1 Kt/V) increase. Held, Port, Wolfe, et al. (1996) reported that an increase of this magnitude was associated with a 7 percent decline in the relative risk of mortality, clinically significant in a population whose annual mortality rate exceeds 20 percent.

Treatment Duration. For the average facility, a 10 percent increase in treatment duration would require an additional 19.4 minutes. Given the point estimate of a 1.4 percent increase in costs per 10-minute increase in treatment time, this would result in a 2.7 percent increase in costs. Previous research by Held et al. (1990) has demonstrated the sensitivity of treatment duration to economic incentives, as reductions in treatment time were largest in units experiencing the greatest cuts in Medicare payments following a series of policy changes enacted in 1983.

Membrane Type and Membrane Reuse. Dialysis dose can also be increased by changing dialyzers. Synthetic and modified cellulose membranes generally clear more urea per unit of time than cellulose membranes, and the dialysis machines that they are used with can support higher blood flow and dialysate flow rates than conventional machines. These membranes may have other advantages relative to cellulose membranes, including reductions in the likelihood of infection-related hospitalizations, poor nutritional status, and inflammatory responses (see Hakim, Held, Stannard, et al. 1996, and the references therein). In their observational study, Hakim et al. also found that modified cellulose or synthetic membranes (both relative to cellulose membranes) reduced the risk of death even after controlling for dose of dialysis.

To determine how much additional urea was cleared as a function of membrane type, we used Wave I of the USRDS Dialysis Morbidity and Mortality Study (USRDS 1996) to estimate a regression model in which the dependent variable was delivered dose of dialysis. Independent variables included the natural log of treatment time (alternative specifications entered treatment time as linear, quadratic, and cubic functions), membrane type, and patient weight (a proxy for V). The regression estimate of the effect of membrane type on delivered dose of dialysis (holding t and V constant) indicated that modified cellulose membranes raised Kt/V by .036 and synthetic membranes raised Kt/V by .105.

The .036 increase in Kt/V achieved by switching to a modified cellulose membrane (associated with 14.9 percent higher costs) could be achieved by increasing treatment duration only 7 minutes (associated with 1.0 percent higher costs). The .105 increase in Kt/V achieved by switching to a synthetic membrane (associated with 11.2 percent higher costs) would require a 20.4-minute increase in treatment duration (associated with a 2.9 percent increase in costs). Thus, longer treatments are the most efficient way to increase dose of dialysis.

Under Medicare's flat-rate payment system, facilities contemplating a switch to a more expensive dialyzer might attempt to recoup the higher cost by reusing the dialyzer. If a facility simultaneously switches from single use of cellulose dialyzers to reuse of modified cellulose or synthetic dialyzers, the savings from reuse would be insufficient to offset fully the higher costs associated with the more costly dialyzers. The overall cost increase would fall to 8.1 percent for reuse of modified cellulose membranes or 4.4 percent for reuse of synthetic membranes. However, adopting reuse is likely to be a quality-reducing measure as it has been associated with increased mortality risk (Feldman, Kinosian, Bilker, et al. 1996; Held, Wolfe, Gaylin, et al. 1994).

Even if reuse is adopted simultaneously with the more costly membrane types, increasing treatment duration remains less costly to the dialysis unit.[5] However, the cost increase associated with simultaneous adoption of synthetic membranes and reuse (4.4 percent per .105 increase in Kt/V) is sufficiently close to that for increasing treatment time (2.9 percent per .105 increase in Kt/V) that units located in high-wage areas may find changing membranes and reuse policy to be a more efficient method of increasing dose of dialysis. With this possible exception for high-wage facilities, the decision to use more expensive membranes must be justified at least in part by the benefits, other than increased dose of dialysis, of more expensive membranes.

