Toward Developing a Relative Value Scale for Medical and Surgical Services

by William C. Hsiao and William B. Stason

A methodology has been developed to determine the relative values of surgical procedures and medical office visits on the basis of resource costs. The time taken to perform the service and the complexity of that service are the most critical variables. Interspecialty differences in the opportunity costs of training and overhead expenses are also considered.

Results indicate some important differences between the relative values based on resource costs and existing standards, prevailing Medicare charges, and California Relative Value Study values. Most dramatic are discrepancies between existing reimbursement levels and resource cost values for office visits compared to surgical procedures. These vary from procedure to procedure and specialty to specialty but indicate that, on the average, office visits are undervalued (or surgical procedures overvalued) by four- to five-fold. After standardizing the variations in the complexity of different procedures, the hourly reimbursement rate in 1978 ranged from $40 for a general practitioner to $200 for surgical specialists.

The dramatic escalation of health care costs has brought physicians' fees under increasing scrutiny. Concern exists not only with regard to high fees, but also with the equivalency of fees between different types of services and between different specialties. At the present time charges for physician services are, in large measure, determined by the individual physician.

If the market for physician services were reasonably competitive, determination of price by the physician would be reasonable. Under these circumstances the informed consumer could accept or reject the service depending on its price and on the perceived value of that service. Such is not the case, however. The consumer's imperfect knowledge of the benefits s/he can expect from a given medical or surgical service, the physician/patient relationship in which the patient relies upon the physician to determine the appropriate course of therapy, and present medical insurance reimbursement policies all distort the market place for medical services. Furthermore, the unpredictable and acute nature of many health problems often precludes "shopping" for health services. A person afflicted by disconcerting or life-threatening symptoms is hardly in a position to search the market for the "best deal."

It is highly unlikely, given existing circumstances in the medical care market and the increasing pressures toward regulation of medical practice, that conditions for a competitive market will ever exist. If the fee-for-service option is to be retained, therefore, it is essential that a systematic and equitable means be devised for pricing each medical and surgical service relative to one another.

The California Relative Value Study (CRVS), first published in 1956, is the most comprehensive effort to date in this direction. In the CRVS, relative values were initially based upon existing median charges of California physicians. In periodic revisions that have been made since 1956, it is not clear what criteria have been applied, although in some cases revisions are known to be the results of bargaining and negotiations among specialties. The intent of the CRVS has been to provide a guide to assist physicians in establishing fees but not to constrain physicians from charging what they deem appropriate.

Other relative value scales that have appeared since the CRVS bear close resemblance to it. This is true for Medicaid schedules and schedules adopted independently by Blue Shield plans and by some commercial insurance companies. Hence, through the CRVS, all current relative scales can be traced more or less directly to prices that existed at a past point in time. Any distortions at that time are likely to have been perpetuated.

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Alternatives to relying upon market mechanisms to determine the relative values of medical services include estimating the resource costs required to produce different services or establishing values based on the consensus of a group of medical and/or non-medical experts.

We have focused on the former approach. The wide acceptance of resource costs as the basis for establishing the value of goods in society; their use in the pricing of public utilities; the susceptability of resource costs to relatively objective measurement; and the feasibility of monitoring and updating such a value scale to reflect changes in medical skills and technology all contributed to this decision.

The objectives of this study were to develop a methodology for computing these resource costs and for melding them into a relative value scale; to apply this methodology to a limited number of medical and surgical services; and to compare the resulting relative values to those of the California Relative Value Study and to prevailing prices.

Methods and Data Sources

The major inputs into the production of medical services are the professional time expended, the intensity of effort and degree of skills represented by this time, the physicians' level of training, and the overhead expenses incurred in providing the service.

Time

The time spent by a physician in performing a surgical procedure or office visit should unquestionably be an important determinant of its value. Professional time for surgical procedures includes the "skin to skin" time (the time from the initial incision until the final suture is in place) and time spent in preoperative evaluation and postoperative care. For office visits, time spent reviewing past medical records or laboratory results and preparing records of the present visit and relevant correspondence need to be considered in addition to time actually spent with the patient.

"Skin to skin" time for a variety of surgical procedures was obtained from the Study of Surgical Services in the United States (SOSSUS) (1975). In this study, time estimates were obtained from operating room logs on 285,160 principal operations performed in four defined geographic areas in the U.S. during 1970. Procedures were coded according to the Commission on Professional and Hospital Activities (1968). Consideration in this paper is limited to procedures:

(1) which are characteristically performed by general surgeons, obstetricians and gynecologists, opthalmologists, orthopedic surgeons, and urologists;
(2) which are relatively well-defined in terms of the usual extent of the procedure;
(3) for which the coding systems employed by SOSSUS and those of the California Relative Value Scale (California Medical Association, 1969) are similar; and
(4) for which at least 30 observations were available in the SOSSUS data.

Mean "skin to skin" time in minutes for selected procedures is presented in Table 1. A one-third random subset of these data was examined in greater depth to evaluate the distribution of "skin to skin" time for each procedure. A few procedures, such as diagnostic D&C and inguinal hernia repair have a high degree of skewness in their distributions of time (skewness > 1.0); in each instance the "long tail" of the distribution is "to the right" in the direction of increased length of operation. These findings could be due to a subset of patients who had particularly complicated procedures or, alternatively, (but less likely) to a group of particularly slow surgeons. Despite these non-normal distributions, "mean time" was chosen for use in this analysis.

Empirical data on the time a surgeon spends in the pre- and post-operative care of patients undergoing different surgical procedures are not available. In their absence the following assumptions were made:

(1) Pre-operative evaluation occurs following an office visit and, for elective procedures, takes *15 minutes*. (This estimate, obviously, applies to elective procedures only. The prolonged periods of pre-operative evaluation that may be required in the case of trauma or other acute illnesses, including appendicitis, are not adequately acknowledged by this figure.)
(2) Time spent in surgery over and beyond "skin to skin" time (dressing, scrubbing, waiting, preparing the patient, etc.) takes *20 minutes*.
(3) Time spent in the immediate post-operative period dictating an operative note, writing orders, and checking the patient in the recovery room takes *15 minutes*.
(4) Time spent in post-operative follow-up takes *10 minutes* on the day of surgery and an average of *five minutes* per day thereafter.

These assumptions, therefore, divide the time spent in pre- and post-operative care into a fixed portion, 60 minutes in duration, that applies uniformly to all surgical procedures and a variable portion that is determined by the length of hospital stay (Commission on Professional & Hospital Activities, 1976). Although these assumptions undoubtedly overestimate the time required for some procedures and underestimate it for others, they can be considered first approximations until better data become available.

Finally, for office visits it was esltmated that an initial visit takes an average of 30 minutes and that a follow-up visit takes 15 minutes (National Ambulatory Medical Care Survey, 1978).

