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Abbreviations:

RVU = relative value unit
 SLIP = Seattle Lumbar Imaging Project

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Conventional Radiography, Rapid MR Imaging, and Conventional MR Imaging for Low Back Pain: Activity-based Costs and Reimbursement¹

PURPOSE: To incorporate personnel and equipment use time in an activity-based cost comparison of conventional radiography and conventional and rapid magnetic resonance (MR) imaging for low back pain (LBP).

MATERIALS AND METHODS: At each of four Seattle Lumbar Imaging Project (SLIP) sites, patients were randomized to undergo conventional radiography or rapid MR imaging of the lumbar spine. For sample SLIP patients and for similar non-SLIP patients undergoing conventional lumbar spine MR imaging as usual care in calendar year 2000, measured imaging room use and technologist and radiologist times were multiplied by costs per minute of standard equipment acquisition, personnel compensation, and related expenses. Resulting provider-perspective costs and Seattle area Medicare reimbursements for conventional MR imaging and radiography for calendar year 2001 were used to estimate future “normative” reimbursement for rapid MR imaging.

RESULTS: For 23 conventional radiography, 27 rapid MR imaging, and 38 conventional MR imaging examinations timed in calendar year 2000, all rapid MR imaging times exceeded those of conventional radiography but were less than those of conventional MR imaging. All 0.3- and 0.35-T MR imaging room and technologist times exceeded those for 1.5-T MR imaging. Average costs (in 2001 dollars) were \$44 for conventional radiography, \$126 for 1.5-T rapid MR imaging, \$128 for 0.3–0.35-T rapid MR imaging, \$267 for 1.5-T conventional MR imaging, and \$264 for 0.3–0.35-T conventional MR imaging. Conclusions regarding cost differences between conventional radiography and rapid MR imaging were robust to plausible parameter value changes evaluated in sensitivity analyses. Conventional radiography reimbursement was \$44. Applying the ratio of reimbursement (\$620) to costs (\$264–\$267) for conventional MR imaging to rapid MR imaging costs predicted reimbursement of \$292–\$300 for the new modality.

CONCLUSION: Times and costs for rapid MR imaging are roughly three times those for conventional radiography but about half those for conventional MR imaging for LBP. While current conventional radiography costs exceed reimbursement, current conventional MR and projected rapid MR imaging reimbursements exceed costs.

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After upper respiratory tract complaints, low back pain is the most common reason for symptom-driven physician visits in the United States (1). This common condition generates an estimated \$24 billion in direct health care costs and \$50 billion in total costs (2,3). As is consistent with current guidelines (4), conventional radiography of the lumbar spine is the major imaging modality used to evaluate low back pain. However, in patients presenting with low back pain, conventional radiography is not highly sensitive in the diagnosis of serious conditions of greatest concern, such as malignancy and infection (5). Conventional radiographs also do not enable detection of many degenerative causes of

low back pain or sciatica, including various forms of spinal stenosis and disk herniation with root compression.

As an alternative to conventional radiography, conventional magnetic resonance (MR) imaging is sensitive in the detection of tumors involving the axial skeleton (6) and mass lesions compressing the cauda equina (7). It also enables detection of important degenerative causes of back pain and sciatica, as well as diskitis and osteomyelitis, even without the use of intravenous contrast material (8). However, apparent drawbacks of conventional MR imaging include long imaging times and high cost. In addition, this modality may depict clinically unimportant abnormalities that could inadvertently lead to additional testing, patient anxiety, specialist referrals, and possibly even unnecessary surgery (9).

Recent modifications in MR imaging software (10,11) have facilitated development of rapid MR imaging protocols (12) that limit image contrast to T2 weighting, with only slight reductions in image resolution. If the time necessary to acquire acceptable images decreases, then personnel and machine time required for rapid MR imaging should also decrease. Resulting increased throughput might reduce rapid MR imaging costs to a level approaching those of conventional radiography.

Unfortunately, there is little information available on provider times or costs of lumbar spine imaging with conventional radiography, conventional MR imaging, or rapid MR imaging. Our study had three major purposes: (a) to evaluate the hypothesis that, from the perspective of the radiology department, imaging and personnel times and attendant costs for rapid MR imaging are between those of conventional radiography and conventional MR imaging; (b) to generate ratios of standard Medicare reimbursement to costs for conventional radiography and conventional MR imaging; and (c) to apply reimbursement-to-cost ratios for conventional MR imaging to costs of rapid MR imaging to project potential "normative" Medicare reimbursement for rapid MR at 0.3, 0.35, and 1.5 T. More simply stated, the purpose of our study was to incorporate personnel and equipment use time in an activity-based cost comparison of conventional radiography, conventional MR imaging, and rapid MR imaging for low back pain.

MATERIALS AND METHODS

Patients

This activity-based cost analysis was conducted in conjunction with the Seat-

tle Lumbar Imaging Project (SLIP). SLIP was a randomized trial in which further diagnostic work-up, therapeutic interventions, general health, and back-specific outcomes and costs were compared between primary care patients randomized to undergo conventional radiography and those randomized to undergo rapid MR imaging of the lumbar spine. SLIP included nonpregnant, English-speaking patients of at least 18 years of age who had a chief complaint of low back pain and for whom primary care clinicians at one of four Seattle area sites had already requested two-view conventional radiographs of the lumbar spine. Patients whose physicians had ordered flexion and extension views were excluded from the study.

Eligible patients had (a) no history of lumbar spine surgery during the previous year, (b) no history of acute external trauma, (c) no contraindications to MR imaging (eg, implanted metallic devices or metallic foreign bodies), (d) a telephone in the home, and (e) no plans to move within the next 12 months. SLIP study patients were randomized to undergo outpatient conventional radiography or rapid MR imaging at one of four sites (a university outpatient imaging facility, the imaging facility of a teaching hospital with no university affiliation, and two nonacademic private outpatient imaging facilities).

All study procedures were approved by the institutional review boards of the participating centers. Institutional review board approvals precluded the identification of the individual institutions that provided specific data items. Hence, herein, institutions that provided specific data items are identified only in terms of their type (eg, university outpatient imaging facility, nonacademic private outpatient imaging facility). In the SLIP trial itself, informed consent was obtained from the randomized SLIP study patients. In the related time-motion study described herein, we tracked times of imaging room use and provider care rather than of patients. Therefore, the institutional review boards directed that informed consent for the time-motion study be obtained from the technologists and radiologists who were timed rather than from the non-SLIP patients themselves. Because the non-SLIP patients were not approached for consent, we could not collect demographic or clinical data on them.

In the SLIP trial, the choice of conventional radiographic views was left to the ordering clinician but generally included

standard anteroposterior and lateral views of the lumbar spine. The rapid MR imaging protocols mandated for use in SLIP study patients included widely available two-dimensional fast spin-echo sagittal and transverse pulse sequences that have reasonable reliability and sensitivity as compared with traditional four-sequence conventional MR imaging protocols (10–12).

