

Supplementary Online Content

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eTable 1. Baseline diagnostic categories and *ICD-9-CM* diagnosis codes included in each

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This supplementary material has been provided by the authors to give readers additional information about their work.

eTable 1. Baseline diagnostic categories and ICD-9-CM diagnosis codes included in each.

Axial Back Pain Alone		Lumbar Spinal Stenosis	
721.3	Lumbosacral spondylosis without myelopathy	724.0	Spinal stenosis other than cervical
721.9	Spondylosis, unspecified site	724.00	Spinal stenosis, unspecified region
722.5	Degeneration, thoracic or lumbar disc	724.01	Thoracic stenosis
722.51	Degeneration, thoracic or thoracolumbar intervertebral disc	724.02	Lumbar stenosis
722.52	Degeneration, lumbar or lumbosacral intervertebral disc	724.03	Lumbar stenosis with neurogenic claudication
722.6	Degeneration of intervertebral disc, site unspecified	Other Diagnoses	
724.2	Lumbago	721.6	Ankylosing vertebral hyperostosis
724.5	Backache, unspecified	722.11	Thoracic disc displacement
724.6	Disorders of sacrum	722.3	Schmorl's nodes
739.4	Nonallopathic lesion, sacral	722.93	Other disc disorder, lumbar
846.0	Sprains & strains, lumbosacral	724.1	Pain in thoracic spine
847.2	Sprains & strains, lumbar	733.13	Pathologic fracture of vertebrae
847.3	Sprains & strains, sacrum	738.4	Acquired spondylolisthesis
847.9	Sprains & strains, unspecified site of back	738.5	Other acquired deformity of spine
Back and Leg pain or Herniated Disc		739.2	Nonallopathic lesions, thoracic
722.1	Displacement of thoracic or lumbar disc without myelopathy	756.11	Spondylolysis
722.10	Displacement lumbar disc without myelopathy	756.12	Spondylolisthesis
722.2	Displacement of disc without myelopathy	846.9	Sprain, unspecified site, sacroiliac region
724.3	Sciatica	847.1	Sprain thoracic region
724.4	Thoracic or lumbosacral neuritis or radiculitis	999.99	Specialty code: non-specified indication

eText. Use and verification of natural language processing algorithm used to identify malignancy in imaging reports.

We developed an algorithm with high sensitivity in detecting any indication of cancer among the 5239 radiology reports. First, we string matched the reports against the word list detailed above in the Python programming language. We processed these reports ignoring any capitalization and punctuation associated with the keywords. Next, we defined a “match” as reports containing one or more occurrence of one or more of the keywords.

We found 297 imaging reports with a “ match”. An investigator (SDR) read these 297 reports and classified the findings for a cancer diagnosis as: yes, no, or possible. Then a neuroradiologist co-author (JGJ) reviewed all the reports marked "yes" or "possible" and determined which reports were indicative of a spine cancer diagnosis. Lastly, these diagnoses of spine cancer were either confirmed or not confirmed by review of the participants electronic health record at the study site (ALA).

eTable 2. Type of imaging by CPT code. Note: includes any spine imaging that occurred between day 0 and day 42 (inclusive). Some patients had >1 image.

