Effect of Computerized Order Entry with Integrated Decision Support on the Growth of Outpatient Procedure Volumes: Seven-year Time Series Analysis[1]

Christopher L. Sistrom, MD, MPH
Pragya A. Dang, MD
Jeffrey B. Weilburg, MD
Keith J. Dreyer, DO, PhD
Daniel I. Rosenthal, MD
James H. Thrall, MD

Purpose: To determine the effect of a computerized radiology order entry (ROE) and decision support (DS) system on growth rate of outpatient computed tomography (CT), magnetic resonance (MR) imaging, and ultrasonography (US) procedure volumes over time at a large metropolitan academic medical center.

Materials and Methods: Institutional review board approval was obtained for this study of deidentified aggregate administrative data. The research was compliant with HIPAA; informed consent was waived. This was a retrospective study of outpatient advanced imaging utilization before, during, and after implementation of a Web-based ROE and DS system. Dependent variables were the quarterly volumes of outpatient CT, MR imaging, and US examinations from quarter 4 of 2000 through quarter 4 of 2007. Outpatient visits during each quarter were included as control variables. These data were analyzed as three separate time series with piecewise linear regression for simultaneous estimation of quarterly examination volume trends before and after ROE and DS system implementation. This procedure was repeated with log-transformed quarterly volumes to estimate percentage growth rates.

Results: There was a significant decrease in CT volume growth (274 per quarter) and growth rate (2.75% per quarter) after ROE and DS system implementation ($P < .001$). For MR imaging, growth rate decreased significantly (1.2%, $P = .016$) after ROE and DS system implementation; however, there was no significant change in quarterly volume growth. With US, quarterly volume growth ($n = 98$, $P = .014$) and growth rate (1.3%, $P = .001$) decreased significantly after ROE implementation. These changes occurred during a steady growth in clinic visit volumes in the associated referral practices.

Conclusion: Substantial decreases in the growth of outpatient CT and US procedure volume coincident with ROE implementation (supplemented by DS for CT) were observed. The utilization of outpatient MR imaging decreased less impressively, with only the rate of growth being significantly lower after interventions were in effect.

© RSNA, 2009

[1] From the Department of Radiology, University of Florida Health Center, PO Box 100374, Gainesville, FL 32610 (C.L.S.); and the Departments of Radiology (P.A.D., K.J.D., D.I.R., J.H.T.) and Psychiatry (J.B.W.), Massachusetts General Hospital, Boston, Mass. Received July 5, 2008; revision requested August 5; revision received August 29; accepted October 3; final version accepted October 26. **Address correspondence to** C.L.S. (e-mail: *sistrc@radiology.ufl.edu*).

No other branch of medical technology has experienced the explosive growth in volume and variety of available services that radiology has during the past 2 decades. The medical care industry in the United States has purchased and installed advanced radiology equipment at an astounding rate, outpacing all other countries. Imaging costs to the Medicare system in the 1990s rose more rapidly than any other component and now alone accounts for at least 14% of the total Part B expenditures for physician services, as specified in a 2003 report by the Medicare Payment Advisory Commission to the U.S. Congress (1). Imaging costs grew by about 10% per year during the period covered by the report (1999–2002), compared with an average yearly cost increase for all other services of 3.3%.

More recent testimony by Medicare Payment Advisory Commission leadership amplified and extended these concerns (2,3). For example, 1999–2004 data show growth in Medicare claims for diagnostic imaging as being the highest of all services at 62%. Furthermore, growth was especially high for emerging modalities (up to 140%), with even established technologies like head computed tomography (CT) outpacing general growth at 43%. Similar trends in costs of imaging are experienced by private-sector payers, and they have responded in various ways, including specific risk-sharing provisions related to imaging in contracts with providers, preauthorization schemes, and carve-outs to imaging benefits management entities (4,5). The recently enacted Medicare Improvements for Patients and Providers Act of 2008 (House of Representatives 6331) calls for targeted strategies to curtail inappropriate high-cost imaging utilization and includes funding for a demonstration project to explore use of imaging appropriateness criteria in the medical imaging decision-making process.

Radiology departments are beginning to adopt some form of computerized order entry and scheduling, primarily for noninvasive outpatient imaging procedures. A few of these efforts include methods to educate ordering physicians about appropriateness of diagnostic imaging. The most ambitious systems attempt to gather enough clinical information to score individual orders for appropriateness and give direct feedback to providers about them. There are several possible advantages to such integrated point-of-care solutions, including reducing variation in utilization and promoting a more optimal mixture of imaging studies appropriate to the clinical circumstances. Perhaps most important, if such physician-driven utilization management efforts also result in mitigation of the per-capita growth of high-cost imaging, all stakeholders (including payers and regulators) will be satisfied.

The purpose of this study was to determine the effect of a computerized radiology order entry (ROE) and decision support (DS) system on the growth rate of outpatient CT, magnetic resonance (MR) imaging, and ultrasonography (US) procedure volumes over time at our large metropolitan academic medical center.

Advance in Knowledge

- Introduction of computerized radiology order entry (ROE) with decision support (DS) in our institution was followed by a substantial reduction in the annual growth rate of outpatient CT (12% to 1%), MR imaging (12% to 7%), and US imaging (9% to 4%); these reductions occurred despite concomitant increases of outpatient visit activity, with a compound yearly growth rate of just below 5%.

Implication for Patient Care

- Introducing computerized ROE with DS into a large integrated multispecialty group practice may substantially reduce the growth rate of high-cost outpatient imaging volumes.

Materials and Methods

Institutional review board approval was obtained for this retrospective study of deidentified aggregate administrative data. The research was compliant with the Health Insurance Portability and Accountability Act, and the requirement to obtain informed consent was waived. Two of the authors (C.L.S. and K.J.D.) serve on an unpaid radiology products advisory board for Nuance Communications (Burlington, Mass), and the DS rules engine described below has been licensed to the same company for commercial distribution by the parent institution.