Complexity of Services

The time required to perform a surgical procedure or medical service does not fully describe the professional effort involved. Not all time is equal; rather, the degree of skill and intensity of effort required per unit of time vary widely from one service to another. Presumably, the value of a service should reflect these differences. Complexity here is defined to include: (1) the intensity of physical and mental effort involved including the risk of intraoperative complications; (2) the diagnostic skills and clinical judgments required

TABLE 1

"Skin to Skin" Time by Procedure

Specialty	Procedure	Number of Observa-tions	Mean Time (in minutes)
General Surgery	Excision and ligation of varicose veins	139	125.8
	Hemorrhoidectomy	166	50.6
	Inguinal hernia repair	552	65.7
	Excision biopsy of breast	145	44.6
	Appendectomy	269	52.2
	Cholecystectomy	340	94.5
	Cholecystectomy with common duct exploration	54	145.8
Obstetrics and Gynecology	Diagnostic D & C	737	23.5
	Excision biopsy of breast	145	44.6
	Oophorectomy, unilateral	50	75.0
	Caesarian section	93	59.3
	Abdominal hysterectomy, total	502	112.3
	Vaginal hysterectomy, with A-P repair	156	101.8
Ophthalmology	Chalazion	32	33.2
	Strabismus correction	46	67.9
	Lens extraction, intracapsular	299	51.6
Orthopedics	Bunionectomy	56	71.7
	Menisectomy	62	64.4
	Intertrochanteric fracture of hip with internal fixation	63	93.7
	Bankhart procedure	30	125.3
	Lumbar laminectomy	149	119.3
Urology	Cystoscopy, diagnostic	539	29.0
	Vasectomy	34	30.7
	Transurethral bladder surgery-tumors 0.5cm to 2.0 cm	102	50.5
	Suprapubic prostatectomy	35	84.3
	Transurethal prostate resection	202	68.3

to choose the appropriate therapeutic procedure; and (3) the technical skills required to perform the procedure. Although the expression of each of these measures varies not only from one procedure to another but also from one patient to another for a given procedure, the focus in this analysis is on the average overall complexity of one procedure relative to another.

To assess the complexity of different surgical and medical services personal interviews were conducted with 25 board-certfiied physcians, five each from General Surgery, Obstetrics and Gynecology, Ophthalmology, Orthopedics, and Urology. Physicians were selected non-randomly to represent various practice modes (fulltime fee-for-service practice, salaried practice, fulltime academic); different institutions (teaching hospitals, community hospitals); and a broad spectrum of ages and lengths of experience. All were located in the Boston area.

Each physician was asked, first, to rank on a 10 point scale the complexity of procedures he performed reasonably frequently; hence, procedures that might appear complex to a given surgeon because they were not a regular part of his practice were excluded. Having done this he then was asked to choose a procedure falling near the middle of his scale and, assigning a value of 100 units to this procedure, to estimate the complexity per unit time of:

(1) the least complex procedure listed;
(2) the most complex procedure;
(3) an initial diagnostic office visit.

The initial 10 point scale was then converted to a cardinal scale by anchoring ends of the scale by the value estimates for the most complex and least complex procedures and by calculating proportional values for procedures above and below the reference procedure (100 units/unit time). The values obtained were averaged within specialties and then expressed as relative complexities by dividing all values by that of the least complex procedure.

To allow physicians to reassess their estimates, a modified Delphi technique was carried out in which each physician was provided with his own relative complexity values and those representing the average of physicians in his specialty. Changes were then incorporated into the final calculations.

Two findings were of particular interest. First, rank orders by complexity of procedures within a specialty varied very little from one physician to another despite the diverse characteristics of the practices surveyed. Second, the range of relative complexities varied widely from one specialty to another; from 1.0 to 2.6 for orthopedics to 1.0 to 10.2 for ophthalmology. There is a widespread consensus among physicians that the most complex procedure in one specialty is comparable to that in another, given an equal length of residency training. Consequently it was assumed that wide differences in the scale of complexity values did not represent true differences between specialties. All scales, therefore, were standardized to the range for general surgery (1.0 to 4.0). Results of complexity value determinations are presented in Table 2. Note that the spectrum of procedures for which complexity estimates were obtained is much broader than that for which "skin to skin" times were available and for which relative values were subsequently calculated.

A methodologic issue here is whether or not physicians were able to hold time constant when they provided estimates of the complexity of procedures. Figure 1 shows that with a few exceptions there was a close correlation between "skin to skin" time and complexity per unit of time. When asked directly about this relationship, most surgeons indicated that the high degree of correlation between these two variables reflects the true nature of surgical practice; procedures that require more complexity per unit of time also take longer. Others pointed to fatigue as an element contributing to the correlation between time and complexity; as operating time increases, the intensity of effort or concentration required also increases. Pre- and post-operative care, on the average, represents the same complexity per unit of time as routine office visits, which equal 1.0.

Investment in Professional Training

The length of time a physician spends in training varies widely from one specialty to another, ranging from one year of postdoctoral training for a general practitioner to seven years for a neurosurgeon or thoracic surgeon (Wechsler, 1976). Earnings foregone during the training period are estimated by applying the principles of human capital theory in which the opportunity cost of a training [1] is calculated and amortized over the working lifetime of a physician. The assumption is that each specialty should earn the same rate of return on its investment in training.

Physicians who undertake residency training programs beyond a single year of internship incur yearly positive opportunity costs equal to the difference in salaries between that of a practicing general practitioner and a resident. The sum of opportunity costs taken over the duration of residency programs can be expressed by:

$$Y=\sum_{t=1}^{a} X_t\,(1+r)^{a-t},\ (t=1,\ldots,a)$$

where X_t = (GP net earnings$_t$ − resident salary$_t$) for a given year

r=interest rate

a= number of years of residency program

t=counter for number of years from the beginning of residency.

[1] The opportunity cost of a training refers to the direct expenses involved in getting the training (tuition, books, etc.) plus the earnings lost during the time the physician was in school.

The opportunity cost amortized over the working lifetime can be expressed as:

$$\delta=\left[\frac{(1+r)^{n-a}-1}{r(1+r)^{n-a}}\right]^{-1}\left[\sum_{t=1}^{a} X_t(1+r)^{a-t}\right]$$

For an explanation of how this equation was derived, see Technical Note A at the end of this article.

To perform these calculations, data are needed on the lengths of residency training programs for different specialties, career lifetimes in medicine, resident salaries, and net income by specialty including the relationship of incomes to the length of time in practice.

Lengths of residency training requirements by specialty are based on the actual specialty Board requirements (Wechsler, 1976). The mean working career for physicians from the end of the first year of post-graduate education (internship) was estimated from two sources to be 41 years (Goodman, 1975; Li, 1968). Important differences may exist, however, between the peak earning periods of different specialties. Using, as a criterion, the period during which a physician is expected to earn at least 75 percent of the average of all physicians in his specialty, a Canadian report indicates the peak working career for a general practitioner to be 38 years, an ophthalmologist 37 years, a general surgeon 32 years, a urologist 28 years, and a cardiovascular surgeon 27 years (Korcok, 1975). It is not known whether these differences result from the greater physical and mental demands of some specialties or from the greater ability of some specialists to achieve financial security at an earlier age. Given this uncertainty, we assumed in this analysis that the working careers of different specialists are of equal length.