Time-Motion Study

Patients were enrolled in the SLIP trial from May 1998 through June 2000. In April and May of 2000, an activity-based cost analysis (13) based on formal time-motion study techniques (14–17) was performed at three SLIP sites (the university outpatient facility, the unaffiliated teaching hospital, and one private imaging facility) and one SLIP-affiliated site (a university hospital). The time-motion study included imaging examinations of sample SLIP patients randomized to undergo either conventional radiography or rapid MR imaging. It also included conventional MR imaging examinations of the lumbar spine performed as part of standard care in a nonrandomized group of non-SLIP patients with similar indications for imaging, as noted on the radiology requisition forms. Thus, the group of randomized SLIP encounters and the group of nonrandomized non-SLIP encounters that were timed constituted convenience samples. Patient encounters were timed when seven research assistants, including four University of Washington senior industrial engineering students, were available to perform these activities.

After receiving an introduction to time-motion study techniques, the research assistants used stopwatches to time activities to the nearest minute. They timed imaging room use as the interval from patient entry into the imaging room through patient departure from the room. This included the time it took for the technologist to perform imaging and film review. For each examination, 5 minutes were added to the measured room use time to account for room cleaning and related activities performed between patient encounters.

The research assistants measured times that one or more technologists spent in (a) preparing the patient before imaging and escorting him or her to the examination room, (b) image acquisition and other imaging room activities, (c) image quality evaluation, (d) repeat imaging room activity and repeat image quality

evaluation if applicable, (e) film and jacket preparation, (f) postimaging provider-patient contact until patient departure from the radiology suite, (g) film delivery to reading room, and (h) other activities (eg, patient registration, if performed by technologists). Radiologists were timed as they (a) interpreted images, (b) discussed findings with other radiologists (but not with primary care physicians), and (c) dictated results.

Separate entries were made for each of multiple time intervals spent in performing the same activity for the same patient (eg, when a radiologist's dictation was interrupted for consultation regarding another patient). Conversely, any overlapping time intervals listed for multiple activities for the same provider treating the same patient were only counted once. Any activity listed as starting and stopping in the same minute was assigned a ½-minute time interval.

In consensus, we (D.T.G., J.G.J.) decided to consider certain individual activities (ie, technologist activities *b* and *c* and radiologist activities *a* and *c* [described earlier]) to be obligatory, in that they were assumed to have been performed even if they had not been specifically noted on the timing form. However, because radiologist image interpretation, discussion, and dictation could overlap, we considered image interpretation to be included in the discussion and/or dictation time intervals if no separate time interval for image interpretation was noted. When possible, we (D.T.G.) imputed start and/or stop times not noted for obligatory activities on the basis of start and/or stop times for other timed activities occurring immediately before and/or after the missing activity. Otherwise, we (D.T.G.) estimated missing time intervals for obligatory activities on the basis of the mean times for those activities recorded for other encounters at the same site in which the same imaging modality and field strength were used. We (D.T.G., J.G.J.) assumed that non-obligatory activities (eg, radiologists discussing findings with other radiologists) had not occurred if times were not recorded for them, and, therefore, we did not impute values for these other activities.

Cost Estimation

To estimate costs per patient associated with these encounters, we combined measured time data with unit cost estimates. The investigator group gathered data and performed the calculations defined below in consensus.

Machine and building use costs per

patient.—We (D.T.G., W.H., M.A.A., J.G.J., C.C.B.) estimated costs of acquiring new conventional radiography machines, 0.3- or 0.35-T MR imaging units, and actively shielded 1.5-T MR imaging units with spine surface coils on the basis of recommended negotiated discount purchase prices for standard models produced by one leading imaging equipment manufacturer. One author (M.A.A.) obtained these price estimates (effective as of October–November 2001) from MD Buyline (Dallas, Tex; www.mdbinfont.com), a broker of negotiated purchase price information for medical equipment. Prices included costs for delivery, installation, taxes, and 1-year service warranties.

We (D.T.G., W.H., M.A.A., J.G.J., C.C.B.) added costs of annual service contracts that were estimated at 4% of the conventional radiography machine purchase price and 6% of the MR imaging unit purchase price. Contracts included tube service for the radiography machines and cryogen service for the MR imaging units. By combining the cost of the original 1-year warranty with the costs of subsequently purchased contracts, service contract costs were annualized over the assumed technologically useful lifetimes of the conventional radiography and MR imaging (18,19) equipment. Because there is no specific definition of the useful lifetime of a piece of imaging equipment, we (D.T.G., W.H., J.G.J., C.C.B., S.D.S., M.A.A.) assumed that the literature estimates of useful lifetimes represented the interval from initial purchase of new imaging equipment until the time at which costs of necessary repair or maintenance would approximate the value that the machine would have after the repair.

We (D.T.G., W.H., M.A.A., J.G.J.) estimated annual costs of MR imaging unit upgrades at 5% of the purchase price of 0.3-T units and 4% of the higher purchase price for 1.5-T MR imaging units. We (D.T.G., W.H., M.A.A., J.G.J., C.C.B.) assumed that conventional radiography machines would be replaced rather than upgraded and that neither MR imaging nor conventional radiography units would have any resale value at the end of their useful lives.

A Seattle area imaging suite construction contractor (speaking anonymously) estimated year 2001 costs for adding equipment and imaging and processing rooms for MR imaging (with magnetic shielding) and conventional radiography (with lead shielding and ceiling supports). Rooms were assumed to be added to an existing ground floor radiology suite more than 25 feet from the street,

with no special vibration-damping or other requirements. Per Internal Revenue Service conventions, estimated construction costs were annualized over assumed building lifetimes of 39 years. For MR imaging, we (D.T.G., W.H., M.A.A., J.G.J.) added costs of copper radio-frequency shielding, which was assumed to last until the room remodeling that would occur with magnet replacement at the end of the useful life of the MR imaging unit. We (D.T.G., W.H., M.A.A., J.G.J.) assumed there would be no room remodeling costs associated with replacement of conventional radiography machines.

The combined machine and building costs were amortized over the useful life of the imaging equipment so that we could determine cost per minute of machine availability. However, because costs per minute of machine availability are incurred regardless of the actual use of the machine, costs per minute of use increase as machine use declines below 100% of capacity. Therefore, to calculate true costs of machine use, we (D.T.G., W.H., J.G.J., M.A.A.) divided the cost per minute as calculated above by the estimated percentage of calendar-year clock time that the machine would be used. This reflects estimates of annualized hours of outpatient conventional radiography and MR imaging machine use obtained from one study site (the nonuniversity teaching hospital facility with a 1.5-T MR imaging unit). These hours were calculated as the numbers of specific procedures completed per year multiplied by the estimates of required time per specific procedure type at that site. The estimated machine use at this site, expressed as a proportion of reported opening hours (ie, the number of hours in a day the imaging suite is open) per week, was applied to reported opening hours for the other sites so that we could estimate the annual hours of machine use at the other sites. The ratio of estimated conventional radiography machine use to reported conventional radiography suite opening hours per week at the nonuniversity teaching hospital imaging facility was applied to the wide range of opening hours reported by the different MR imaging facilities included in this study. Application of this ratio assumes that conventional radiography facilities can match the longer opening hours of MR imaging facilities. Estimates of machine use for completed examinations, expressed as a percentage of opening hours per year, should capture productivity that is lost due to missed appointments or equipment failures, as

well as time spent in MR imaging procedures that were aborted or prolonged because of patient claustrophobia. Therefore, separate costs for these occurrences were not added.