Assuming typical dialyzer costs of $10 for cellulose, $15–$20 for modified cellulose, and $25 for synthetic, the observed cost increment for units using modified cellulose membranes was too large to be explained solely by membrane costs. Units choosing to use higher-cost dialyzers may also be different in other respects not controlled for in the cost function. The regressions for components of cost are instructive in this regard: facilities using higher-cost membranes, particularly modified cellulose membranes, had higher labor costs in addition to the expected increase in supply costs. Facilities using higher-cost membranes may also be "better" in other dimensions such as staffing levels and skills, raising the possibility that anticipated outcome improvements from a policy to, for example, mandate the use of a particular class of membranes might not materialize.

Although our data are from 1991, the basic technology decisions facing dialysis units have not changed. Some new models of dialyzers have been introduced, but the choice of type (cellulose, modified cellulose, or synthetic) and the relative prices remain similar. While the shares of synthetic and modified cellulose have grown since the time of our study (USRDS 1997), the less expensive cellulose membranes retain a market share of more than 20 percent. The percentage of facilities reusing dialyzers has risen slightly from 75 percent in our sample to 81 percent in 1996 (USRDS 1997). The payment system also has not changed appreciably. Thus, decisions about how to provide the dialysis treatment (membrane type, reuse, and treatment time) and the economic environment (capitation) remain similar to what they were at the time our data set was collected.

Wage-Adjusted Payment

The spline function allows us to test how HCFA's decision to place a floor and a ceiling on the wage adjustment affected actual costs incurred by facilities. The floor payment represents a "windfall" to facilities who would have received less had their payment been fully adjusted for geographic differences in labor costs, and the ceiling represents a "shortfall" to facilities in high-wage areas. The finding that the slope of the cost function below the floor was not significantly different than the slope between the floor and ceiling implies that facilities receiving the floor payment did not pass their windfall on to patients in the form of higher spending on treatment. If the windfall had been passed on in this manner, the slope would have been zero below the floor (i.e., incurred costs would have been consistent with the actual payment received [the floor level]).

Conversely, facilities whose payment was constrained by the ceiling incurred substantially higher costs than would be expected given their actual payment.[6] This could result from differing levels of competition faced by facilities at the floor and ceiling. Facilities at the floor are in low-wage areas, which are likely to be rural and to have few competing dialysis providers, making it easier for them to retain the windfall. Facilities at the ceiling are likely to be in large metropolitan areas, facing greater competition for physicians and patients from a number of other dialysis providers and leading to higher costs despite the fact that payment is constrained by the ceiling. This interpretation is consistent with earlier findings by Held and Pauly (1983) on the relationship between competition and dialysis costs.

An economic rationale for not fully adjusting payments for wage variations is that the delivery of dialysis treatments does not require fixed input proportions. It would be expected that facilities in high-wage areas substitute equipment (e.g., more efficient dialyzers) for staffing to deliver dialysis in the most efficient manner given their local environment. Imposing a ceiling on the wage adjustment is a crude method of taking this substitution into account. Intuitively, equitable payment to facilities in high-wage areas may not require full adjustment because facilities in those areas will tend to use fewer workers and more labor-saving technologies than their counterparts in lower-wage areas.[7] However, the strength of the effect at the ceiling suggests that these facilities are unable to adjust completely to the constrained payment levels.

Further, the regressions for components of costs show that the higher costs at the ceiling were indeed in the labor category.

Facility Characteristics

The much higher costs we observed in hospital-based facilities may be attributable to better quality, adverse unmeasured case mix, or inefficiency. However, cost allocation issues almost certainly play a role, as it is difficult to assign certain fixed or overhead hospital costs to specific units (such as the dialysis center). The regressions examining components of costs revealed that most of the higher costs observed in hospital-based units were indeed in the overhead category. Current Medicare payment policy favors hospital-based units. A better understanding of the allocation of fixed and overhead costs is required to determine conclusively the proportion of the observed cost difference that constitutes an appropriate basis for differential payments to hospital-based units. As for relatively easy-to-attribute costs, hospital-based units (versus freestanding units) had higher supply costs and similar labor costs. The existing payment difference is much smaller than the estimated total cost difference but is in line with the estimated difference in supply costs. Differentiating payments by type of facility is far easier to implement than a policy that sets patient-specific rates as a function of comorbidities. Thus, the lack of a strong relationship between case mix and costs supports continuing the policy of differentiating by type of units rather than developing a complex system to condition dialysis payments on the characteristics of individual patients.