Salaries for first year residents in 1975 averaged $11,914 (Directory of Approved Residencies, 1975-76). For later years of residency, it was asumed that salaries of residents increased at the rate of 15 percent per year (Salary$_t$ = 11,914 × (1.15)^t). Medical salaries by specialty and increases in salary by length of practice were available from surveys performed by *Medical Economics* (Owens, 1976; Jeffers, 1967). Earnings of general practitioners (GP) were used to calculate residents' opportunity costs. Earnings estimates for GPs by the length of time in practice were obtained for 1975 by assuming linearity for step functions with time between 1965 and 1975.

Estimates of the annual differential amount due specialists based on opportunity costs incurred during years of training following internship are presented in Table 3, assuming that the average working career following internship is 41 years. Results, by the number of years of training, are presented for 7 percent and 10 percent rates of interest. These figures imply that, for full-time practitioners, an internist who has two additional years of training beyond internship should receive an annual increment in income of $4,000 over a GP, if the rate of return is seven percent; a general surgeon, who spends four additional years in training, should receive $8,300 more per year. These increments, obviously, could be used to adjust hourly reimbursement rates as well as annual income. Because the number of hours worked per week and number of weeks worked per year varies little, at least

TABLE 2

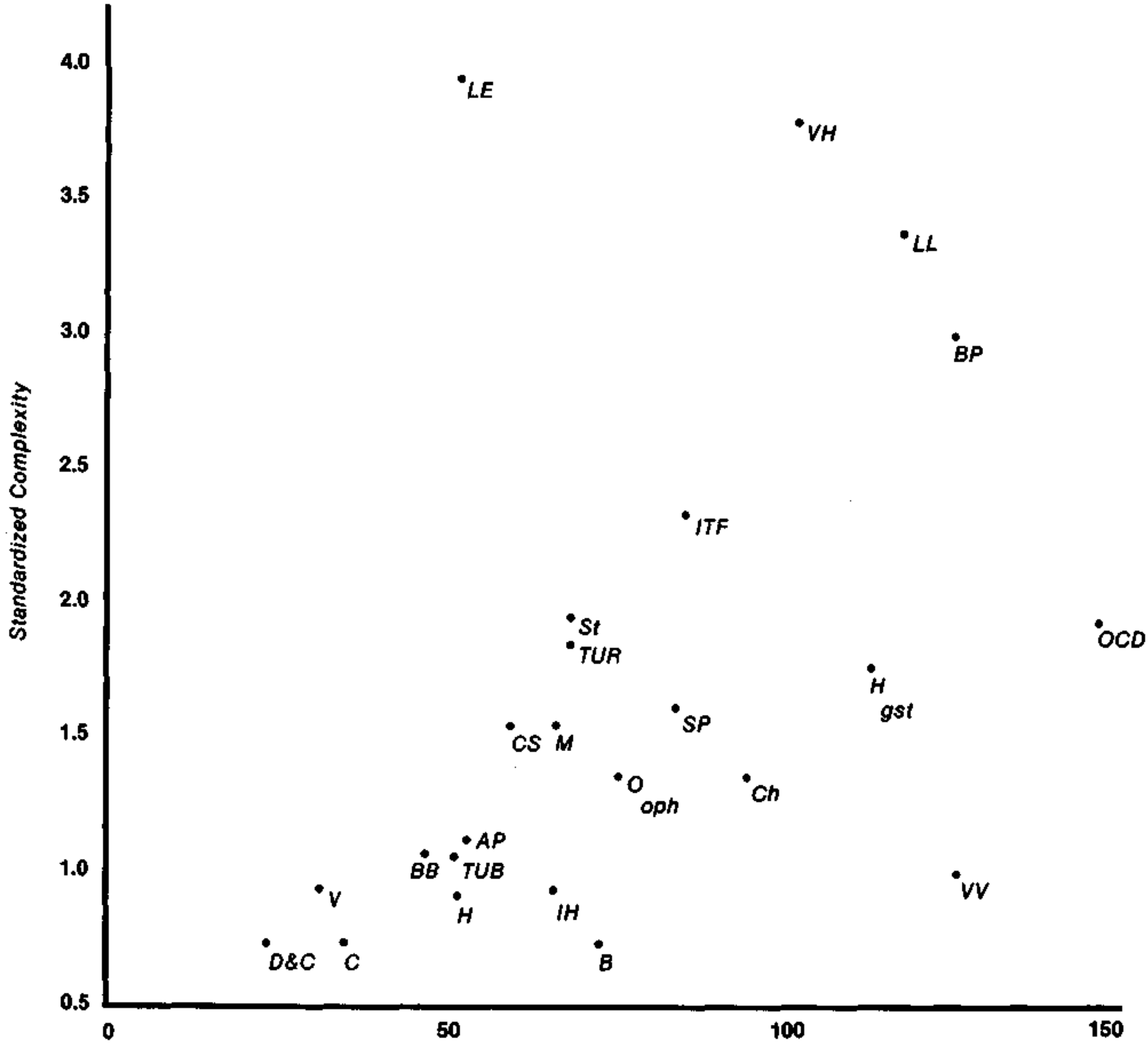
Relative Complexity of Surgical Procedures and Initial Office Visits By Specialty

Specialty	Procedure	Complexity/ Unit Time	Relative Complexity	Standardized Relative Complexity[1]
General Surgery	Excision and ligation of varicose veins	47	1.0	1.0
	Hemorrhoidectomy	56	1.2	1.2
	Inguinal hernia repair, except recurrent	58	1.2	1.2
	Initial office visit	62	1.3	1.3
	Excision biopsy of breast	62	1.3	1.3
	Appendectomy	65	1.4	1.4
	Cholecystectomy	78	1.6	1.6
	Modified radical mastectomy	102	2.2	2.2
	Cholecystectomy with common duct exploration	103	2.2	2.2
	Pyloroplasty and vagotomy	120	2.5	2.5
	Total gastrectomy	149	3.1	3.1
	Left colectomy with coloproctostomy	172	3.6	3.6
	Complete colectomy with combined abdomino-perineal resection	190	4.0	4.0
	Parathyroid exploration, initial	191	4.0	4.0
Obstetrics and Gynecology	Initial office visit—obstetrics	40	1.0	1.0
	Diagnostic D & C	41	1.0	1.0
	I & D Bartholin cyst	44	1.1	1.0
	Excision biopsy of breast	70	1.7	1.3
	Normal delivery	70.8	1.7	1.3
	Initial office visit—gynecology	76	2.1	1.3
	Laporoscopy and tubal ligation	83	2.0	1.4
	Oophorectomy, unilateral	100	2.5	1.6
	Caesarian section	124	3.1	1.8
	Marshall-Marchetti operation	131	3.2	1.8
	Abdominal hysterectomy, total	146	3.6	2.0
	Modified radical mastectomy	262	6.4	3.1
	Vaginal hysterectomy, total	333	8.2	3.8
	Abdominal hysterectomy, radical	360	8.9	4.0
Ophthalmology	Chalazion	18	1.0	1.0
	Initial office visit	20	1.1	1.0
	Enucleation	55	3.1	1.7
	Peripheral iridectomy	79	4.5	2.1
	Strabismus correction	85	4.8	2.2
	Filtering procedure	147	8.3	3.4
	Lens extraction, intracapsular	180	10.2	4.0
Orthopedics	Bunionectomy	63	1.0	1.0
	Initial office visit	78	1.2	1.4
	Meniscectomy	91	1.4	1.8
	B/K amputation	102	1.6	2.2
	Triple arthrodesis	108	1.7	2.4
	Intertrochonteric fracture of femur with internal fixation	116	1.8	2.6
	Bankhart procedure	128	2.0	3.0
	Lumbar laminectomy	141	2.2	3.4
	Total hip replacement	164	2.6	4.0
Urology	Initial office visit	39	1.0	1.0
	Vasectomy	52	1.3	1.2
	Transurethral bladder surgery—tumors 0.5cm—2.0cm	56	1.4	1.3
	Ureterolithotomy	89	2.3	1.9
	Suprapubic prostatectomy	92	2.3	1.9
	TURP	104	2.7	2.1
	Pyelolithotomy	110	2.8	2.2
	Pyeloplasty	118	3.0	2.3
	Complete nephrectomy	120	3.1	2.4
	Radical nephrectomy	159	4.1	3.1
	Nephrotomy for staghorn calculus	199	5.1	3.7
	Radical cystectomy with ileal loop	212	5.4	4.0