Technologist time cost per patient.—Estimates of annual technologist compensation were based on annual salary and benefits figures published in year 2001 Seattle area classified advertisements. We (D.T.G., W.H., M.A.A., J.G.J.) added the university-based site estimates of a 23% fringe benefit rate, along with an annual allotment of \$1,000 per technologist for expenses such as continuing education. Total annual compensation costs were divided by the average number of technologist work hours per year (excluding vacation, paid holidays, sick leave, and overtime) estimated by the lead technologist at that site. To capture the entrained costs of technologists' time spent in activities not included in our time-motion study, we (D.T.G., W.H.) divided the cost per minute of time that technologists spent in timed activities by site-specific and literature (20) estimates of the percentage of work time that technologists typically spend in patient care.

Radiologist time cost per patient.—Assuming that general radiologists in private practice would read lumbar spine conventional radiographs and MR images, we (D.T.G., W.H., J.G.J., C.C.B.) based estimates of compensation (after expenses, but before taxes, and excluding deferred compensation) for private practice general diagnostic radiologists on results of a recently published survey (21). We (D.T.G., W.H., J.G.J., C.C.B.) added physician-related practice costs (including fringe benefits and professional liability, medical license, dues, local travel, and meeting expenses) on the basis of recently published estimates (22). We (D.T.G., W.H., J.G.J., C.C.B.) divided the total costs for one full-time equivalent radiologist by estimates of average on-site work hours for general radiologists in group practice (23) to calculate costs per minute of observed radiologist reading time. To estimate radiologist costs per examination, we (D.T.G., W.H., J.G.J., C.C.B.) multiplied this estimate of costs per minute of radiologist time by the times that we observed staff or private practice radiologists to spend in performing image interpretation, discussion, and dictation in cases in which radiology residents were not involved.

In a recent time-motion study (24), it was estimated that 58% of academic radiologists' clinical time is spent reading images or performing procedures. There-

fore, we (D.T.G., W.H., J.G.J., C.C.B.) divided radiologist costs per examination calculated as described in the preceding paragraph by 0.58 to capture entrained costs for radiologist activities not included in our time-motion study. We (D.T.G., W.H., J.G.J., C.C.B.) assumed that costs of radiologist time spent in research and teaching activities would be recovered from other funding sources and therefore would not need to be included in our analysis.

Other costs.—Estimated costs of conventional radiography and MR image film, developing reagents, and plate and film readers were obtained from the university hospital site in which 1.5-T equipment was used. Because picture archiving and communication systems were not used at our study sites at the time of our study, the costs of these systems were not considered. We (D.T.G., W.H., J.G.J., C.C.B., M.A.A.) estimated the department of radiology fixed direct costs for the conventional radiography and MR imaging centers at the university hospital site. We (D.T.G., W.H., J.G.J., C.C.B., M.A.A.) also used the estimates of aggregate annual costs for other supplies and other personnel (eg, receptionists, schedulers, file and billing clerks, registered nurses, technologist supervisors, program coordinators, program support supervisors, patient services representatives) at the conventional radiography and MR imaging cost centers of this site. The previously mentioned individuals provide services to patients undergoing conventional radiography and MR imaging but are not directly involved in image generation or interpretation and therefore were not included in our time-motion study.

We (D.T.G., W.H., J.G.J., C.C.B., M.A.A.) divided these additional supply and personnel costs by the annual procedure volumes at the university hospital site to estimate fixed costs per conventional radiograph and per conventional MR image of the lumbar spine. Because rapid MR imaging was not generally available at this site, it did not contribute to these fixed costs. To estimate departmental fixed costs per rapid MR imaging examination, we (D.T.G., W.H., J.G.J., C.C.B., M.A.A.) multiplied fixed costs per conventional MR imaging examination by the ratio of rapid MR imaging technologist times recorded as being spent in lumbar imaging-related activities.

Per published guidelines (19), facility overhead costs were estimated as 20% of total direct costs, excluding depreciated items (eg, equipment purchase and con-

struction costs). We (D.T.G., W.H., J.G.J., C.C.B., M.A.A.) included costs of equipment maintenance contracts and upgrades, as well as radiologist time costs, in the direct cost base for calculating overhead costs. We (D.T.G., W.H., J.G.J., C.C.B., M.A.A.) assumed that radiologist overhead costs (eg, for billing and transcription) would be captured by departmental fixed costs and/or facility overhead costs.

We (D.T.G., W.H., M.A.A., J.G.J.) added Washington state sales tax of 8.6% to all costs except salaries and radiologist practice expenses. Future costs used for amortization were discounted 3% per year (25). Nationwide costs (eg, equipment purchase price, radiologist salaries) originally generated in other years were expressed in year 2001 dollars by using the Medical Care component of the U.S. Consumer Price Index, while costs from other years generated by using Seattle area figures (eg, technologist salaries, site construction costs) were converted to year 2001 dollars by using the Seattle area Consumer Price Index (26). When possible, upper and lower bounds for sensitivity analyses were based on empirical observation or expert opinion. When only point estimates were available, we (D.T.G., W.H.) generated ranges based on $\pm 25\%$ of the point estimate.

Reimbursement Estimates

Data for the technical and professional components of year 2001 Seattle area Medicare Part B reimbursement for conventional radiography and conventional MR imaging were obtained from the 2001 Medicare Physician Fee Schedule (27). We (D.T.G.) calculated ratios of observed costs to reimbursement separately for the technical and professional components of conventional radiography and conventional MR imaging at 0.3–0.35 T and 1.5 T. To estimate "normative" possible reimbursement for rapid MR imaging, we (D.T.G., W.H., J.G.J., C.C.B., M.A.A.) applied the reimbursement-to-cost ratios from conventional MR imaging to the costs of rapid MR imaging.

Statistical Analysis

Characteristics of the SLIP patients for whom conventional radiography and rapid MR examinations were timed are presented as proportions and 95% CIs, along with means and SDs, as calculated by using SPSS for Windows (release 10.0.07; SPSS, Chicago, Ill). Imaging room and provider times for SLIP and

TABLE 1
Numbers of Patients Whose Examinations Were Timed, According to Site and Modality

Modality	University-affiliated Outpatient Facility with 0.3-T MR Imaging Unit	University Hospital-based Facility with 1.5-T MR Imaging Unit	Nonuniversity Academic Hospital-based Facility with 1.5-T MR Imaging Unit	Nonacademic Private Outpatient Facility with 0.35-T and 1.5-T MR Imaging Units		All Sites
				0.35 T	1.5 T	
Conventional radiography	7	0	16	0	0	23
Rapid MR imaging	11	0	16	0	0	27
Conventional MR imaging	0	11	2	6	19	38
All modalities	18	11	34	6	19	88

Note.—Data are numbers of patients whose examinations were timed.

non-SLIP patients were aggregated across sites into the following categories: conventional radiography, rapid MR imaging at 1.5 T, rapid MR imaging at 0.3–0.35 T, conventional MR imaging at 1.5 T, and conventional MR imaging at 0.3–0.35 T. Observed times are presented as means with 95% CIs, as calculated by using SPSS for Windows.