ROE and DS System

We implemented a Web-based computerized ROE system that allowed referring physicians to request and schedule outpatient diagnostic imaging studies at our institution. Design, deployment, and initial experience have been reported previously (6). The system was initially introduced in late 2001 and was gradually rolled out for outpatient clinical use through 2003. Prior to implementing ROE, all studies were ordered by using paper, facsimile, and telephone methods. After implementation, these legacy systems remained in use for the tests not ordered by using the ROE system. In addition to specifying the type of examination being requested, ordering physicians were asked to check off relevant indications from a prepopulated list keyed to the requested examination.

Published online before print
10.1148/radiol.2511081174

Radiology 2009; 251:147–155

Abbreviations:
DS = decision support
ROE = radiology order entry

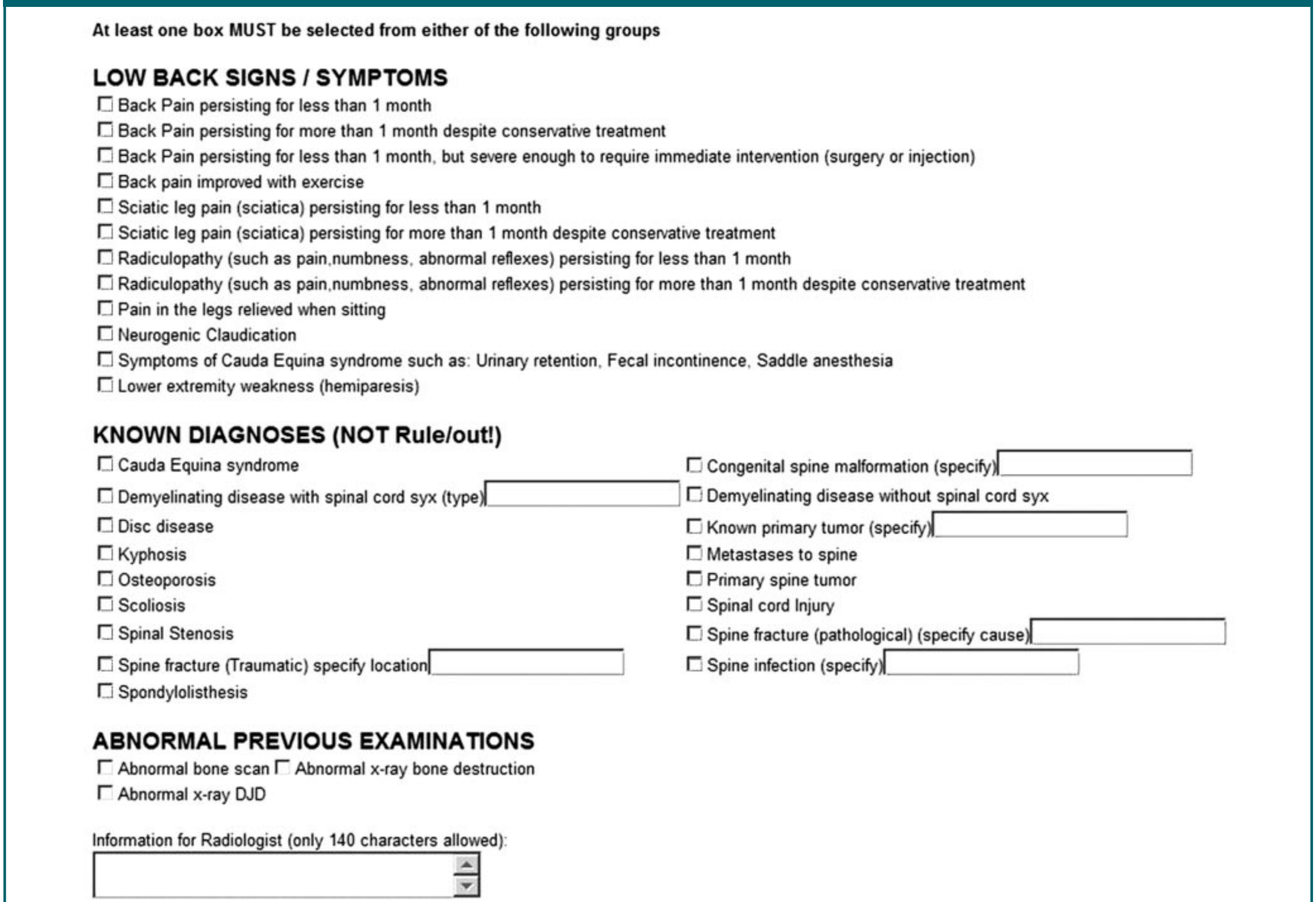
Author contributions:
Guarantors of integrity of entire study, C.L.S., K.J.D.; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; manuscript final version approval, all authors; literature research, C.L.S., P.A.D.; clinical studies, D.I.R.; experimental studies, P.A.D., K.J.D.; statistical analysis, C.L.S.; and manuscript editing, P.A.D., K.J.D., J.H.T.

See Materials and Methods for pertinent disclosures.

A space for free-text entry of clinical information, special considerations, or questions to the interpreting radiologist was also available, although physicians were not required to use this. In the last quarter of 2004, we integrated a new component—DS—to the ROE system. The ROE and DS system assists in ordering high-cost imaging tests (MR imaging, CT, and nuclear cardiology) by providing a 1–9 appropriateness score at the time a clinician submits the request, after he or she has chosen clinical indications. The sets of indications for specific examinations and the appropriateness scores were based on the American College of Radiology Appropriateness Criteria (7–9). We supplemented the existing American College of Radiology Appropriateness Criteria scores with locally developed indication and procedure pairs where needed. These additional appropriateness scores were created by consensus panels of radiologists, primary care physicians, and clinicians in relevant clinical specialties. These are continually reviewed and modified as needed by clinical and radiology experts (6).