[1] Standardized relative complexity is computed by standardizing the range of complexity to 1.0 to 4.0.

Figure 1
"Skin to Skin" Time

Complexity Per Unit Time vs. "Skin to Skin" Time



Note: "Skin to Skin" time is compared to estimates of complexity per unit of time for selected surgical procedures. Abbreviations: D&C = diagnostic dilation and curretage; V = vasectomy; C = chalazion; BB = breast biopsy; Ap = appendectomy; TUB = transurethral bladder surgery; H = hemorrhoidectomy; LE = lens extraction; CS = Caesarian section; M = meniscectomy; IH = inguinal hernia repair; TUR = transurethral resection of the prostate; St = strabismus correction; B = bunionectomy; Ooph = unilateral oophorectomy; SP = suprapubic prostatectomy; ITF = intertrochanteric fracture of the femur; Chol = cholecystectomy; VH = vaginal hysterectomy; Hyst = abdominal hysterectomy; LL = lumbar laminectomy; BP = Bankhart Procedure; VV = varicose vein stripping; CCD = cholecystectomy with common duct exploration.

Table 3

Annual Differential in Income Due to the Opportunity Costs of Additional Years of Residency Training Based on 1975 Median Incomes

a	$GP	$Resident	$GP_t - $Res_t	$Y @ 7%	$Y @ 10%	(n—a)	d @7%	d @ 10%	Factor for differential years of training @ 7%	Factor for differential years of training @ 10%
1	37912	11914	25998	25998	25998	40	1950	2660	1.05	1.07
2	38944	13701	25243	53061	53841	39	4001	5519	1.10	1.14
3	39976	15756	24220	80995	83445	38	6139	8570	1.15	1.21
4	41008	18120	22888	109553	114677	37	8348	11812	1.20	1.29
5	42040	20838	21202	138423	147347	36	10617	15221	1.25	1.36
6	43072	23963	19109	167222	181190	35	12910	18789	1.30	1.44

a=years of training after internship.
n=years of active career lifetime after internship.
$GP=expected income after "a" years of practice (1975 figures).
$Resident=expected resident income after "a" years of residency (1975 figures).
$Y=total opportunity costs over the duration of residency at 7% and 10% discount rates.
d=differential annual income after "a" years of training at 7% and 10% discount rates.

between internists, general surgeons, and GPs (NCHSR and AMA, 1973), no correction to standardize for number of hours worked was considered necessary.

Overhead Expenses of Practices

Variations from specialty to specialty in the legitimate expenses of running a practice also need to be reflected in the prices of services rendered. These expenses include office payroll, office space costs, malpractice premiums, drugs and medical supplies, and depreciation on medical equipment. We assumed that overhead expenses are spread equally over all services performed.

Overhead expenses in dollars and as a percent of gross receipts, by specialty, were obtained from *Medical Economics* (Owens, 1977). Of surgical specialties, figures were available only for general surgery and obstetrics and gynecology. The assumption was made that expenses for other specialties under consideration—ophthalmology, orthopedics and urology—were the average of those for general surgery and OBG. To adjust for differences in overhead between general practitioners and other specialties, a standardized factor calculated as $\frac{1-P_{GP}}{1-P_{spec}}$ where P_{GP} and P_{spec} represent overhead expenses as a proportion of gross receipts for a GP and a given specialist, respectively. The resulting overhead expense factors are shown in Table 4.

Construction of a Relative Value Scale—Two Methods

Multiplicative Model

The value of each procedure or service is the multiplicative function of time, complexity per unit of time, and factors representing differences between specialties in the opportunity costs of training and differences in overhead expenses between a general practitioner and a given specialty.

The value of a given procedure, then, equals (T) × (C) × (OC) × (O) where:

T is the mean "skin to skin" time or office visit time in minutes;
C is the standardized relative complexity of the procedure per unit time;
OC is the amortized opportunity cost of years of training in a specialty beyond internship expressed as a percent of the expected income for a GP who has been in practice for a number of years equal to the duration of the specialty residency training program:

$$OC = \frac{\text{GP income} + \text{total opportunity costs}}{\text{GP income}}$$

O is a standardized factor that adjusts for differences in overhead expenses between general practitioners and given specialties.

Principal Component Analysis

An alternative way to compute relative values is to weight the resource cost variables before combining them. To accomplish this, principal component analysis was applied to the time and complexity variables. The resulting factor scores were then adjusted for interspecialty differences in the opportunity costs of training and overhead expenses by multiplying by the appropriate standardized factors.

Because we are interested in the ratios, rather than the differences between procedures, a multiplicative model was chosen.