The economies experienced by members of at least one of the two largest chains, combined with the failure to find that members of small and medium-sized chains had lower costs than independent dialysis units, may provide an explanation for the recent growth in the market share of the largest chains. Likewise, the tradeoff between efficiencies achieved by chains versus the adverse effects of diminished competition should be considered carefully in antitrust enforcement decisions. The regressions for individual components of costs are useful in examining this tradeoff. The large chain that had significantly lower costs accomplished this primarily through a reduction in supply costs. Supply costs are determined primarily by the type of membrane and reuse policy, which were controlled for separately in the model. Thus, lower supply costs in this large chain probably reflect its ability to bargain for lower prices, and not any reductions of real resources devoted to care. The failure of the largest chain to have significantly lower costs would seem to contradict this bargaining power interpretation. However, the largest chain also manufactures dialyzers, which it uses internally and sells to other units. Thus, the reported supply costs depend on the chain's internal transfer pricing policy. Economic theory implies that this transfer price should equal the price charged to external buyers, suggesting that units in this chain would not report lower supply costs than other units. Further, because future payment policy may in part depend on reported costs at the aggregate level, this chain is large enough to have a strategic incentive not to set artificially low transfer prices.

In an earlier study, Griffiths, Powe, Gaskin, et al. (1994) found that nonprofit, freestanding dialysis facilities used more inputs (labor and dialysis machines) per treatment than did their for-profit counterparts. Because Griffiths et al. did not have data on treatment parameters such as duration, type of membrane, and reuse, they could not determine if their finding represented differences in efficiency or quality. Our failure to find higher costs among nonprofit, freestanding facilities after controlling for these treatment parameters suggests that inefficiency by nonprofits is not the explanation.

The result that costs increased with population density, which was included in the model as a proxy for unobserved input prices, may also reflect the types of competitive effects described in the previous subsection. It is likely that facilities in more densely populated areas have a greater number of competitors.

SUMMARY OF MAIN POLICY IMPLICATIONS

The cost function estimates in this study provide insights into the usefulness of adjusting Medicare dialysis payment policy for three factors: case mix, the delivered dose of dialysis, and local healthcare wages. In contrast to the results of research on other sectors of the healthcare system such as long-term care, there was little evidence that adjusting dialysis payment to account for differences in case mix across facilities would be necessary to ensure access to care for high-cost patients or to reimburse facilities equitably for their costs. Thus, the complexities of developing and implementing a case mix–adjusted payment system can be avoided in favor of maintaining the existing, non-case mix–adjusted system. In the case of long-term care, case-mix adjustment has been found to be necessary to ensure access for patients requiring complex care and to reduce inequities in payment to facilities (Fries, Schneider, Foley, et al. 1994). Three factors may explain the failure to find analogous relationships between case mix and dialysis costs. First, capacity constraints created by certificate-of-need regulation appear to be stronger in long-term care, giving nursing homes more freedom to select only the most profitable patients. Second, because institutional long-term care is often discretionary while few dialysis patients have any real alternative, dialysis facilities probably would face significant criticism if they blatantly refused to care for large subsets of the patient population. Third, dialysis treatments may be more homogeneous than long-term care services.

Although dialysis providers have faced a capitation system with little nominal change in payment rates for more than a decade, technological innovation and improvements in patient outcomes have continued. This may provide some reassurance that quality of care will not markedly deteriorate in other segments of the U.S. healthcare system as they adjust to increasingly stringent cost control. Nonetheless, because all of the methods of raising dialysis dose considered in this study were associated with higher costs, the existing payment system may be hindering ongoing efforts by the federal government and professional societies to implement guidelines calling for an increase in dose. Adherence to these guidelines is expected to yield further, clinically significant reductions in the dialysis mortality rate.