When requesting a particular examination through an ROE and DS program, the physician selects the modality, body region, and type of test he or she wishes to order. On the basis of this first selection, a list of indications for the examination is presented on a Web form, along with additional checkboxes and text fields relating to protocol selection and special considerations. The indications are divided into logical groups, including signs and symptoms, known diagnoses, and prior test (including imaging) results. An example of this is shown in Figure 1. Prior to implementation of the DS system in 2004, the submit button served to instantiate an order for the examination. This original ROE workflow still exists for examinations (eg, radiography and US) other than those targeted for DS (CT, MR imaging, and nuclear cardiology). After implementation of the ROE and DS system in 2004, clinicians were presented with a second form after submitting from the order-details screen. This screen provides the DS feedback as a series of nine colored boxes labeled low utility (red boxes: 1–3), marginal (yellow boxes: 4–6), and indicated (green boxes: 7–9). The appropriateness score of the currently submitted examination and selected indications is highlighted for visual clarity. Alternate examinations are

Figure 1


At least one box MUST be selected from either of the following groups

LOW BACK SIGNS / SYMPTOMS
- ☐ Back Pain persisting for less than 1 month
- ☐ Back Pain persisting for more than 1 month despite conservative treatment
- ☐ Back Pain persisting for less than 1 month, but severe enough to require immediate intervention (surgery or injection)
- ☐ Back pain improved with exercise
- ☐ Sciatic leg pain (sciatica) persisting for less than 1 month
- ☐ Sciatic leg pain (sciatica) persisting for more than 1 month despite conservative treatment
- ☐ Radiculopathy (such as pain,numbness, abnormal reflexes) persisting for less than 1 month
- ☐ Radiculopathy (such as pain,numbness, abnormal reflexes) persisting for more than 1 month despite conservative treatment
- ☐ Pain in the legs relieved when sitting
- ☐ Neurogenic Claudication
- ☐ Symptoms of Cauda Equina syndrome such as: Urinary retention, Fecal incontinence, Saddle anesthesia
- ☐ Lower extremity weakness (hemiparesis)

KNOWN DIAGNOSES (NOT Rule/out!)
- ☐ Cauda Equina syndrome
- ☐ Demyelinating disease with spinal cord syx (type)
- ☐ Disc disease
- ☐ Kyphosis
- ☐ Osteoporosis
- ☐ Scoliosis
- ☐ Spinal Stenosis
- ☐ Spine fracture (Traumatic) specify location
- ☐ Spondylolisthesis
- ☐ Congenital spine malformation (specify)
- ☐ Demyelinating disease without spinal cord syx
- ☐ Known primary tumor (specify)
- ☐ Metastases to spine
- ☐ Primary spine tumor
- ☐ Spinal cord Injury
- ☐ Spine fracture (pathological) (specify cause)
- ☐ Spine infection (specify)

ABNORMAL PREVIOUS EXAMINATIONS
- ☐ Abnormal bone scan ☐ Abnormal x-ray bone destruction
- ☐ Abnormal x-ray DJD

Information for Radiologist (only 140 characters allowed):

Figure 1: Example of ROE form displayed after provider selects MR imaging of the lumbar spine. *DJD* = degenerative joint disease, *syx* = symptoms.

shown along with their scores for comparison (6). This is shown in Figure 2.

Data Sources

An existing radiology data warehouse was queried to obtain counts of diagnostic MR imaging, CT, and US studies performed on an outpatient basis in our teaching hospital and associated ambulatory imaging facilities during each calendar quarter from October 1, 2000, through December 31, 2007. This warehouse collates data from the radiology information system and the ROE system and has complete records of all radiology encounters going back to 1995. The unit of counting was a single dictated examination. These counts were independent of the Current Procedural Terminology billing codes. For instance, if a patient underwent abdominal and pelvic CT, it was counted as a single examination despite possibly being billed with two Current Procedural Terminology codes. The final observation for US (quarter 4 of 2007) was not included in the analysis because administrative changes in the coding of US procedures resulted in an anomalously low value. Accordingly, the time series for US volumes was truncated at quarter 3 of 2007. In addition to the quarterly procedure volumes, we also determined the fraction of these same examinations ordered through the ROE system with the remainder ordered with legacy methods (phone, facsimile, or paper forms).

For the same time interval, we obtained the total number of outpatient visits to our institution from the records maintained and updated monthly by the finance and operations departments. These included patients visiting primary care physicians and specialists at the main campus, as well as other satellite centers of the institution. We noted seemingly anomalous counts of outpatient visits for quarter 1 of 2003 (too low) and quarter 2 of 2003 (too high). During interviews, practice managers and billing personnel acknowledged that some fraction of total visits was known to be misattributed to quarter 2 from quarter 1 in 2003 because of an unrecoverable administrative error. We did not impute or otherwise correct the counts for these intervals in the formal analysis because it did not make any meaningful difference to the results of modeling described below.