The factors derived from the principal component analysis are:

$$Y_K^M = \left[\frac{X_{1k}}{S_{x1}}\right]^{w_1}\left[\frac{X_{2k}}{S_{x2}}\right]^{w_2}$$

The deviation of the Y_K^M is explained in Technical Note B. The value, Y_K^M, was multiplied by the correction factors for opportunity costs (OC) and over-

Table 4

Relative Values of Selected Surgical Procedures Based on Resource Costs Using 'Skin to Skin' Time as the Measure of Professional Time Commitment and the Multiplicative Model for Combining Components

Specialty	Procedure	Mean Time (T)	Com-plexity Factor (C)	Oppor-tunity Cost Factor (OC)	Over-head Expenses Factor (O)	(T)×(C)× (OC×(O)	Relative Value (with Inguinal Hernia Repair Stand-ardized =1.0)
General Surgery	Excision and ligation of varicose veins	125.8	1.0	1.20	.90	135.9	1.6
	Hemorrhoidectomy	50.6	1.2	1.20	.90	65.5	0.8
	Inguinal hernia repair	65.7	1.2	1.20	.90	85.2	1.0
	Excision biopsy of breast	44.6	1.3	1.20	.90	62.6	0.7
	Appendectomy	52.2	1.4	1.20	.90	78.9	0.9
	Cholecystectomy	94.5	1.6	1.20	.90	163.3	1.9
	Cholecystectomy with common duct exploration	145.8	2.2	1.20	.90	346.5	4.1
Obstetrics/ Gynecology	Diagnostic D&C	23.5	1.0	1.15	.94	25.5	0.3
	Excision biopsy of breast	44.6	1.3	1.15	.94	63.0	0.8
	Oophorectomy, unilateral	75.0	1.6	1.15	.94	130.2	1.5
	Caesarian section	59.3	1.8	1.15	.94	115.8	1.4
	Abdominal hysterec-tomy, total	112.3	2.0	1.15	.94	243.8	2.9
	Vaginal hysterectomy with A&P repair	101.8	3.8	1.15	.94	419.6	4.9
Ophthalmology	Chalazion	33.2	1.0	1.15	.92	35.1	0.4
	Strabismus correction	67.9	2.2	1.15	.92	158.4	1.9
	Lens extraction, intracapsular	51.6	4.0	1.15	.92	218.4	2.6
Orthopedics	Bunionectomy	71.7	1.0	1.15	.92	76.1	0.9
	Menisectomy	64.4	1.8	1.15	.92	123.0	1.4
	Intertrochanteric fracture of hip with internal fixation	93.7	2.6	1.15	.92	258.4	3.0
	Bankhart procedure	125.3	3.0	1.15	.92	398.8	4.7
	Lumbar laminectomy	119.3	3.4	1.15	.92	430.2	5.0
Urology	Cystoscopy, diagnostic	29.0	1.0	1.20	.92	32.1	0.4
	Vasectomy	30.7	1.2	1.20	.92	40.8	0.5
	Transurethral bladder surgery	50.5	1.3	1.20	.92	72.6	0.9
	Suprapubic prostatec-tomy	84.3	1.9	1.20	.92	177.3	2.1
	Transurethral resection of prostate	68.3	2.1	1.20	.92	158.7	1.9

head expenses (O) to obtain the relative value index of surgical procedures:

$$RV = (Y_K^M) \times (OC \times (O).$$

Results

Resource Cost Relative Values (RCRV)

The relative values of selected surgical procedures based on resource costs were first calculated using "skin to skin" time as the measure of professional time commitment ($RCRV_S$), and then calculated again after estimates of time spent in pre- and post-operative care were incorporated ($RCRV_T$). Results derived from "skin to skin" time using the multiplicative model are presented in Table 4, and equivalent results derived from total time are presented in Table 5. All values are standardized to inguinal hernia repair, which is assigned a value of 1.0. Comparison of results from the multiplicative model and principal component analysis are shown in Table 6.

Comparison of Resource Cost Relative Values to the California Relative Value Study (CRVS) Values

As can be seen in Table 5, there is only approximate agreement between RCRV and CRVS values which have been standardized to inguinal hernia repair; agreement is within 33 percent (ratio between 0.70 and 1.30) for 17 of 20 or 85 percent of the procedures. Procedures outside this range, in general, are at the extremes of the scale (RCRV≤0.4 or ≥2.9).

Table 5

Resource Costs Relative Values Compared to California Relative Value Study (CVRS) Values: Valuation of Time Spent in Pre- and Post-Operative Care Included

Procedure	(A) CRVS (1969) Unit Value	(A) CRVS (1969) Relative Value[1]	(B) Resource Cost[1] Relative Value ($RCRV_T$)	A/B	Rank Order CRVS (1969)	Rank Order Resource Costs
Chalazion	1.2	0.1	0.6	0.17	1	1
Vaginal hysterectomy with A-P repair	18.0	2.0	3.0	0.67	16	19
Bankhart procedure	19.0	2.1	. .	. . .	. .	. .
Cholecystectomy with common duct exploration	17.0	1.9	2.7	0.70	15	18
Cystoscopy, diagnostic	2.0	0.2	. .	. . .	. .	. .
Lumbar laminectomy	26.0	2.9	3.2	0.91	20	20
Abdominal hysterectomy, total	16.0	1.8	2.0	0.90	14	17
Hemorrhoidectomy	4.8	0.5	0.9	0.56	3	3
Intertrochanteric fracture of femur with internal fixation	20.0	2.2	. .	. . .	. .	. .
(OBG) Excision biopsy of breast	5.0	0.6	. .	. . .	. .	. .
Transurethral bladder surgery	6.0	0.7	1.0	0.70	4	4
Caesarian section	10.0	1.1	1.2	0.92	7	8
Vasectomy	3.6	0.4	. .	. . .	. .	. .
Lens extraction, intracapsular	20.0	2.2	1.7	1.29	17	15
Oophorectomy, unilateral	12.0	1.3	1.2	1.08	9	8
Excision and ligation of varicose veins	12.0	1.3	1.3	1.00	9	11
Cholecystectomy	14.5	1.6	1.6	1.00	11	13
Strabismus correction	14.0	1.6	1.3	1.23	11	11
(GS) Excision biopsy of breast	5.0	0.6	. .	. . .	. .	. .
Bunionectomy	7.0	0.8	1.0	0.80	5	4
Suprapubic prostatectomy	20.0	2.2	1.8	1.22	17	16
Inguinal hernia repair	9.0	1.0	1.0	1.0	6	4
Menisectomy	14.0	1.6	1.2	1.33	11	8
Transurethral resection of prostate	20.0	2.2	1.6	1.38	17	13
Appendectomy	9.5	1.1	1.0	1.10	7	4
Diagnostic D&C	4.0	0.4	0.6	0.67	2	1

[1] All values standardized to inguinal hernia repair=1.0.

Table 6

Relative Values Based on Resource Costs: Multiplicative Model Compared to Principal Component Analysis Model (skin to skin time only)

Specialty	Procedure	(A) Principal Components Analysis Relative Value of Inguinal Hernia Repair =1.0	(B) Multiplicative Model Relative Value of Inguinal Hernia Repair =1.0	A/B
General Surgery	Excision and ligation of varicose veins	1.2	1.6	0.8
	Hemorrhoidectomy	0.9	0.8	1.1
	Inguinal hernia repair	1.0	1.0	1.0
	Excision biopsy of breast	0.9	0.7	1.3
	Appendectomy	1.0	0.9	1.1
	Cholecystectomy	1.4	1.9	0.7
	Cholecystectomy with common duct exploration	2.0	4.1	0.5
Obstetrics/Gynecology	Diagnostic D&C	0.6	0.3	2.0
	Excision biopsy of breast	0.9	0.8	1.1
	Oophorectomy, unilateral	1.2	1.5	0.9
	Caesarian section	1.2	1.4	0.9
	Abdominal hysterectomy, total	1.7	2.9	0.6
	Vaginal hysterectomy with A&P repair	2.3	4.9	0.5
Ophthalmology	Chalazion	0.7	0.4	1.8
	Strabismus correction	1.3	1.9	0.7
	Lens extraction, intracapsular	1.6	2.6	0.6
Orthopedics	Bunionectomy	1.0	0.9	1.1
	Menisectomy	1.2	1.4	0.9
	Intertrochanteric fracture of hip with internal fixation	1.7	3.0	0.6
	Bankhart procedure	2.1	4.7	0.5
	Lumbar laminectomy	2.3	5.0	0.5
Urology	Cystoscopy, diagnostic	0.7	0.4	1.8
	Vasectomy	0.7	0.5	1.4
	Transurethral bladder surgery	1.0	0.9	1.1
	Suprapubic prostatectomy	1.4	2.1	0.7
	Transurethral resection of prostate	1.4	1.9	0.8