Base case cost estimation.—According to the assumptions described in Materials and Methods, we (D.T.G., W.H.) generated base case estimates of component unit costs and of ranges of values to be used for sensitivity analyses. Using Microsoft Excel 97 SR2 (Microsoft, Redmond, Wash), we (D.T.G., W.H.) calculated total costs per patient by multiplying these unit cost estimates by observed mean time intervals and other measurements of resource use.

Sensitivity analyses for costs.—In one-way sensitivity analyses performed by using Microsoft Excel 97, we (D.T.G., W.H.) assessed how ranges of values of individual base case estimate parameters affected base case average cost for conventional radiography, rapid MR imaging, and the differences between the two modalities. Given the increasing use of 1.5-rather than 0.3-T MR imaging equipment and the fact that the SLIP trial involved the comparison of conventional radiography and rapid (rather than conventional) MR imaging, we (D.T.G., W.H., J.G.J., C.C.B.) focused our comparison on conventional radiography versus rapid MR imaging at 1.5 T. A tornado diagram was constructed to show how changing values of single parameters over a wide range of plausible values affected net differences in per-patient costs.

As an alternative to multiple two-way sensitivity analyses, we (D.T.G., W.H., J.G.J., C.C.B.) performed a “most favorable scenario” analysis (28) in which we calculated costs given a single set of plausible conditions consistently favoring

rapid and conventional MR imaging at 1.5 T versus conventional radiography. For this scenario, we set MR imaging equipment purchase price (and, consequently, maintenance and upgrade costs) at 25% less than the base case values and used the upper bound of the postulated range of the technologically useful life of MR imaging equipment. Costs per minute of MR imaging equipment use were also reduced by setting MR imaging equipment use closer to full capacity by using the upper bound of observed MR imaging facility opening hours. In anticipation of future reductions in imaging times, we (D.T.G., W.H., J.G.J.) also set MR technologist and patient imaging times at their lower 95% CI limits. In a separate sensitivity analysis, we (D.T.G., W.H., J.G.J.) estimated the combination of variable and overhead costs alone for each modality according to the (unlikely) assumption that existing unused capacity would allow lumbar spine conventional radiography or MR imaging capability to be added to existing facilities without specific capital expenditures.

Our use of standardized unit costs suppresses the variability in estimates of true costs (29). Value ranges used in our one-way and most-favorable-scenario sensitivity analyses were generally based on expert opinions. These value ranges generally had a greater effect on our results than did observed variations (eg, 95% CIs of imaging room times). Consequently, because our results are not truly stochastic, we addressed the uncertainty surrounding our cost estimates in primarily deterministic sensitivity analyses rather than by generating 95% CIs or performing tests of significance on estimated costs or cost differences.

Comparison of costs and reimbursement.—For conventional radiography and conventional MR imaging, we compared our estimates of physician and facility costs with standard Seattle area year

2001 Medicare Part B reimbursements for the technical and professional components of these procedures. Medicare reimbursement figures were obtained from the 2001 Medicare Physician Fee Schedule (27).

Calculation of “normative” reimbursement for rapid MR imaging.—Ratios of standard reimbursement to estimated base case costs for the technical and professional components of conventional radiography and conventional MR imaging were generated by using a hand calculator (41CV; Hewlett-Packard, Corvallis, Ore). The ratios of reimbursement to costs for conventional MR imaging at 0.3–0.35 T and 1.5 T were then applied to the costs of rapid MR imaging at 0.3–0.35 T and 1.5 T to estimate “normative” reimbursement for rapid MR imaging at these field strengths.

RESULTS

Site Distribution and Times

In April and May of 2000, the research assistants timed the encounters of 23 SLIP patients randomized to undergo conventional radiography and 27 SLIP patients randomized to undergo rapid MR imaging at one of three sites (the university clinic, the nonuniversity academic hospital, and one of the private clinics). These 50 patients constituted 67% of the 75 patients enrolled in the SLIP trial at those sites in that time frame. In this same time frame, the research assistants also timed the encounters of 38 non-SLIP patients who underwent conventional MR imaging in the course of usual care at two SLIP sites (the private clinic and nonuniversity academic sites mentioned above) and one SLIP-affiliated university hospital setting. The distribution of patients whose examinations were timed, stratified by site and imaging modality, is shown in Table 1. As shown

in Table 2, the demographic characteristics of the SLIP patients whose conventional radiographic examinations were timed were similar to those of the patients whose rapid MR imaging examinations were timed. No demographic data are presented for patients who underwent conventional MR imaging (ie, non-SLIP patients) because institutional review board approval for the time-motion study precluded collecting such data on them.

We imputed one or more missing obligatory time intervals for technologist activities in 31 (35%) of the 88 SLIP and non-SLIP patients involved in the time-motion study. As shown in Table 3, resulting technologist times and patient times in the imaging room during rapid MR imaging were longer than those during conventional radiography but much shorter than those during conventional MR imaging. Times for private practice and staff radiologists aggregated for 0.3-, 0.35-, and 1.5-T MR imaging equipment followed the same trend.

Base Case Costs

Applying unit cost estimates shown in Table 4 to observed resource use produced the aggregate unit costs, costs per care component, and total costs per patient shown in Table 5. The lower equipment and staffing costs per hour for conventional radiography were somewhat balanced by the use of MR imaging facilities and staff at closer to full capacity. Imaging equipment purchase, maintenance, and related costs comprised only 5% of the total costs for conventional radiography versus 33%–36% of the costs for rapid MR imaging and 29%–35% of the costs for conventional MR imaging. Costs per patient also reflected higher purchase prices and maintenance costs for 1.5-T MR imaging equipment relative to the purchase prices and maintenance costs of 0.3- or 0.35-T MR imaging equipment; this was balanced by shorter imaging room use and personnel times for 1.5-T MR imaging. Consequently, within either the rapid or conventional MR imaging groups, average costs per patient for the two field strengths were roughly equivalent. However, for each field strength, costs were lower for rapid MR than for conventional MR imaging.