Statistical Analysis

Statistical analysis was performed with software (SAS, Windows, version 9.13; SAS, Cary, NC). Hypothesis tests about the effect of the implementation of ROE and DS system were performed at the .05 level of significance. Parameter estimates were calculated with 95% confidence intervals. The analytic data set consisted of 29 sequentially numbered observations, each one representing a calendar quarter ranging continuously from quarter 4 of 2000 to quarter 4 of 2007. The three dependent variables were the numbers of outpatient CT, MR imaging, and US examinations during each quarter. We included a control variable (thousands of outpatient visits during each quarter) in the analysis to correct for and estimate effects on outpatient imaging volume from changes in overall activity in the associated outpatient practice. These data were analyzed as three separate time series: one each for CT, MR imaging, and US quarterly examination volume. We sought to estimate two slopes—before and after period 16 of 29 (when use of the ROE and DS system was started)—and to test a single two-tailed hypothesis (slopes were significantly different from each other). This was performed by using piecewise linear regression (PROC NLIN; SAS) with the following composite model for linear change in procedure volume per quarter:

Model 1.—$Y_i = \alpha_1 + \beta_1 X_i + \beta_4 O_i + \varepsilon_i$ if quarter 4 of 2004 or before and $\alpha_1 + \beta_1 X_i + \beta_1 - \beta_2(X_i - 16) + \beta_5 O_i + \varepsilon_i$ otherwise. Y_i is quarterly procedure volume (CT, MR imaging, or US), α_1 is intercept term (procedure volume at quarter 0), X_i is quarter (n = 1–29), O_i is quarterly outpatient visits per 1000, and ε_i is the error term.

The coefficients are interpreted as linear change in imaging procedure volume per quarter (β_1 before ROE and DS system implementation and β_2 after ROE and DS system implementation) and the effect of outpatient clinic activity on imaging procedure volume (β_4 before ROE and DS system implementation and β_5 after ROE and DS system implementation). We used a second model specification with identical variable definitions, except for a new coefficient ($\beta_3 = \beta_1 - \beta_2$ from model 1) so that we could directly test the hypothesis that the slopes of volume by quarter were significantly different after ROE and DS system implementation compared with before ROE and DS system implementation:

Model 2.—$Y_i = \alpha_1 + \beta_1 X_i + \beta_4 O_i +$

Figure 2

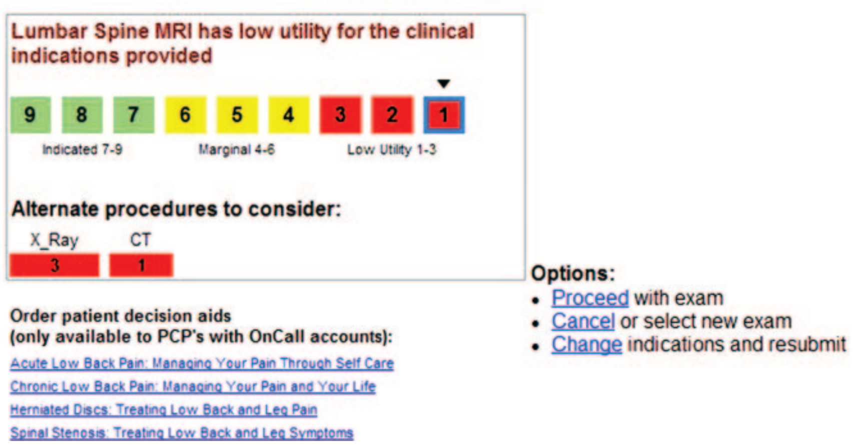


Figure 2: Screenshot of the DS feedback displayed after submitting a request for MR imaging of the lumbar spine with symptom of "back pain improved with exercise" and abnormal result at previous examination of "abnormal x-ray DJD [degenerative joint disease]." *PCP's* = primary care physicians.

ε_i if before period 16 and $\alpha_1 + \beta_1 X_i + \beta_3(X_i - 16) + \beta_5 O_i + \varepsilon_i$ otherwise. The only difference between the first and second models is that we substituted β_3 for $\beta_1 - \beta_2$, thus allowing simultaneous estimation (with confidence intervals and *P* values) of the slope before ROE and DS system implementation, slope after ROE and DS system implementation, and the change in slope due to implementation of the ROE and DS system for each modality (CT, MR imaging, US). The regressions were recalculated by using log-transformed quarterly procedure counts as the dependent variable so as to interpret the coefficients (after multiplying by 100) as percentage growth rates analogous to economic inflation. This produced estimates of the growth rate before ROE and DS system implementation, the growth rate after ROE and DS system implementation, and the change in growth rate after ROE and DS system implementation. Visual analysis of model residuals plotted against quartiles was performed to check for autocorrelation over time. Residuals plotted against predicted values were used to check for symmetry and homogeneity of variance. Finally, residuals from each model were examined (PROC UNIVARIATE; SAS) for distributional statistics, as well as for quantile plots to check for normality.

Table 1

Raw Counts of Outpatient Visits and Examinations according to Calendar Quarter

Period	Year/Quarter	No. of Outpatient Visits	No. of CT Examinations	No. of MR Imaging Examinations	No. of US Examinations
1	2000/4	306 852	8154	4622	8075
2	2001/1	300 674	8012	5020	8209
3	2001/2	309 281	8779	5801	8709
4	2001/3	301 538	8559	5634	8274
5	2001/4	324 268	9495	6234	8768
6	2002/1	319 770	9524	5944	9096
7	2002/2	325 598	10 475	6811	9989
8	2002/3	320 076	10 254	6331	9625
9	2002/4	328 314	10 729	6810	10 142
10	2003/1	283 427	10 430	6504	10 303
11	2003/2	372 276	11 843	7029	10 592
12	2003/3	325 235	11 491	6868	10 845
13	2003/4	348 426	11 665	6716	10 635
14	2004/1	336 164	12 357	7655	10 875
15	2004/2	350 094	13 308	8389	11 439
16	2004/3	336 613	12 428	7519	10 794
17	2004/4	359 367	14 293	8687	12 291
18	2005/1	354 263	12 966	8063	11 500
19	2005/2	381 869	13 111	8759	12 152
20	2005/3	400 865	11 953	8642	11 889
21	2005/4	384 190	12 166	8496	11 612
22	2006/1	392 083	12 491	8932	12 008
23	2006/2	402 673	13 648	9414	12 709
24	2006/3	379 539	12 632	9345	12 694
25	2006/4	392 279	13 741	9806	12 593
26	2007/1	402 032	13 249	9653	13 098
27	2007/2	415 493	14 413	10 288	13 719
28	2007/3	397 888	13 656	10 307	12 543
29	2007/4	406 493	13 446	9851	NA*

Note.—Period 16 was used in the piecewise regression models as the break point between two linear slopes (before and after ROE and DS system implementation).