Possible explanations for the observed differences between RCRV and CRVS values are many. Differences in the definitions of surgical procedures between the SOSSUS and CRVS; difficulties in obtaining reliable estimates of complexity of surgical procedures per unit of time; and the lack of empirical data on time spent by surgeons in pre- and post-operative care all are clear limitations of our resource cost methodology. On the other hand, there is no reason to believe that CRVS values, based as they are on market prices, would necessarily reflect more accurately the resource costs. In particular, it appears that the CRVS does not recognize differences in the complexity of procedures over and beyond that reflected in operative time.

Comparison of Resource Cost Relative Values to Prevailing Medicare Charges and to California Relative Value Scale Values

Table 7 compares resource cost relative values to prevailing Medicare charges and CRVS values for those commonly performed surgical procedures for which charge data were available. The prevailing charges are for Massachusetts in 1978 and apply to specialists located in urban areas (HCFA, 1978). To facilitate comparisons, charges were converted to relative values standardized to inguinal hernia repair. In general, agreement between all three scales is extremely close for these selected procedures. The higher relative values for several procedures when "skin to skin" time alone is used ($RCRV_S$) disappear when estimates of pre- and post-operative time are incuded ($RCRV_T$).

Table 7

Resource Cost Relative Values Compared to Prevailing Medicare Charges And the Relative Value Study Values [1]

Surgical Procedure	Prevailing Medicare Charges (1978)[2] $	Prevailing Medicare Charges (1978)[2] Relative Value	$RCRV_S$[3]	$RCRV_T$[4]	CRVS[5]
Hemorrhoidectomy	271	0.8	0.8	0.9	0.5
Inguinal hernia repair	339	1.0	1.0	1.0	1.0
Appendectomy	339	1.0	0.9	1.0	1.1
Cholecystectomy	570	1.7	1.9	1.6	1.6
Hysterectomy	640	1.9	2.9	1.9	1.8
Lens extraction	678	2.0	2.6	1.7	2.2
Cystoscopy, diagnostic	68	0.2	0.4	. . .[6]	0.2
Suprapubic prostatectomy	720	2.1	2.1	1.8	2.2
Transurethral prostatic resection	678	2.0	1.9	1.6	2.2

[1] All values standardized to inguinal hernia repair at 1.0.
[2] Data on prevailing charges were available only for the procedures listed. Figures are for Massachusetts in 1978 and apply to specialists located in urban areas.
[3] Uses "skin to skin" time as the measure of physician time commitment.
[4] Incorporates both "skin to skin" time and estimates of time spent in pre- and post-operative care.
[5] California Relative Value Study (1969) values.
[6] Not calculated because no length of stay data available. Often done on an ambulatory basis.

Relative Values of Office Visits Based on Resource Costs

Interspecialty comparisons of the values of initial complete office visits are presented in Table 8. It was assumed that, regardless of specialty, an initial visit requires 30 minutes of a physician's time. Complexity factors for the surgical specialties were provided by the physicians interviewed; complexity for the medical specialties was assumed to be the average of those for surgical specialties. Relative to a general practitioner, values for initial office visits range from 0.9 for obstetrics and urology to 1.2 for an internal medicine subspecialty, general surgery, gynecology, and orthopedics. On this basis, values for follow-up visits, assuming a 15-minute duration and a complexity of 1.0, would range from 0.4 for a general practitioner to 0.6 for an internist with a subspecialty.

Table 9 presents values of initial and routine office visits relative to surgical procedures.

For comparisons between office visits and surgical procedures to be valid, account must be taken of the surgeon's effort in providing pre- and post-operative care as well as that in actually performing the operation. Hence, resource cost relative values represent the estimated total time commitment by surgeons. On this basis, values of initial office visits relative to inguinal hernia repair range from 0.17 for ophthalmology to 0.24 for orthopedics with a mean of 0.21. The relative value of a routine office visit for a general practitioner is 0.08; for all specialists it is 0.09.

Table 8

Interspecialty Comparisons of the Values of Initial Office Visits Based on Resource Costs

Specialty	Time (T)	Complexity Factor (C)	Opportunity Cost Factor (OC)	Overhead Factor (O)	(T)×(O)× (OC)×(O)	Values Relative To GP=1.0
General Practice	30[1]	1.2[2]	1.0	1.0	36	1.0
Internal Medicine	30	1.2[2]	1.1	0.97	38.4	1.1
Internal Medicine (sub-specialty)	30	1.2[2]	1.2	0.97	41.9	1.2
General Surgery	30	1.3	1.2	0.90	42.1	1.2
Obstetrics	30	1.0	1.15	0.94	32.4	0.9
Gynecology	30	1.3	1.15	0.94	42.4	1.2
Ophthalmology	30	1.0	1.15	0.92	31.7	0.9
Orthopedics	30	1.4	1.15	0.92	44.5	1.2
Urology	30	1.0	1.2	0.92	33.1	0.9

[1] Assumed time required for an average initial office visit.
[2] The average of estimates for surgical specialties was taken as the complexity factor for medical specialties.

Table 9

Values of Initial Office Visits Based on Resource Costs Relative To Surgical Procedures; By Specialty

Specialty	Initial Office Visit (T)×(C)×(OC)×(O)	Initial Office Visit Relative Value With Inguinal Hernia Repair =1.0	Routine Brief Office Visit (T)×(C)×(OC)×(O)	Routine Brief Office Visit Relative Value With Inguinal Hernia Repair =1.0
General Practice	36	0.19	15.0	0.08
Internal Medicine	38.4	0.21	16.0	0.09
Internal Medicine (sub-specialty)	41.9	0.23	17.5	0.09
General Surgery	42.1	0.23	16.2	0.09
Obstetrics	32.4	0.18	16.2	0.09
Gynecology	42.4	0.23	16.2	0.09
Ophthalmology	31.7	0.17	15.9	0.09
Orthopedics	44.5	0.24	15.9	0.09
Urology	33.1	0.18	16.6	0.09
Average for Specialists		0.21		0.09

Comparison Between the Resource Cost Relative Values of Office Visits and Prevailing Medicare Charges

Comparison of resource cost relative values of office visits to prevailing Medicare charges (Table 10) reveals two important findings. First, it appears that general practitioners are being under-remunerated relative to specialists. On the basis of prevailing charges there is a 30-40 percent differential while resource cost estimates indicate that a 10 percent differential would be more appropriate. Second, resource cost relative values suggest that office visits are undervalued relative to surgical procedures. When the reimbursement rate for inguinal hernia repair is applied to resource cost relative values, the charge for an initial office visit to a specialist rises from the prevailing rate of $34 to $71 and a routine visit from $15 to $31, more than two-fold increases. Alternatively, it may be that surgical rates are inflated by a factor of two.