Sensitivity Analysis

One-way sensitivity analyses illustrated how variation in the values of the individual parameters listed in Table 4

TABLE 2
Characteristics of Patients Whose Conventional Radiographic and Conventional MR Imaging Examinations Were Timed as Part of the SLIP Study

Characteristic	Conventional Radiography Patient Group (<i>n</i> = 23)*		Rapid MR Imaging Patient Group (<i>n</i> = 27)†	
	No. of Patients	Percentage of Patients‡	No. of Patients	Percentage of Patients‡
Female	14	61 (41, 78)	18	67 (48, 82)
White race	19	83 (63, 93)	23	85 (67, 94)
Coexistent morbidity of any kind	7	30 (15, 50)	8	30 (16, 49)
Current or planned disability, worker's compensation, or Social Security claim for back pain	3	13 (5, 32)	2	7 (2, 23)
Ever smoked	12	52 (33, 71)	11	44 (27, 62)
Depression	5	23 (10, 43)	7	27 (14, 46)
Previous episodes of low back pain				
None	2	9 (3, 27)	2	7 (2, 23)
One to five	5	22 (10, 42)	4	15 (6, 33)
Six or more	8	35 (19, 55)	12	44 (27, 62)
Continuous pain	8	35 (19, 55)	9	33 (18, 52)
Previous back surgery more than a year ago	2	9 (3, 27)	3	12 (4, 29)
Pain traveling into leg(s)	16	76 (56, 89)	18	72 (53, 85)
Currently working	7	32 (17, 52)	16	59 (40, 75)

* Mean age in years \pm SD, 55 \pm 15.2; mean body mass index \pm SD, 28.9 \pm 28.0.

† Mean age in years \pm SD, 55 \pm 16.2; mean body mass index \pm SD, 29.0 \pm 28.7.

‡ Data in parentheses are 95% CIs. The denominator used to calculate the percentages was not always 23 or 27 because not all patients provided all demographic information.

TABLE 3
Staff Radiologist, Technologist, and Patient Times

Modality	No. of Examinations Timed	Mean Time (min)*		
		Radiologist	Technologist	Patient†
Conventional radiography	12 23	1.8 (1.3, 2.3)	10.7 (8.8, 12.6)	7.4 (4.7, 10.1)
Rapid MR imaging				
0.3–1.5 T‡	15	3.3 (2.2, 4.4)	21.2 (14.5, 27.9)	18.5 (15.7, 21.3)
0.3–0.35 T	11		15.5 (11.1, 19.8)	12.4 (9.4, 15.4)
1.5 T	16			
Conventional MR imaging				
0.3–1.5 T‡	26	6.6 (5.3, 7.9)	50.2 (38.5, 61.9)	37.7 (22.8, 52.6)
0.3–0.35 T	6		35.5 (31.3, 39.7)	30.3 (26.2, 34.4)
1.5 T	32			

Note.—Examinations at which radiologists were timed were not always the same ones at which patients and technologists were timed.

* Numbers in parentheses are 95% CIs.

† Data represent mean patient times in imaging room.

‡ Because field strength would not affect reading time, radiologist times at 0.30-T, 0.35-T, and 1.5-T MR imaging examinations were aggregated.

affected the difference between the base case cost for rapid MR imaging at 1.5 T (\$126 per patient) and the base case cost for conventional radiography (\$44 per patient). One-way threshold analyses required the incorporation of unreasonable assumptions (eg, setting costs of conventional radiography machines at more than double the current prices) to generate scenarios in which costs of rapid MR imaging and conventional radiography were equal. Some parameters (eg, MR im-

aging equipment purchase price) had no values (ie, not even zero) that would generate total MR imaging costs as low as those of conventional radiography.

As shown in a tornado diagram (Figure), the costs of rapid MR imaging still exceeded those of conventional radiography across wide ranges of plausible values for various parameters. The parameters considered included facility overhead, imaging equipment purchase price, imaging room and technologist times, imaging equip-

TABLE 4
Unit Cost Estimates

Resource	Base Case Value	Source*	Range for Sensitivity Analyses
Purchase price for 1.5-T MR imaging unit	\$1,607,280	MDB	1,205,460–\$2,009,100 [†]
Purchase price for 0.3-T MR unit	\$1,047,280	MDB	\$785,460–\$1,309,100 [†]
Purchase price for conventional radiography machine	\$89,413	MDB	\$67,060–\$111,766 [†]
Yearly service/maintenance contract for 1.5-T MR unit	\$82,660	CA/MDB	\$61,995–\$103,325 [‡]
Yearly service/maintenance contract for 0.3-T MR unit	\$53,860	CA/MDB	\$40,395–\$67,325 [‡]
Yearly service/maintenance contract for conventional radiography machine	\$3,219	CA/MDB	\$2,414–\$4,024 [‡]
Yearly software/hardware upgrade for 1.5-T MR unit	\$64,291	SR	\$48,218–\$80,364 [‡]
Yearly software/hardware upgrade for 0.3-T MR unit	\$52,364	SR	\$39,273–65,455 [‡]
Yearly software/hardware upgrade cost for conventional radiography machine	\$0	CA	0
Technologically useful life of 0.3- and 1.5-T MR units	7 y	Bell (19) and Evens and Evens (18)	5–10 y
Technologically useful life of radiography machine	10 y	CA	5–15 y
Resale value at end of useful life of conventional radiography and MR machines	\$0	CA/SR	0
Construction cost for 0.3- and 1.5-T MR imaging rooms (including magnetic shielding)	\$342,090	SAC	\$256,568–\$427,613 [†]
Construction cost for conventional radiography rooms	\$81,450	SAC	\$61,088–\$101,813 [†]
Useful life of buildings (including magnetic shielding)	39 y	IRS rules	29–49 yrs [†]
RF shielding costs over useful life of MR equipment	\$57,232	SAC	\$42,924–\$71,540
Remodeling cost for radiography room at time of conventional radiography machine replacement	0	SAC	0
Percentage of 8,766 hours per year each MR machine is used	30% (for 69 opening h/wk)	SSS	20%–43% [§]
Percentage of 8,766 hours per year each radiography machine is used	14% (for 58 opening h/wk)	SSS	12%–23% [§]
Purchase price of film per conventional MR patient	\$19.00 (5 film sheets)	CA	\$15.20–22.80 (for 4–6 sheets)
Purchase price of film per rapid MR patient	\$9.50 (2.5 film sheets)	CA	\$7.60–11.40 (for 2–3 sheets)
Purchase price of film per conventional radiography patient	\$3.80 (2.5 film sheets)	CA	\$3.04–\$4.56 (for 2–3 sheets)
Film developing cost per conventional MR patient	\$3.75	CA	\$2.81–\$4.69 [†]
Film developing cost per rapid MR patient	\$1.88	CA	\$1.40–\$2.34 [†]
Film developing cost per conventional radiography patient	\$1.88	CA	\$1.40–\$2.34 [†]
Technologist clinical hours worked per year	1,725	SSS	1,725
Radiography technologist annual salary (including fringe benefits)	\$50,702	Classified ads	\$43,185–\$58,217
MR technologist annual salary (including fringe benefits)	\$62,871	Classified ads	\$53,546–\$72,197
Percentage of MR tech work time spent in patient-related activities assumed to have been captured in time-motion study	80%	Authors' assumption	60%–100% [†]
Percentage of radiography tech work time spent in patient-related activities assumed to have been captured in time-motion study	66%	Netten et al (20)	50%–83%
Mean diagnostic radiologist annual compensation	\$307,526	Wassenaar and Thran (21)	\$230,645–\$38,408 [†]
Mean annual practice-related costs per radiologist	\$67,106	Sunshine et al (22)	\$50,330–\$83,883 [†]
Radiologist hours worked on-site per year	2,125 h (50 h/wk × 42.5 wk/yr)	CA/Sunshine and Bansall (23)	1,594–2,656 [†]
Percentage of radiologist clinical time assumed to have been spent in performing procedures or reading films	58%	Cohen et al (24)	44%–73% [†]
Radiology department fixed cost per conventional MR examination	\$53.05	SSS	\$39.79–\$66.31 [†]
Radiology department fixed cost per rapid MR examination	\$22.72	TMS/SSS	\$17.04–\$28.40 [†]
Radiology department fixed cost per radiography examination	\$11.40	SSS	\$8.55–\$14.25 [†]
Site overhead for rapid or conventional MR imaging (as a percentage of specific costs)	20%	Bell (19)	15%–25%
Site overhead for radiography (as a percentage of specific costs)	20%	CA	15%–40%
Discount rate	3%	Gold et al (25)	0%–7%

Note.—Unit cost estimates were calculated on the basis of the assumptions detailed in the Materials and Methods section. All costs are expressed in year 2001 dollars. All figures other than compensation and practice costs include a Washington state sales tax of 8.6%.