*NA = not applicable, data were not included in the analysis.

Results

Table 1 lists the raw counts according to calendar quarter of outpatient visits, as well as CT, MR imaging, and US examinations performed during the same quarters. Figure 3 is a scatterplot of the number of outpatient visits per quarter during the study period. Figures 4–6 are scatterplots of CT, MR imaging, and US quarterly volumes, respectively. Although not specifically listed in Table 1, the numbers of CT, MR imaging, and US examinations ordered through the ROE system are plotted on Figures 4–6, respectively.

The iterative piecewise regression procedure (PROC NLIN; SAS) converged without error for all the models. Regression diagnostics and residual analysis revealed that the residuals from all models were normally distributed (with the exception of an occasional outlier) and that there was no substantial autocorrelation from quarter to quarter. This finding supports the choice to use simple regression methods as opposed to more complex time series analysis (ie, lagged or stochastic variable effects or autoregression). Table 2 lists the parameter estimates from the regression models with regard to the baseline value, slope before ROE and DS system implementation, slope after ROE and DS system implementation, and the change in slope between the two conditions for the quarterly volumes and the rate of growth for CT, MR imaging, and US procedures. All estimates in Table 2 are adjusted for changes in outpatient visit volume, which grew from 306 852 to 406 493 per quarter (Fig 3). This represents a linear growth of 4161 visits per quarter ($R^2 = 0.99$) and a compound quarterly growth rate of 1.2% per quarter ($R^2 = 0.83$). Figures 4–6 show the quarterly volumes for CT, MR imaging, and US, respectively. The superimposed linear trend lines were obtained from the piecewise regression procedure and are thus corrected for outpatient visit volume. In addition to the absolute number of outpatient examinations per quarter, the number ordered through the computerized order entry system is also plotted on each graph. The "ramp up" of

Figure 3

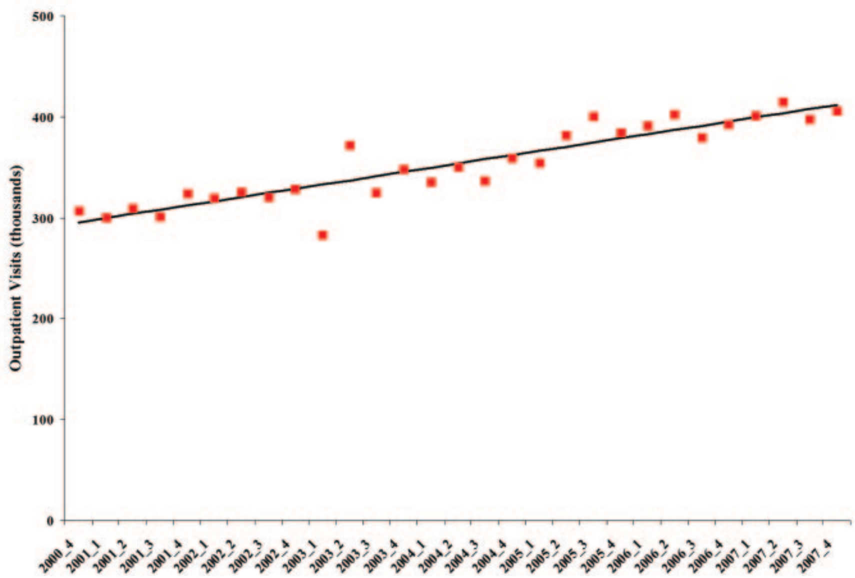


Figure 3: Scatterplot of outpatient visit volume (y-axis) per calendar quarter (x-axis) during the study period. Data were obtained from billing records from the same outpatient practice served by the radiology department. The anomalous-appearing points in the first half of 2003 are because of misattribution of visits from one quarter to the next in the billing data.

Figure 4

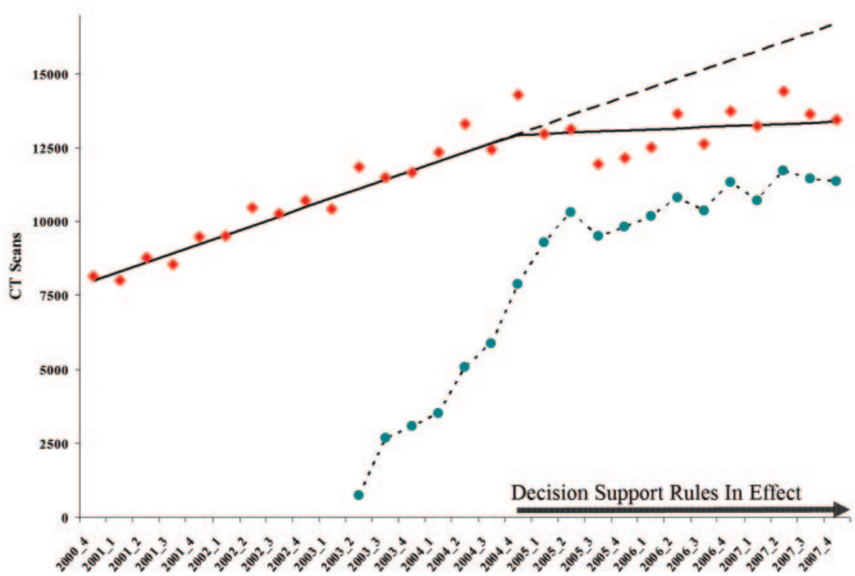


Figure 4: Scatterplot of outpatient CT examination volumes (y-axis) per calendar quarter (x-axis) represented by red diamonds. Solid line represents linear component of the piecewise regression with break point at quarter 4 of 2004 and accounting for outpatient visit volume. Dashed line shows projected linear growth without implementation of ROE and DS system. Dotted line and teal circles depict number of CT examinations ordered through computer order entry. Appropriateness feedback was started in quarter 4 of 2004 and continued through the duration of the study (arrow at lower right).