A dose-adjusted payment system would be more complex than the existing system. The costs associated with extending the length of treatments (the most economical means of increasing dose identified in this study) could serve as a starting point for determining the magnitude of the adjustment. Dose is currently measured by most if not all dialysis units and is already monitored (without sanctions) by HCFA as part of its Core Indicators Project. The greatest barriers to implementing a dose-based payment system are standardizing the methods of measurement and instituting audit capabilities sufficient to deter fraudulent reporting. Further, there should be a target dose beyond which additional payments would not be forthcoming to prevent facilities from raising the dose beyond clinically and economically justifiable levels. This is similar to the method HCFA already uses to pay dialysis units for administering the drug erythropoietin to anemic patients.

Managed care provides an alternative that could result in higher doses without having to modify the existing payment system to account for dose of dialysis. Providing better dialysis may reduce hospitalizations (preventing lost revenues resulting from missed treatments) and mortality (allowing the unit to continue collecting revenues for a longer period of time). These potential effects on revenues should provide some incentive for facilities to provide high-quality dialysis even in the existing system. However, these incentives would become stronger under managed care. For example, the financial costs of the excess hospitalizations and other adverse events are not borne by the dialysis unit. These costs would be internalized only if the dialysis unit (or some other entity) received a capitation payment for the entire scope of medical care received by the patient. Currently, ESRD patients are barred from enrolling in Medicare managed care options. Thus, the only ESRD patients enrolled in managed care are those who choose Medicare managed care plans in which they were enrolled prior to the onset of ESRD and those who maintain managed care coverage through an employer group health plan during the coordination of benefits period. However, the transition of some Medicare ESRD patients to managed care is occurring under a HCFA demonstration project (Hirth and Held 1997).

In addition, we found evidence that HCFA's policy of limiting the wage adjustment resulted in a windfall to facilities in low-wage areas that was not passed on to patients in the form of more resources devoted to treatment. Conversely, facilities in high-wage areas faced a payment shortfall because they were not able to completely adjust their costs downward to account for HCFA's ceiling on the wage adjustment. This policy may have unintended consequences as it places the profits of facilities that were at the adjustment ceiling under greater pressure than those of other facilities. Revising the wage adjustment policy would be approximately revenue-neutral and trivial to implement because it would require only a modification in the wage adjustment formula, not additional measurement or monitoring. The main difficulty would be political, as a change would create winners (facilities currently at the payment ceiling) and losers (facilities currently at the floor).

The results with respect to the limited range over which payments were adjusted for variations in labor costs have implications for pure or modified capitation mechanisms in healthcare. For instance, Frank, McGuire, and Newhouse (1995) discuss the incentives behind physician capitation and mental health/substance abuse carve-outs. Their analysis presumes that the cost curves are fixed, while ours allows for the possibility of a more dynamic process in which costs respond to different levels of pressure on profits that are induced by the payment system. It is interesting to note that incentives created by placing a floor and a ceiling on the dialysis labor cost adjustment work in the opposite direction from incentives under newer forms of capitated payments by HMOs ("soft capitation") that use bonuses and withholds to share profits and losses between the payer and providers.[8] In many of these soft capitation systems, providers with the most adverse cost experience receive a disproportionately large adjustment to their payments.

Like many other sectors of the healthcare system, dialysis providers have been consolidating into larger chains. This trend requires antitrust enforcement agents to weigh increases in market power against any efficiencies created by mergers. In dialysis, the primary adverse outcome of increased market power would not be higher prices because the payment rate for more than 90 percent of patients is fixed by Medicare. Thus, any adverse effect of market power would be expressed through lower quality of care. Because costs incurred by facilities in small and mid-sized chains (which may still have considerable power in local markets) were not lower than costs incurred by independents, no evidence of either efficiencies or quality reductions was found in resources devoted to care within these size classes. We could not determine directly whether the lower costs incurred by members of at least one of the largest national chains resulted from greater efficiency or reduced quality. However, because the savings were in supply costs (even after controlling for membrane type and reuse policy) but not in labor costs, purchasing power in the market for supplies seems to be a more plausible explanation than reduced quality. The heterogeneity of results by chain size indicates that the simple dummy variable characterization of chain versus independent status often found in the health services research literature may be inadequate for understanding the consequences of chain ownership. The effects of the ongoing growth of large chains are worthy of continued monitoring to inform antitrust enforcement both in dialysis and in other sectors of the healthcare system.