CPT Code (Description)	Frequency	Percent
72020 (radiograph, cervical spine)	2	0.1%
72069 (radiograph, scoliosis)	1	0.05%
72070 (radiograph, thoracic spine)	110	5.9%
72072 (radiograph, thoracic spine)	23	1.2%
72074 (radiograph, thoracic spine)	2	0.1%
72080 (radiograph, trunk spine)	2	0.1%
72100 (radiograph, lower spine)	1102	59%
72110 (radiograph, lower spine)	16	0.9%
72114 (radiograph, lower spine)	29	1.6%
72120 (radiograph, spine, lumbosacral)	11	0.6%
72128 (CT chest spine w/out dye)	7	0.4%
72129 (CT chest spine w/ dye)	6	0.3%
72131 (CT lumbar spine w/out dye)	60	3.2%
72132 (CT lumbar spine w/dye)	8	0.4%
72146 (MRI spine, thoracic, w/out dye)	21	1.1%
72148 (MRI lumbar spine w/out dye)	403	22%
72149 (MRI lumbar spine w/ dye)	1	0.05%
72157 (MRI thoracic spine w, w/out dye)	9	0.5%
72158 (MRI lumbar spine w/, w/out dye)	30	1.6%
72265 (Contrast radiograph, lower spine)	1	0.1%
72270 (Contrast radiograph of spine)	2	0.1%
77012 (CT scan for needle biopsy)	7	0.4%
77074 (Osseous survey (metastatic))	1	0.05%
77075 (Radiograph, osseous survey axial & appendicular)	1	0.05%
TOTAL	1885	100

Abbreviations: CPT= current procedural terminology; CT=computed tomography; MRI=magnetic resonance imaging.

eTable 3. No-Early Imaging vs. Early Radiograph Health Care Utilization, Costs, and Falls

Variables	No-Early Radiograph (n=1174)	Early Radiograph (n=1174)	Radiograph vs None: Raw Difference Between Means (95% CI)	Radiograph vs None: Standardized Difference (%)	Mixed Model Estimate (95% CI)^a	Mixed Model P Value
Relative value units						
Overall						
Mean	49.1	71.0				
Median (range)	22.4 (0 to 1050)	29.2 (0 to 1600)	21.9 (11.9 to 31.9)	17.5	22.3 (12.3 to 32.3)	<.001
Overall Spine						
Mean	6.07	18.7	16.4			
Median (range)	0 (0 to 870)	0 (0 to 1480)	12.7 (6.4 to 18.9)		12.7 (6.41 to 19.0)	<.001
Physical Therapy Spine						
No.	67 ^b	93 ^b				
Mean	0.23	0.35	0.12 (0.0042 to 0.24)	8.27	0.12 (0.0045 to 0.24)	.04
Median (range)	0 (10 to 21.8)	0 (0 to 23.7)				
Spine Injections						
No.	66 ^b	123 ^b				
Mean	0.43	1.16	0.73 (0.33 to 1.12)	14.9	0.73 (0.33 to 1.13)	<.001
Median (range)	0 (0 to 64.0)	0 (0 to 137)				
Spine Imaging						
No.	210 ^b	336 ^b				
Mean	1.55	3.88	2.32 (1.67 to 2.97)	28.8	2.32 (1.67 to 2.96)	<.001
Median (range)	0 (0 to 76.4)	0 (0 to 227)				
Spine Surgery						

Variables	No-Early Radiograph (n=1174)	Early Radiograph (n=1174)	Radiograph vs None: Raw Difference Between Means (95% CI)	Radiograph vs None: Standardized Difference (%)	Mixed Model Estimate (95% CI)^a	Mixed Model P Value
No.	15 ^b	26 ^b				
Mean	2.84	10.6	7.76 (2.39 to 13.1)	11.7	7.81 (2.39 to 13.2)	.005
Median (range)	0 (0 to 729)	0 (0 to 1280)				
Payments, \$						
Overall						
Mean	4650	6030	1380 (692 to 2060)	15.8	1410 (726 to 2100)	<.001
Median (range)	2630 (0 to 61 700)	2900 (0 to 114 000)				
Overall Spine						
Mean	348	1040	694 (364 to 1020)	17.0	697 (363 to 1030)	<.001
Median (range)	0 (0 to 51 400)	0 (0 to 79 500)				
Physical Therapy Spine						
Mean	14.1	20.5	6.33 (-1.08 to 13.7)	6.86	6.35 (-1.08 to 13.8)	.09
Median (range)	0 (0 to 1430)	0 (0 to 1460)				
Spine Injections						
Mean	55.2	134	78.9 (32.6 to 125)	13.8	79.2 (32.4 to 126)	.001
Median (range)	0 (0 to 6210)	0 (0 to 16 900)				
Spine Imaging	82.3, 0 (0 to 4230)	205, 0 (0 to 12 700)	123 (87.1 to 158)	28.1	122 (17.9 to 87.3)	<.001
Spine Surgery						
Mean	153	549	396 (117 to 674)	11.5	398 (117 to 679)	.006
Median (range)	0 (0 to 41 900)	0 (0 to 66 800)				
Drug costs (overall), \$						