ROE for each modality can therefore be clearly seen.

In aggregate (summed across all quarters), there were 33.07 CT scans, 21.85 MR imaging examinations, and 30.97 US studies per 1000 outpatient visits. For CT, there was a significant ($P < .001$) decrease in both volume growth (274 per quarter) and growth rate (2.75% per quarter) after institution of the ROE and DS system. In fact, after ROE and DS system implementation, the quarterly volumes for CT were essentially flat, with absolute growth and growth rate 95% confidence intervals both containing zero. For MR imaging, there was no significant change in absolute quarterly volume growth, although the growth rate did decrease significantly (1.2%, $P = .016$) after ROE and DS system implementation. With US, both absolute quarterly volume growth ($n = 98$, $P = .014$) and growth rate (1.3%, $P = .001$) decreased significantly after ROE implementation. Recall that DS was not implemented for US at any point during the study.

The estimates of the effects of quarterly outpatient visit volume on imaging examination volumes (Table 3) were slightly positive but did not reach significance. This implies that the absolute growth of imaging volume prior to ROE and DS system implementation was mostly because of increasing intensity of ordering MR imaging, CT, and US on a per-visit basis. The coefficients for outpatient visit volumes were of similar magnitude for all three modalities before (β_4) and after (β_5) ROE implementation. This can be interpreted as the ROE effect is to decrease the growth of per-visit imaging intensity. At the same time, the growth of imaging volume due to more patients being seen over time remained stable (and small) before and after ROE implementation.

Discussion

Our analysis showed significant decreases in the quarterly compound growth rates of outpatient CT (3.0% to 0.25% = 2.75%), MR imaging (2.9% to 1.7% = 1.2%), and US (2.2% to 0.9% = 1.3%) coincident with the implementation of a computerized ROE and DS system for the pool of referring physicians. On a yearly basis, the growth rates before and after ROE and DS system implementation would be roughly as follows: CT (12% to 1%), MR imaging (12% to 7%), and US (9% to 4%). The most impressive change occurred for CT, in which the growth rate (and absolute quarterly increase) after ROE and DS system implementation was essentially flat. MR imaging exhibited the smallest decrease in growth rate, with no significant difference in the absolute quarterly volume increase before and after implementation of an ROE and DS system. Interestingly, after implementation of ROE alone, the quarterly growth rate of US volume decreased about the same as for MR imaging. Even though clinicians ordering US with ROE did not receive DS, they were required to check off one or more clinical indications tailored to the examination, as with CT and MR imaging.

We believe that our results are attributable to two previously described effects of changes in the process for ordering diagnostic tests on procedure volumes (10,11). The first is called the "gatekeeper effect," and it is simply due to the fact that a new (and sometimes more difficult) set of steps are required to order, schedule, or authorize the examination (eg, our computerized ROE system). This seems to hold true even when the new process design did not intend to limit access in any way. When an overt attempt is made to somehow screen requests by using preauthorization or some other method, the gatekeeper effect may be magnified because of the extra effort and time required to supply medical justification information.

In addition to the gatekeeper effect, a second phenomenon may come into play, and it can be called the "educational effect." This is limited to situations in which the new ordering process attempts to change practice patterns (as in our appropriateness DS rules) or at least provide some educational feedback. We assert that the substantial decreases in CT and US volumes after implementation of a computerized ROE system demonstrate the gatekeeper ef-

Figure 5

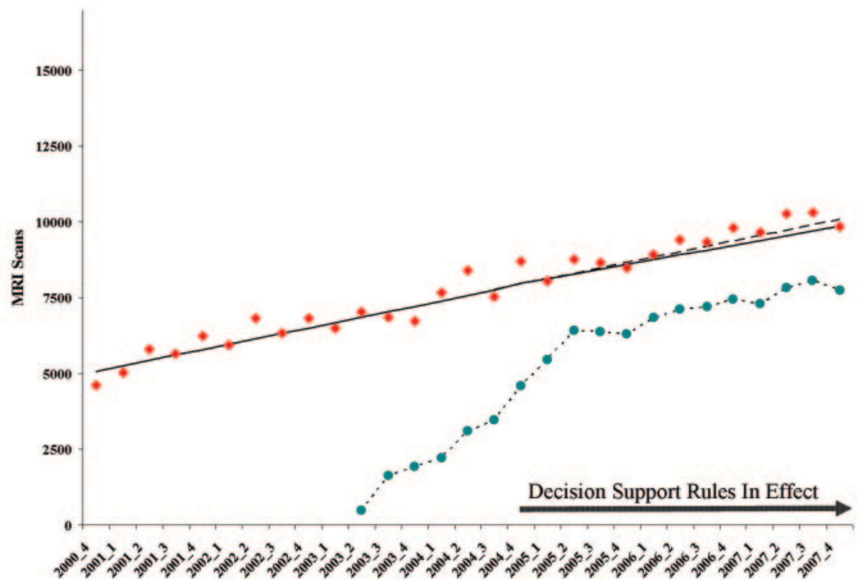


Figure 5: Scatterplot of outpatient MR imaging examination volumes (y-axis) per calendar quarter (x-axis) represented by red diamonds. Solid line represents linear component of the piecewise regression with break point at quarter 4 of 2004 and accounting for outpatient visit volume. Dashed line shows projected linear growth without implementation of ROE and DS system. Dotted line and teal circles depict number of MR imaging examinations ordered through computer order entry. Appropriateness feedback was started in quarter 4 of 2004 and continued through the duration of the study (arrow at lower right).