* CA = one or more coauthors of the present study, IRS = Internal Revenue Service, MDB = MD Buylines, SAC = Seattle area imaging suite construction contractor, SR = sales representative of the leading imaging equipment manufacturer for which MDB purchase price quotes were used, SSS = one or more SLIP study sites, TMS = time-motion study results.

[†] Range represents ±25% of base case value estimate.

[‡] Range varies with purchase price.

[§] Reflects reported range of 40–99 opening hours per week for MR imaging sites.

TABLE 5
Unit Costs, Component Costs, and Total Costs

Cost Component	Radiography	Rapid MR Imaging at 1.5 T	Rapid MR Imaging at 0.3 T	Conventional MR Imaging at 1.5 T	Conventional MR Imaging at 0.3 T
Resource use costs per hour (\$)					
Machine use	11.56	157.86	108.07	157.86	108.07
Room use	3.28	5.12	5.12	5.12	5.12
Technologist time	45.60	46.20	46.20	46.20	46.20
Radiologist time	304.02	304.02	304.02	304.02	304.02
Component costs per patient (\$)					
Imaging equipment use costs (including maintenance/upgrades)					
Imaging room use costs (including depreciated construction, radio-frequency, and magnetic shielding)	2.40	45.78	42.33	92.88	76.91
Technologist time costs	0.68	1.49	2.01	3.01	3.64
Radiologist time costs	8.10	11.96	16.35	27.38	38.72
Film purchase and processing costs	9.07	16.57	16.57	33.59	33.59
Other radiology department (eg, fixed) costs	5.68	11.38	11.38	22.75	22.75
Total radiology department and radiologist direct (fixed and variable) costs	11.40	21.22	21.22	53.05	53.05
Overhead costs	37.32	109.88	111.35	232.66	228.67
Total costs per patient (\$)	6.97	15.77	16.58	33.95	35.39
Total costs for base case					
Total costs for most favorable scenario for rapid MR imaging	44.29	125.66	127.93	266.60	264.05
Total costs assuming the presence of excess capacity (ie, including overhead but excluding machine and room use costs)	44.29	90.46	94.10	202.18	193.53
	41.22	78.39	83.59	170.72	183.50

ment use as a percentage of calendar time, and technologically useful lifetimes of conventional radiography and MR imaging equipment. The ranges of parameter values shown in parentheses in the Figure were obtained from Table 4.

Parameters are shown in the Figure in decreasing order of the effect that changing their values had on departures from the difference between the base case cost for rapid MR imaging at 1.5 T and the base case cost for conventional radiography. Thus, as is represented by the uppermost horizontal bar in the Figure, results were most sensitive to variations in the percentage of annual capacity at which MR imaging machines were used (when all other values were fixed). For this parameter, rapid MR imaging costs exceeded those of conventional radiography by amounts ranging from \$67 (when MR imaging machines were used at a maximum observed potential of 43% of annual capacity) to \$107 (when MR imaging machines were used at a minimum observed potential of 20% of annual capacity and thus became more expensive). Conversely, varying the assumed lifetime of buildings used to house MR imaging or conventional radiography equipment to between 29 and 49 years had little effect on the cost difference.

When parameter values most favorable

to rapid MR imaging were used and when no accompanying changes in conventional radiography costs were assumed, rapid MR imaging costs were reduced by \$35. However, they were still \$46 higher than those of conventional radiography (Table 5). Application of the same parameter values to rapid MR imaging at 0.3–0.35 T and to conventional MR imaging at both field strengths still resulted in these modalities being more expensive than conventional radiography (Table 5).

Both conventional radiography and MR imaging facilities are typically used well below full capacity (Table 4). Therefore, one might argue that lumbar spine imaging with MR or conventional radiography could be provided at existing facilities that do not currently have this capacity without additional capital expenditures. Even given this somewhat unlikely scenario, the variable, other fixed, and overhead costs of rapid MR imaging would be double those of conventional radiography (Table 5), and costs of conventional MR imaging would still exceed those of conventional radiography and rapid MR imaging by wide margins.