Variables	No-Early Radiograph (n=1174)	Early Radiograph (n=1174)	Radiograph vs None: Raw Difference Between Means (95% CI)	Radiograph vs None: Standardized Difference (%)	Mixed Model Estimate (95% CI)^a	Mixed Model P Value
Mean	861	917				
Median (range)	355 (0 to 34 300)	354 (0 to 56 800)	55.9 (to 124 to 236)	2.51	62.7 (−118 to 243)	.50
Opioid costs, \$						
Mean	21.6	25.4	3.80 (−3.16 to 10.8)	4.30	4.00 (−2.96 to 11.0)	.26
Median (range)	0 (0 to 1790)	0 (0 to 1740)				
Falls						
3 mo						
Mean	0.09	0.08	−0.017 (−0.041 to 0.0078)	−5.35	−0.015 (−0.04 to 0.008)	.20
Median (range)	0 (0 to 1)	0 (0 to 1)				
6 mo	0.10					
Mean		0.09	−0.013 (−0.041 to 0.014)	−3.97	−0.011 (−0.03 to 0.01)	.36
Median (range)	0 (0 to 1)	0 (0 to 1)				
12 mo						
Mean	0.10	0.10	0.0065 (−0.021 to 0.034)	−0.27	−0.0007(−0.02 to 0.02)	.96
Median (range)	0 (0 to 1)	0 (0 to 1)				

^aAdjusted for sex, age, diagnosis (axial back pain only, back and leg, spinal stenosis or other), back pain duration and total RVUs in the year prior to the index visit.

^bNumber of people who had >0 RVUs in that category.

eTable 4. No-Early Imaging vs. Early MRI/CT Health Care Utilization, Costs, and Falls

Variables	MRI/CT		MRI/CT vs None		Mixed-Model Estimate (95% CI) ^a	Mixed Model P Value
	No-Early (n=349)	Early (n=349)	Raw Difference Between Means (95% CI)	Standardized Difference, %		
Relative value units						
Overall						
Mean	58.4	87.4	28.9 (6.51 to 51.4)	19.3	28.7 (6.52 to 50.9)	.01
Median (range)	20.1 (0 to 1490)	34.2 (0 to 1610)				
Overall Spine						
Mean	9.24	32.3	23.1 (7.93 to 38.3)	22.8	23.2 (8.23 to 38.1)	.002
Median (range)	0 (0 to 834)	1.0 (0 to 1360)				
Physical Therapy Spine						
No.	24 ^b	54 ^b				
Mean	0.31	0.60				
Median (range)	0 (0 to 12)	0 (0 to 11.8)	0.29 (0.09 to 0.48)	17.9	0.27 (0.08 to 0.46)	.005
Spine Injections						
No.	31 ^b	107 ^b				
Mean	0.55	2.51				
Median (range)	0 (0 to 26)	0 (0 to 44.6)	1.95 (1.24 to 2.66)	41.7	1.97 (1.27 to 2.67)	.001
Spine Imaging						
No.	80 ^b	143 ^b				
Mean	1.98	3.13				
Median (range)	0 (0 to 38.9)	0 (0 to 51.8)	1.14 (0.25 to 2.04)	19.1	1.16 (0.30 to 2.02)	.008
Spine Surgery						
No.	5 ^b	21 ^b				