Figure 6

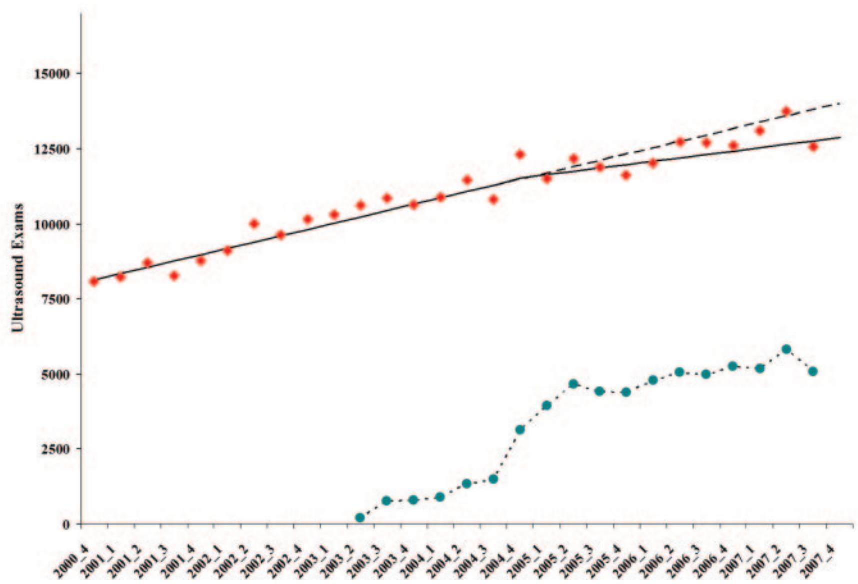


Figure 6: Scatterplot of outpatient US volumes (y-axis) per calendar quarter (x-axis) represented by red diamonds. Solid line represents linear component of the piecewise regression with break point at quarter 4 of 2004 and accounting for outpatient visit volume. Dashed line shows projected linear growth without implementation of ROE. Dotted line and teal circles depict number of US examinations ordered through computer order entry.

fect and that at least some of the large decrement in CT growth rate is because of the educational effect related to the DS rules. In support of our assertions of a gatekeeper effect, we note that even though appropriateness feedback was not given for US, providers were still required to enter indications for each examination (as in Fig 1). MR imaging volumes were affected much less than CT or US volumes, despite the fact that after implementation of a ROE and DS system for MR imaging both effects should have been operational (gatekeeper and educational). This may be partly a result of the DS appropriateness feedback favoring MR imaging over CT for some indications, in addition to a general tendency for providers to substitute MR imaging for CT, abetted by concerns reflected in publications about radiation risks associated with CT scanning (12–14).

Our use of outpatient visit volume as a control variable was done to eliminate confounding by overall practice activity on imaging procedure volumes. However, the estimates of the effect of clinic visit volume are of interest in the larger context of health care utilization trends in the United States. We found that marginal quarterly increases in clinic visit numbers had essentially identical small positive effects (not statistically significant) on the growth of CT, MR imaging, or US procedure volumes both before and after the implementation of the ROE and DS system. However, imaging procedure volumes did indeed increase substantially during the study (at least before ROE and DS system implementation). This reflects national trends in which the absolute growth of imaging (and many other medical procedures) volumes is not driven by population increases or demographic trends but by greater intensity of utilization on a per-capita basis (2,15,16).

Our study had certain limitations. We assume (but cannot prove) that the trends we have demonstrated are because of actual imaging practice alteration caused by implementation of the ROE and DS system and not primarily because of changes in where the tests were performed (ie, leakage to other imaging providers). We believe that a large majority of the outpatient imaging volume in our practice is referred by physicians in the associated professional organization and those practicing at affiliated clinics. This assumption justifies using outpatient visit volume as a control variable in our analysis of imaging volumes. Because there was no control group, we could not specifically account for unmeasured external factors operating regionally and nationally that might have served as confounders. These include increasing use of benefits management and precertification for outpatient imaging and changes in reimbursement rates, as well as the above-mentioned concerns about radiation at CT (12–14,17,18). We can address the first issue by noting that the order entry system was implemented within specific contractual agreements between our group practice and major regional payers to accept ROE and DS system claims without precertification for CT and MR imaging. Among these were pay-for-performance incentives and/or withholds, affecting the faculty group practice as a whole, that were contingent on reduction of high-cost

Table 2

Regression Model Results for Estimated Slopes

Parameter	Model/ Coefficient	CT Examinations per Quarter	MR Imaging Examinations per Quarter	US Examinations per Quarter
Before ROE and DS system implementation				
Baseline volume	Model 1/$\alpha_1 + \beta_1$	8003 (6682, 9318)	5079 (4271, 5887)	8122 (7248, 8996)
Absolute growth	Model 1/β_1	311 (233, 389)	178 (126, 229)	210 (159, 263)
Growth rate	Model 1 (log Y_i)/β_1	3.0 (2.4, 3.6)*	2.9 (2.1, 3.6)*	2.2 (1.7, 2.7)*
After ROE and DS system implementation				
Absolute growth	Model 1/β_2	37 (− 70, 143)	157 (93, 221)	112 (34, 191)
Growth rate	Model 1 (log Y_i)/β_2	0.25 (−0.6, 1.1)*	1.7 (0.74, 2.6)*	0.90 (0.17, 2.7)*
Difference				
Absolute growth	Model2/β_3	−274 ($P < .001$)	−21 ($P = .51$)	−98 ($P = .014$)
Growth rate	Model 2 (log Y_i)/β_3	−2.75* ($P < .001$)	−1.2* ($P = .016$)	−1.3* ($P = .001$)

Note.—Unless otherwise indicated, data are number of examinations, with 95% confidence intervals around the estimated slopes in parentheses. For differences, numbers in parentheses indicate probability that the observed effect was different from zero.