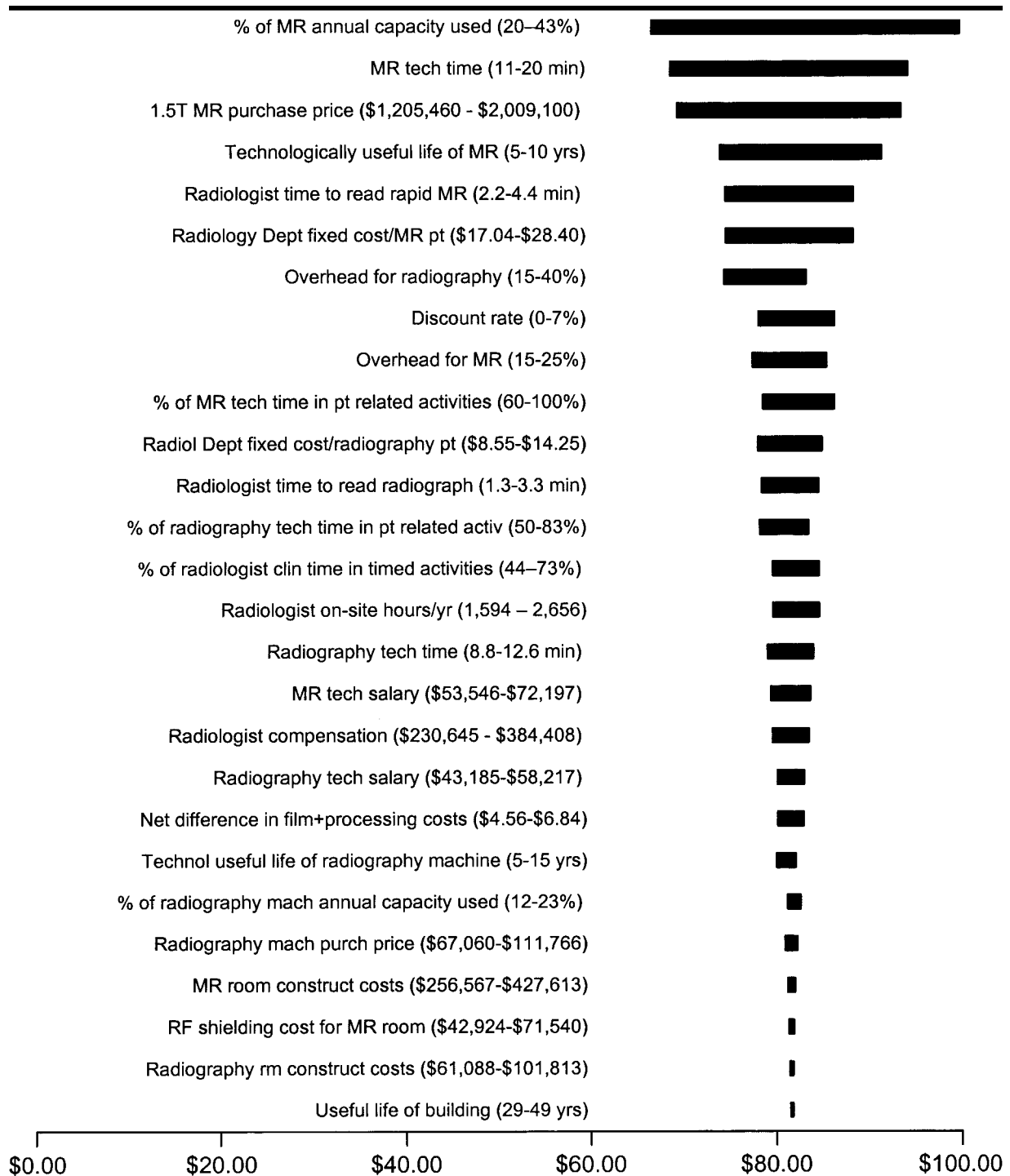
Reimbursement versus Costs

As shown in Table 6, our estimate of the technical component of conven-

tional radiography costs exceeds current reimbursement for these costs. However, the professional component of conventional radiography reimbursement and both components of conventional MR imaging reimbursement exceed estimated costs. Separately applying the technical and professional component ratios of reimbursement-to-cost for conventional MR imaging to our rapid MR imaging cost figures generates estimated normative reimbursement of \$292 for rapid MR imaging at 1.5 T and \$300 for rapid MR imaging at 0.3 or 0.35 T.

DISCUSSION

In calendar year 2000, Medicare made approximately \$55 million in combined technical and professional component payments for 1.36 million claims for conventional radiography of the lumbar spine (Current Procedural Terminology [CPT-4] code 72100). With the higher reimbursement for MR imaging examinations (CPT-4 code 72148), approximately 592,000 lumbar spine MR imaging claims generated Medicare payments of roughly \$339 million (Division of Physician and Ambulatory Care, Center for Medicare Management, Centers for Medicare &



Tornado diagram shows cost differences yielded by one-way sensitivity analysis. Black bars represent differences in average costs (for 1.5-T rapid MR imaging minus those of conventional radiography). Values in parentheses are those used for sensitivity analysis. *activ* = activities, *clin* = clinical, *construct* = construction, *mach* = machine, *pt* = patient, *purch* = purchase, *RF* = radio-frequency, *rm* = room, *tech* = technologist, *technol* = technologically.

Medicaid Services, personal communication, December 2001). While these values are for Medicare beneficiaries alone, they indicate that replacing substantial portions of the use of conventional radiography and/or conventional MR imag-

ing for lumbar spine imaging with rapid MR imaging could greatly affect resource use and costs for the U.S. population as a whole.

In the current health care environment, costs of emerging technologies

(30) such as rapid MR imaging must be rigorously considered along with clinical outcomes. Production costs are of interest to providers considering adopting various MR modalities (31) and may influence the dissemination of rapid MR

imaging for lumbar imaging and other indications. It is important for health care providers to understand the costs they incur in performing various procedures, especially if costs may exceed reimbursement (32).

As a result, cost-effectiveness analyses are appearing more frequently in the medical literature (33). Our cost-effectiveness analysis of rapid MR imaging versus conventional radiography of the lumbar spine included provider-perspective analyses of costs of rapid MR imaging, conventional MR imaging, and conventional radiography. Ours was one of a growing number of cost studies in radiology (34–38) in which time-motion analyses were used to estimate variable direct costs associated with medical imaging procedures.

In our study, times for conventional radiography were shorter than earlier published estimates that included times for examinations performed in both inpatients and outpatients (39,40). While radiologist times for reading conventional radiographs were similar to reported values (41), we (D.T.G., J.G.J., W.H.) identified no previous studies in which the technologist or imaging room times for rapid MR imaging were evaluated. Our results indicate that imaging and personnel times and attendant provider-perspective costs for rapid MR imaging are less than half of those for conventional MR imaging but still greatly exceed those for conventional radiography. Higher costs of acquiring and maintaining MR imaging equipment rather than conventional radiography equipment were the major determinant of our results. Because film costs were a minor component of observed expenses, the introduction of picture archiving and communication systems would be expected to have had little effect on our conclusions.

Approaches used to determine the share of facility overhead reasonably ascribable to radiology procedures vary. Published analyses of computed tomography (CT) costs have included overhead rates ranging from 33% (38) to 82% (42), although the appropriateness of the higher rates has been challenged (43). We estimated overhead as 20% of direct costs (excluding depreciated expenses) (19) for both conventional radiography and MR imaging. This approach eliminates a major potential source of distortion in overhead estimates for conventional radiography and MR imaging because differences in equipment purchase prices should have little effect on

TABLE 6
Costs versus Medicare Reimbursement for Conventional Radiography and MR Imaging

Modality*	Technical Cost Component	Professional Cost Component	Total
Conventional radiography (0.8 RVUs)			
Cost (\$)	33.41 [†]	10.88 [‡]	44.29
Reimbursement (\$)	28.82	12.80	41.62
Reimbursement-to-cost ratio	0.86	1.18	0.94
Conventional MR imaging at 1.5 T (15.3 RVUs)			
Cost (\$)	226.29 [†]	40.31 [‡]	266.60
Reimbursement (\$)§	536.36	83.14	619.50
Reimbursement-to-cost ratio	2.37	2.06	2.32
Rapid MR imaging at 1.5 T (no RVUs established)			
Cost (\$)	105.78 [†]	19.88 [‡]	125.66
Reimbursement-to-cost ratio	2.37	2.06	2.32
Expected reimbursement (\$)***	250.72	41.00	291.72
Conventional MR imaging at 0.3 T (15.3 RVUs)			
Cost (\$)	223.74 [†]	40.31 [‡]	264.05
Reimbursement (\$)§	536.36	83.14	619.50
Reimbursement-to-cost ratio	2.40	2.06	2.35
Rapid MR imaging at 0.3 T (no RVUs established)			
Cost (\$)	108.05 [†]	19.88 [‡]	127.93
Reimbursement-to-cost ratio**	2.40	2.06	2.35
Expected reimbursement (\$)***	259.02	41.00	300.02

Note.—All costs are in 2001 dollars. Source for medicare reimbursement values: reference 27.