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NOTES

1. A small proportion of facilities have received exceptions from the payment formulas based on their patient population. Most of these facilities have heavy pediatric caseloads.
2. In regressions with a logarithmic dependent variable, the actual effect of a binary independent variable is approximately equal to $100 \times \{\exp(b) - 1\}$, where exp is the

base of the natural logarithm and *b* is the binary variable's estimated regression coefficient (see Halvorsen and Palmquist 1980).

3. Bound, Jaeger, and Baker (1995) demonstrate that OLS estimates are often superior to instrumental variables estimates when the instrumental variables are less than ideal.
4. K is the rate of urea clearance by the dialyzer; t is the dialysis treatment time; V is the patient's volume of distribution of urea (closely related to the patient's weight).
5. This calculation obviously ignores the value of the patient's time, which is external to facility costs.
6. Despite the statistical significance of the increase in slope at the ceiling, this result should be interpreted cautiously, because it is based on a fairly small number of facilities (16) at the payment ceiling.
7. Note that this rationale would actually imply *overadjustment* for wage differences at the low end of the wage distribution because the efficient input mix in low-wage areas would include more than the average amount of labor. This is exactly the opposite of the existing policy of making no downward adjustment below the floor, and it is consistent with the finding that facilities in low-wage areas receive a windfall.
8. These payment systems have been described in greater detail by Gold, Hurley, Lake, et al. (1995) and Frank, McGuire, and Newhouse (1995).

REFERENCES

Bound, J., D. A. Jaeger, and R. M. Baker. 1995. "Problems with Instrumental Variables Estimation When the Correlation Between the Instruments and the Endogenous Explanatory Variable Is Weak." *Journal of the American Statistical Association* 90 (4): 443–50.

Consensus Development Conference Panel. 1994. "Morbidity and Mortality of Renal Dialysis: An NIH Consensus Conference Statement." *Annals of Internal Medicine* 121 (1): 62–70.

Dor, A., and D. E. Farley. 1996. "Payment Source and the Cost of Hospital Care: Evidence from a Multiproduct Cost Function with Multiple Payers." *Journal of Health Economics* 15 (1): 1–21.

Dor, A., P. J. Held, and M. V. Pauly. 1992. "The Medicare Cost of Renal Dialysis: Evidence from a Statistical Cost Function." *Medical Care* 30 (10): 879–91.

Farley, D. O. 1996. "Competition Under Fixed Prices: Effects on Patient Selection and Service Strategies by Hemodialysis Providers." *Medical Care Research and Review* 53 (3): 330–49.

Feldman, H. I., M. Kinosian, W. B. Bilker, C. Simmons, J. H. Holmes, M. V. Pauly, and J. J. Escarce. 1996. "Effect of Dialyzer Reuse on Survival of Patients Treated with Hemodialysis." *Journal of the American Medical Association* 276 (8): 620–25.

Frank, R. G., T. G. McGuire, and J. P. Newhouse. 1995. "Risk Contracts in Managed Mental Health Care." *Health Affairs* 14 (1): 50–64.

Fries, B. E., D. P. Schneider, W. J. Foley, M. Gavazzi, R. Burke, and E. Cornelius. 1994. "Refining a Case-Mix Measure for Nursing Homes: Resource Utilization Groups (RUG-III)." *Medical Care* 32 (7): 668–85.

Gardner, J. 1997. "Dialysis Outcomes in Works: HCFA May Set Quality, Practice Guidelines for ESRD Program." *Modern Healthcare* (3 February): 64–65.