*Data are percentages.

Table 3

Effect of Outpatient Visit Volume on Imaging Procedure Volume

Parameter	Model/ Coefficient	CT Examinations per Quarter	MR Imaging Examinations per Quarter	US Examinations per Quarter
Before ROE and DS system implementation	Model 1/β_4	8.3 (−7.4, 24)	6.1 (−3, 15)	3.9 (−6.5, 14)
After ROE and DS system implementation	Model 1/β_5	7.3 (−8, 22)	5.9 (−3.1, 15)	4.1 (−5.9, 14)

Note.—The numbers represent the incremental change in quarterly imaging procedure volume associated with an n of 1000 increase in quarterly outpatient visits. Data in parentheses are 95% confidence intervals.

outpatient imaging utilization rates. We estimate that at most 10% of CT and 15% of MR imaging studies in our sample were ordered for patients covered under other payer arrangements that might have been subject to external precertification. Even if the referring physicians decreased their utilization in this subset of our overall outpatient imaging practice, our inferences about the majority—using the ROE and DS system and exempt from precertification—would be minimally biased.

As for national trends, there is some evidence that utilization decelerated after 2005. For example, in the Medicare program, the growth in service units per beneficiary for CT (other than that for CT of the head, which accelerated slightly) decreased from 12.1 to 10.0 through this period. This does not mean that advanced imaging utilization decreased, just that the intensity growth slowed slightly. In fact, only radiography actually decreased in absolute terms during this period (19). In contrast, from 2005 to 2007, our outpatient CT scan volume was almost flat, and we believe that the majority of this much larger effect was because of ROE and DS system implementation.

In conclusion, we have demonstrated significant and substantial decreases in the growth rate of outpatient diagnostic CT, MR imaging, and US examination volume in our large urban academic health center, despite continued steady growth in outpatient visit activity. These decelerations occurred after we implemented a computerized ROE system for all three modalities supplemented with appropriateness feedback for CT and MR imaging. We believe that reduction in US growth is because of the gatekeeper effect of ROE without DS. The relatively small change in MR imaging volumes after ROE and DS system implementation may be because of substitution of MR imaging for CT in some cases. Finally, outpatient visit activity had little or no effect on any of these trends, which implies that what we are observing, and hopefully reducing, is imaging intensity creep.

References

1. Medicare Payment Advisory Commission. Report to Congress: variation and innovation in medicine. Washington, DC: Medicare Payment Advisory Commission, June 2003.
2. Medicare Payment Advisory Commission. Testimony before Congress: MedPAC recommendations on imaging services. March 17, 2005.
3. Medicare Payment Advisory Commission. Testimony before Congress: MedPAC recommendations on imaging services. July 18, 2006.
4. Rothenberg BM, Korn A. The opportunities and challenges posed by the rapid growth of diagnostic imaging. J Am Coll Radiol 2005;2:407–410.
5. Otero HJ, Ondategui-Parra S, Nathanson EM, Erturk SM, Ros PR. Utilization management in radiology: basic concepts and applications. J Am Coll Radiol 2006;3:351–357.
6. Rosenthal DI, Weilburg JB, Schultz T, et al. Radiology order entry with decision support: initial clinical experience. J Am Coll Radiol 2006;3:799–806.
7. Sistrom CL. In support of the ACR Appropriateness Criteria. J Am Coll Radiol 2008;5:630–635.
8. Sistrom CL. The ACR appropriateness criteria: translation to practice and research. J Am Coll Radiol 2005;2:61–67.
9. Vydareny KH. New tools from the ACR (American College of Radiology): appropriateness criteria and utilization analysis. Radiol Manage 1997;19:40–45.
10. Blachar A, Tal S, Mandel A, et al. Preauthorization of CT and MRI examinations: assessment of a managed care preauthorization program based on the ACR Appropriateness Criteria and the Royal College of Radiology guidelines. J Am Coll Radiol 2006;3:851–859.
11. Levy G, Blachar A, Goldstein L, et al. Nonradiologist utilization of American College of Radiology Appropriateness Criteria in a preauthorization center for MRI requests: applicability and effects. AJR Am J Roentgenol 2006;187:855–858.
12. Brenner DJ, Hall EJ. Computed tomography: an increasing source of radiation exposure. N Engl J Med 2007;357:2277–2284.
13. Cascade PN. Unnecessary imaging and radiation risk: the perfect storm for radiologists. J Am Coll Radiol 2004;1:709–711.
14. Problematic medical scans [editorial]. New York Times. November 11, 2007.
15. Bodenheimer T. High and rising health care costs. I. Seeking an explanation. Ann Intern Med 2005;142:847–854.
16. Bodenheimer T. High and rising health care costs. II. Technologic innovation. Ann Intern Med 2005;142:932–937.
17. Medicare Payment Advisory Commission. Report to Congress: reforming the delivery system. Washington, DC: Medicare Payment Advisory Commission, June 2008.
18. Peddecord KM, Janon EA, Robins JM. Substitution of magnetic resonance imaging for computed tomography: an exploratory study. Int J Technol Assess Health Care 1988;4:573–591.
19. Medicare Payment Advisory Commission. Report to Congress: Medicare payment policy. Washington, DC: Medicare Payment Advisory Commission, March 2008.