Hourly Rates of Remuneration Implied by Prevailing Medicare Charges

Table 11 presents implied hourly rates of remuneration under three sets of assumptions: (1) "skin to skin" time only is valued; (2) estimates of time spent in pre- and post-operative care is valued at $60/hour; and (3) 40 percent of the value of a surgical procedure is ascribed to pre- and post-operative care.

For office visits in 1978, the general practitioner and specialist grossed $40 and $60-68 per hour, respectively. Corresponding rates for time spent in surgery depend on which assumption is accepted with regard to the value of pre- and post-operative care. When no adjustment is made for pre- and post-operative care, the hourly rate of remuneration ranges from $310 per hour for an inguinal hernia repair to $788 per hour for a lens extraction. When pre- and post-operative care is valued at $60 per hour, the range is from $193 per hour for a hemorrhoidectomy to $679 per hour for a lens extraction. Finally, when 40 percent of the value of a surgical procedure is ascribed to pre- and post-operative care, the hourly rate is $186 for an inguinal hernia repair and $473 for a lens extraction. Even under the most conservative assumption the time in surgery is remunerated at between three and seven times that in office practice, with wide variations between specialties. Likewise, marked differences exist between specialties and between procedures within a specialty.

Table 10

Relative Value of Office Visits Based On Resource Costs Compared to Prevailing Medicare Charges

Type of Visit	*Prevailing Medicare Charges* [1] $	*Prevailing Medicare Charges* [1] *Relative Value* [2]	Resource Cost Relative Value [2]	Projected $ Reimbursement If Prevailing Surgical Rates Applied [3]
Initial Complete Office Visit				
General Practitioner	$20	0.6	0.19	$64
Specialist	34	.10	0.21	71
Routine Brief Office Visit				
General Practitioner	10	.03	0.08	27
Specialist	15	.04	0.09	31

[1] Medicare charges are for Massachusetts in 1978 and apply to physicians located in urban areas.
[2] All relative values are standardized to inguinal hernia repair=1.0.
[3] Assumes the prevailing Medicare rate for an inguinal hernia repair ($339) is applied to office visits. Figures rounded to nearest dollar.

Table 11

Hourly Rates of Remuneration Implied by Prevailing Medicare Charges

Surgical Procedures	Prevailing Medicare Charges [1] (dollars)	Time in Minutes [2]	Dollars per hour in surgery [3]: No Adjustment	Estimated Time [4]	40% of value
Hemorrhoidectomy	271	50.6	322	193	193
Inguinal hernia repair, unilateral	339	65.7	310	218	186
Appendectomy	339	52.2	390	272	234
Cholecystectomy	570	94.5	362	275	217
Hysterectomy	640	112.3	342	279	205
Lens extraction	678	51.6	788	679	473
Suprapubic prostatectomy	720	84.3	512	399	307
TURP	678	68.3	596	475	358
Office Visits					
General Practitioner					
Initial	20	30[5]	40		
Routine Brief	10	15	40		
Specialist					
Initial	34	30	68		
Routine Brief	15	15	60		

[1] Massachusetts, (1978).
[2] Study of Surgical Specialties in the U.S.
[3] Adjusted for the proportion of total charge ascribed to pre- and post-operative care.
[4] Adjusted by valuing the estimated time in pre- and post-operative care at $60/hour.
[5] Estimates which appear to be reasonable in light of data from the National Ambulatory Medical Care Survey: 1975 Summary.

Discussion

In the absence of a competitive market, alternatives to market mechanisms must be explored for setting the prices of medical services relative to one another. This need is particularly critical in the face of national health insurance proposals that aim to further reduce competition by centralizing decisions both with regard to the scope of coverage and the levels of reimbursements to be provided. This study demonstrates that analyzing the resource costs of medical services is feasible and could provide the basis for determining the values of medical and surgical services. The goal of such a relative value scale would be to ensure equitable reimbursement both for different services rendered by a given specialty and for services rendered by different specialties. An agency such as HCFA could then convert these relative values to dollar reimbursements by applying conversion factors tailored to geographical differences in the cost of living or to other policy considerations.

Methodologic Considerations

This study has emphasized the average time it takes a physician to provide a given service and the intensity or complexity of effort involved. Adjustments for interspecialty differences in the opportunity costs of training and overheard expenses were then made.

Time

Time is a universal measure of the value of human services and has the advantage of being subject to objective measurement. There can be little question of its importance as a resource cost. The time estimates we have used for intraoperative or "skin to skin" time and for initial and routine office visits were derived empirically in a large, well-organized study of surgical services in the United States, and these estimates appear to be reliable. Pre- and post-operative care is also critical to the successful outcome of surgery, however. Here the paucity of empirical data is striking, and our estimates of pre- and post-operative time involvement by the surgeon could be too high for some procedures and too low for others. Clearly, systematic studies of pre- and post-operative periods of care should be performed.

It can be argued that our decision to use the *average time required* to perform a given operation or to provide a certain type of office visit has the potential disadvantage of inducing physicians to avoid or to refer the difficult patient whose operation or diagnostic evaluation might take longer than average. Conversely, services provided in the tertiary care referral center, which routinely accepts such patients, would be undervalued. A flexible policy toward supplementing reimbursement for the well-documented and unusually complex case would help to answer this objection.

Complexity Per Unit of Time

The complexity of a service, though much more subjective in its estimation than time, is no less important in determining its relative value. There can be little argument that the skills or intensity of effort required by different medical and surgical services vary, and though complex procedures usually take longer, exceptions exist. For example, extraction of a lens requires less than an hour to perform but requires a high degree of manual dexterity and intense concentration. Conversely, varicose vein stripping is a relatively simple though lengthy procedure. Most would argue, and certainly current reimbursement schedules indicate, that lens extraction should be accorded a higher value despite its brevity.

Adjustment of the value of time for differences in its complexity would seem, therefore, to be essential. The challenge is to assess this parameter reliably. The direct scaling techniques used in this study have been widely applied in other utility assessments[2] (Johnson and Huber, 1977). The uniformity of the rank orders of procedures by complexity obtained from different surgeons within individual specialties was remarkable. This suggests that complexity can be reliably evaluated.

However, our estimates pose at least two problems: First, the sample of physicians from which they were obtained was both small and non-random. There is no reason to think, however, that responses were systematically biased unless physicians in Massachusetts see the world differently from their peers elsewhere.

Second, there is the possibility that estimates of complexity per unit of time are confounded by the inability of physicians to dissociate this measure from total operative time. Certainly, the indication is that "skin to skin" time and complexity are closely correlated (Figure 1). In an effort to mitigate this potential problem, time and complexity were combined by principal component analysis before opportunity cost and overhead factors were applied. These results are shown in Table 5.