* RVU = relative value unit.

[†] Combination of all costs per patient except radiologist time and radiologist overhead costs (from Table 5).

[‡] Radiologist time and overhead costs per patient (from Table 5).

[§] Reimbursement is currently the same for conventional MR imaging at 0.3 T and that at 1.5 T.

|| Based on that for conventional MR imaging at 1.5 T.

Calculated as reimbursement for conventional MR imaging divided by the cost of conventional MR imaging multiplied by the cost of rapid MR imaging.

** Rapid MR imaging reimbursements may not appear to reflect reimbursement-to-cost ratios exactly due to rounding. Total reimbursement is the sum of expected reimbursement for technical and professional components, due to rounding error in total reimbursement-to-cost ratios.

^{††} Based on that for conventional MR imaging at 0.3 T.

facility overhead. Overall costs of rapid MR imaging at 1.5 T still greatly exceeded those of conventional radiography when we varied overhead from 15% to 25% of specified direct MR imaging costs and from 15% to 40% of analogous direct conventional radiography costs. The overhead cost estimates may represent costs that radiology administrators can expect to be “charged” by the facility and therefore represent costs they would incur in performing conventional radiography or MR imaging.

The 1.5-T MR imaging room times we observed are consistent with those reported in a 1996 article (44) whose authors anticipated shorter times for 1.5-T MR imaging while also discussing the lack of evidence of superiority of higher-field-strength MR imaging. We identified no published estimates of MR imaging room, radiologist, or technologist times and no published U.S. references to costs of conventional radiography or MR imaging of the lumbar spine. A Swedish group estimated the 1993 cost of MR im-

aging of the lumbar spine to be 3,025 Swedish kronor (45). Given the 1993 relative purchasing power parity figure of 9.85 kronor per U.S. dollar (46) and the U.S. Consumer Price Index, this is approximately equivalent to \$418 in year 2001 U.S. dollars. The difference between this figure and our lower estimate could reflect inflation adjustment, international variation in labor costs and MR purchase prices, increased efficiency reflecting accumulating experience or more modern equipment, and/or ways in which various aspects of the cost analysis methods used in the Swedish study may have differed from those we used.

Medicare prospective payments ideally reflect the relative costs of care (47) as expressed in RVUs. The similarity between our cost estimates for examinations performed with 0.3–0.35-T MR imaging equipment and those for examinations performed with 1.5-T MR imaging equipment supports existing policies providing the same reimbursement for conventional MR imaging examinations,

regardless of field strength. However, our cost estimates challenge assumptions inherent in the 15-fold difference between the 1.03 RVUs allotted for conventional radiography of the lumbar spine and the 15.15 RVUs allotted for conventional MR imaging of the lumbar spine (48). Our finding that estimated conventional radiography costs for lumbar spine imaging exceed reimbursement mirrors the findings of other studies, including studies of cervical spine radiography costs (32,37). Conversely, our finding that conventional MR imaging reimbursement exceeds estimated costs is consistent with reports that Medicare reimbursement exceeds technical component costs for some CT procedures but is below costs for others (49).

Reimbursement rates have not yet been established for rapid MR imaging. Our potential normative reimbursement estimates of \$292 and \$300 for rapid MR imaging at 1.5 T and 0.3–0.35 T, respectively, are based on ratios of estimated costs to reimbursement for conventional MR imaging. The slightly higher normative reimbursement for 0.3–0.35-T machines reflects longer imaging times. These normative figures reflect current patterns of reimbursement for conventional MR imaging. The appropriateness of these amounts is open to question. One use of time-motion and cost data might be to guide changes in reimbursement that may occur as activity-based costs for various imaging modalities increase or decrease over time.

Our analysis had several limitations. Because conventional MR imaging was not studied as part of the SLIP trial, the conventional MR imaging encounters we timed were not for randomized patients. Instead, they represented a convenience sample of encounters from SLIP-affiliated sites. Because institutional review board approval for the time-motion study precluded our collecting demographic or clinical data for patients who underwent conventional MR imaging, we do not know how similar they were to the SLIP patients we described. However, because all time-motion study patients were outpatients, conventional MR imaging patients are likely to have been similar to SLIP patients in specific characteristics (eg, mobility in the radiography or MR imaging room) that were relevant to our time and cost estimates.

Our study was small (incorporating a total of 88 patients), and not all field strengths and modalities were studied at all sites. Therefore, times listed for different combinations of modality and field

strength may also reflect inherent characteristics of the study sites themselves. Because we timed SLIP patients toward the end of patient enrollment in that study, we do not have cost data for the entire SLIP cohort.

Due in part to practical realities of clinical practice, we could not time all provider activities (eg, technologist times and subsequent radiologist reading times) for the same patient. So that we could focus on key technologist and radiologist activities, we did not time some other activities (eg, patient registration, assessment of MR eligibility, repeat imaging of claustrophobic MR patients, radiologist finalization of typed reports dictated days earlier). We also had to impute missing time intervals in approximately 35% of patients. In the absence of evidence of systematic biases, we doubt that these gaps in our data materially affected our conclusions, especially those regarding the net cost differences between MR imaging and conventional radiography. We did not formally track the use of conventional radiography or CT to rule out the presence of orbital metallic fragments that would contraindicate MR imaging. Given the low proportion of MR-imaged patients with exposure histories to prompt them to undergo conventional radiography or CT for that purpose, this limitation is unlikely to have materially affected our results. Including estimates of the costs of testing to detect metallic fragments would only serve to increase MR imaging costs and, consequently, to increase differences between conventional radiography and MR imaging costs.

Our cost estimates involved the application of standardized equipment and personnel unit costs from external sources to resource use recorded at study sites that may have used different imaging equipment. Consequently, our numbers do not represent costs actually observed for individual study patients. Although we did not consider our simulated nonstochastic cost figures to be appropriate for statistical testing, the robust results of our sensitivity analyses should adequately address the uncertainty of our estimates.

We measured the long-run average costs of adding lumbar spine conventional radiography or MR imaging to radiology departments assumed to not have this capability. Estimating the short-run marginal costs of adding lumbar imaging to existing facilities was beyond the scope of this analysis. Use of local timing estimates and construction and labor costs may slightly reduce the

generalizability of our results. However, the use of national values to estimate key equipment costs should make our results relevant to institutions throughout the United States.

In imaging of the lumbar spine, rapid MR imaging times and related costs are three times those of conventional radiography but are half those of conventional MR imaging. This reflects the fact that rapid MR imaging involves longer imaging room and personnel times and higher equipment acquisition and maintenance costs than conventional radiography. These factors make rapid MR imaging considerably more expensive than conventional radiography from the radiology department perspective. On the other hand, rapid MR imaging is considerably less expensive than conventional MR imaging; this fact possibly argues for lower reimbursement of rapid MR imaging. Such cost estimates must be combined with data on measures such as clinical outcomes, functional status, and provider and patient satisfaction to more fully evaluate the proper role of rapid MR imaging in the initial evaluation of low back pain.

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