Gold, M. R., R. Hurley, T. Lake, T. Ensor, and R. Berenson. 1995. "A National Survey of the Arrangements Managed Care Plans Make with Physicians." *The New England Journal of Medicine* 333 (25): 1678–83.

Greene, W. H. 1993. *Econometric Analysis, 2nd ed.* New York: Macmillan Publishing Company.

Griffiths, R. I., N. R. Powe, D. J. Gaskin, G. F. Anderson, G. V. de Lissovoy, and P. K. Whelton. 1994. "The Production of Dialysis by For-Profit Versus Not-For-Profit Freestanding Renal Dialysis Facilities." *Health Services Research* 29 (4): 473–87.

Hakim, R. M., J. Breyer, N. Ismail, and G. Schulman. 1994. "Effects of Dose of Dialysis on Morbidity and Mortality." *American Journal of Kidney Diseases* 23 (5): 661–69.

Hakim, R. M., P. J. Held, D. C. Stannard, R. A. Wolfe, F. K. Port, J. T. Daugirdas, and L. Agodoa. "Effect of the Dialysis Membrane on Mortality of Chronic Hemodialysis Patients." *Kidney International* 50 (2): 566–70.

Halvorsen, R., and R. Palmquist. 1980. "The Interpretation of Dummy Variables in Semilogarithmic Equations." *American Economic Review* 78 (3): 474.

Held, P. J., F. K. Port, R. A. Wolfe, D. C. Stannard, C. E. Carroll, J. T. Daugirdas, W. E. Bloembergen, J. W. Greer, and R. M. Hakim. 1996. "The Dose of Hemodialysis and Patient Mortality." *Kidney International* 50 (2): 550–56.

Held, P. J., J. R. Garcia, M. V. Pauly, and M. A. Cahn. 1990. "Price of Dialysis, Unit Staffing, and Length of Dialysis Treatments." *American Journal of Kidney Diseases* 15 (5): 441–50.

Held, P. J., and M. V. Pauly. 1983. "Competition and Efficiency in the End Stage Renal Disease Program. *Journal of Health Economics* 2 (2): 95–118.

Held, P. J., N. W. Levin, R. R. Bovbjerg, M. V. Pauly, and L. H. Diamond. 1991. "Mortality and Duration of Hemodialysis Treatment." *Journal of the American Medical Association* 265 (7): 871–75.

Held, P. J., R. A. Wolfe, D. S. Gaylin, F. K. Port, N. W. Levin, and M. N. Turenne. 1994. "Analysis of the Association of Dialyzer Reuse Practices and Patient Outcomes." *American Journal of Kidney Diseases* 23 (5): 692–708.

Hirth, R. A., and P. J. Held. 1997. "Some of the Small Print on Managed Care Proposals for End-Stage Renal Disease." *Advances in Renal Replacement Therapy* 4 (4): 314–24.

Owen, W. F., II, N. L. Lew, Y. Liu, E. G. Lowrie, and J. M. Lazarus. 1993. "The Urea Reduction Ratio and Serum Albumin Concentration as Predictors of Mortality in Patients Undergoing Hemodialysis." *The New England Journal of Medicine* 329 (14): 1001–1006.

Renal Physicians Association. 1993. "Clinical Practice Guideline on the Adequacy of Hemodialysis: Clinical Practice Guideline, Number 1." December (pamphlet).

U.S. Renal Data System. 1997. *USRDS 1997 Annual Data Report.* Bethesda, MD: The National Institutes of Health, National Institute of Diabetes and Digestive and Kidney Diseases.

———. 1996. *USRDS 1996 Annual Data Report.* Bethesda, MD: The National Institutes of Health, National Institute of Diabetes and Digestive and Kidney Diseases.

———. 1992. *USRDS 1992 Annual Data Report.* Bethesda, MD: The National Institutes of Health, National Institute of Diabetes and Digestive and Kidney Diseases.

Vladeck, B. C. 1995. "End-Stage Renal Disease Core Indicators Project." *Journal of the American Medical Association* 273 (24): 1896.