Therefore, the major issues to be explored in future research are: (1) to validate our results in a more representative group of physicians, (2) to explore the question of whether different surgical specialties, as we assumed, really perform procedures with like spectrums of complexity and (3) to better define the extent to which the value of time should be adjusted for complexity. Is 4 to 1, 2 to 1, or some other number the appropriate range?

Opportunity Costs

The opportunity costs of training and overhead expenses of practice were incorporated into the determination of relative values to reflect systematic differences that exist between specialties. The thesis that the rate of return on investment in training should be the same between specialties seems undeniable.

Selection of the appropriate discount rate is hotly debated by economists. A change in the discount rate used to calculate the opportunity costs for investment in training from 7 percent to 10 percent would increase the differential in relative values between specialties by approximately two percent per additional year of training, but the relationship between procedures within a specialty would not be affected.

Major Findings

Among one-half of the surgical procedures studied, relative values for surgical procedures determined from resource costs are not greatly different from those of the California Relative Value Study or from current Medicare charges. There are significant differences in the other half of the surgical procedures studied, however dramatic differences are also demonstrated when surgical procedures are compared to office visits. On the basis of resource costs, the value of an initial diagnostic office visit to a specialist should be 21 percent that of an inguinal hernia repair; on the basis of prevailing charges it is only 10 percent, a more than two-fold discrepancy. After standardizing the variations in complexity among different procedures, the prevailing Medicare charges, expressed in terms of standardized hourly rates of reimbursement, range from $40 per hour for a general practitioner to more than $180 per hour for an ophthalmologist performing a lens extraction, even after making conservative adjustments for time spent in pre- and post-operative care. General surgeons, by comparison, tend to average between $150 and $200 per operating room hour for the surgical procedures examined. The question has to be raised as to whether these differences are justified and, if so, on what basis.

Policy Implications of a Relative Value System Based on Resource Costs

Resource cost relative values have the advantage over market prices in that they can be derived by an explicit process that is open to examination. Inequities within specialties and between specialties, therefore, can be readily identified and corrected. As changes in technology or the efficiency of medical providers occur, values can be adjusted, and when new procedures are developed, then can be equitably valued. Because relative values are converted into dollar reimbursements only after application of a conversion factor, the process of relative value determination, fundamentally a professional issue, can be separated from various policy issues. The appliction of financial incentives to induce redistribution of physicians among specialties or to encourage physicians to move to relatively under-served geographic areas of the country could operate primarily through control of the conversion factor. If, for example, it was felt that there were too many surgeons in one subspecialty and too few primary physicians, the appropriate federal agency could adjust the fees charged by each as a financial incentive until such time as the desired distribution between the specialties was achieved.

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[2] Utility is a measurement of the level of satisfaction people obtain by consuming certain commodities or services.

Policy decisions to control increases in the costs of physician services, likewise, coul be achieved through the combination of utilization review and adjustment of the conversion factor used for relative values.

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Technical Note A

The sum of opportunity costs taken over the duration of residency programs can be expressed by:

$$Y=\sum_{t=1}^{a} X_t(1+r)^{a-t},\ (t=1,\ldots,a) \tag{1}$$

where X_t = (GP salary$_t$ − resident salary$_t$) for a given year

r=interest rate or discount rate
a=number of years of residency program
t=counter for number of years from the beginning of residency.

Amortization of (Y) over the career lifetime provides an estimate of how much more a specialist should be paid per year than a GP to compensate him for his foregone earnings. Assuming that the differential to be paid is constant over time, the following equation can be solved for an estimate of its magnitude:

$$Y=\sum_{b=1}^{n-a}\frac{\delta}{(1+r)^b},\ (b=1,\ldots,(n-a)) \tag{2}$$

where n = career lifetime from the beginning of residency

δ=the differential amount to be paid to specialists per year
b=counter for number of years from the completion of residency.

Rearranging (2) leads to:

$$\delta=\left[\sum_{b=1}^{n-a}\frac{1}{(1+r)^b}\right]^{-1}Y,\ (b=1,\ldots,(n-a)) \tag{3}$$

An expression for the series sum in the brackets is:

$$\sum_{b=1}^{n-a}\frac{1}{(1+r)^b}=\frac{(1+r)^{n-a}-1}{r(1+r)^{n-a}} \tag{4}$$

Equation (3) can be rewritten:

$$\delta=\left[\frac{(1+r)^{n-a}-1}{r(1+r)^{n-a}}\right]^{-1}\left[\sum_{t=1}^{a}X_t(1+r)^{a-t}\right] \tag{5}$$

Technical Note B

Principal Component Analysis

First, a log transformation of data was performed:

$$m_{jk}=\log\left(\frac{x_{jk}}{s_{xj}}\right)\text{ where: } \begin{matrix} j=1,2 \\ k=1\ldots n\end{matrix} \tag{1}$$

The resultant values were standardized and the factor score, f_1, was obtained as:

$$f_{1k}=b_{11}\left(\frac{m_{1k}-m_1}{s_{m1}}\right)+b_{21}\left(\frac{m_{2k}-m_2}{s_{m2}}\right)$$
$$=\left(\frac{b_{11}}{s_{m1}}\right)m_{1k}+\left(\frac{b_{21}}{s_{m2}}\right)m_{2k}-\underbrace{\left(\frac{b_{11}m_1}{s_{m1}}+\frac{b_{21}m_2}{s_{m2}}\right)}_{c} \tag{2}$$

$$f_{1k}=v_1m_{1k}+v_2m_{2k}-c \tag{3}$$

(where v_j, the weight, $=\frac{b_{j1}}{s_{mj}}$) and k=1 . . . . n)

If we divide both sides of the equation by (v_1+v_2) and denote $v_j/(v_1+v_2)=w_j$ and $C/(C_1+C_2)=-c'$, we then have:

$$\frac{f_{1k}}{v_1+v_2}=w_1m_{1k}+w_2m_{2k}+c'$$
$$=w_1\log\frac{x_{1k}}{s_{x1}}+w_2\log\frac{x_{2k}}{s_{x2}}+\log c''\text{ (where } c'=\log c''. \tag{4}$$

By taking exponentials we obtain:

$$\exp\left(\frac{f_{1k}}{v_1+v_2}\right)=c''\left(\frac{x_{1k}}{x1}\right)^{w1}\left(\frac{x_{2k}}{x2}\right)^{w2} \tag{5}$$

where c″ is a constant for all k=1, . . . , n. Both sides of the equation are divided by c″. The relative value, Y_k^M, thus becomes:

$$Y_k^M=\left(\frac{x_{1k}}{s_{x1}}\right)^{w1}\left(\frac{x_{2k}}{s_{x2}}\right)^{w2} \tag{6}$$

where $w_1+w_2=1$ and k=1, . . . n. The constraint $w_1+w_2=1$ has been imposed so that if both time and complexity for a certain procedure are multiplied by a constant, the relative value of that procedure will be also multiplied by the same constant.

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