Variables	MRI/CT		MRI/CT vs None		Mixed-Model Estimate (95% CI) ^a	Mixed Model P Value
	No-Early (n=349)	Early (n=349)	Raw Difference Between Means (95% CI)	Standardized Difference, %		
Mean	2.79	24.5				
Median (range)	0 (0 to 809)	0 (0 to 1220)	21.7 (8.21 to 35.2)	24.0	21.9 (8.64 to 35.1)	.001
Payments, \$						
Overall						
Mean	5210	6630				
Median (range)	2350 (0 to 75 240)	3050 (0 to 91 370)	1430 (36.8 to 2820)	15.2	1420 (42.9 to 2790)	.04
Overall Spine						
Mean	553	1900	1350 (510 to 2180)	24.1	1350 (534 to 2170)	.001
Median (range)	0 (0 to 45 900)	68.0 (0 to 75 000)				
Physical Therapy Spine						
Mean	18.5	31.1				
Median (range)	0 (0 to 951)	0 (0 to 589)	12.7 (1.18 to 24.1)	14.1	12.1 (1.17 to 23.1)	.03
Spine Injections						
Mean	69.3	300				
Median (range)	0 (0 to 2160)	0 (0 to 5790)	230 (150 to 311)	43.0	232 (152 to 312)	<.001
Spine Imaging						
Mean	105	167				
Median (range)	0 (0 to 2000)	0 (0 to 2840)	62.5 (15.0 to 110)	19.6	143 (-126 to 412)	.30
Spine Surgery						
Mean	163	1320				
Median (range)	0 (0 to 44 600)	0 (0 to 67 200)	1160 (425 to 1900)	23.6	1170 (449 to 1900)	.002
Drug costs (overall), \$						

Variables	MRI/CT		MRI/CT vs None		Mixed-Model Estimate (95% CI) ^a	Mixed Model P Value
	No-Early (n=349)	Early (n=349)	Raw Difference Between Means (95% CI)	Standardized Difference, %		
Mean	927	785				
Median (range)	325 (0 to 31 600)	329 (0 to 21 700)	-141.6 (-421 to 138)	-7.29	-143 (-415 to 128)	.30
Opioid costs, \$						
Mean	33.6	37.9				
Median (range)	0 (0 to 2430)	0 (0 to 2030)	4.25 (-18.1 to 26.6)	2.73	4.33 (-16.0 to 24.7)	.68
Falls						
3 mo						
Mean	0.12	0.12	-0.0069 (-0.060 to 0.046)	0.19	0.004 (-0.04 to 0.05)	.87
Median (range)	0 (0 to 1)	0 (0 to 1)				
6 mo						
Mean	0.10	0.10	-0.0073 (-0.055 to 0.040)	0.42	0.002 (-0.04 to 0.05)	.94
Median (range)	0 (0 to 1)	0 (0 to 1)				
12 mo						
Mean	0.13	0.11	-0.032 (-0.082 to 0.019)	-7.12	-0.02 (-0.07 to 0.03)	.39
Median (range)	0 (0 to 1)	0 (0 to 1)				

^aAdjusted for sex, age, diagnosis (axial back pain only, back and leg, spinal stenosis or other), back pain duration and total RVUs in the year prior to the index visit.

^bNumber of people who had >0 RVUs in that category.

eTable 5. Baseline Measures: Unmatched Early Imaging vs. No-Early Imaging Patients

Variable	No-Early Radiograph (n=3223)	Early Radiograph ^a (n=1264)	P-value ^b : Radiograph vs none	No-Early MRI/CT (n=3223)	Early MRI/CT ^a (n=366)	P-Value ^b : MRI/CT vs None
Age, mean (SD) ^c , years	73.5 (6.8)	74.5 (7.0)	<0.001	73.5 (6.8)	72.8 (6.1)	0.04
Female, No. ^d (%)	2084 (65%)	824 (65%)	0.74	2084 (65%)	242 (66%)	0.58
Study Site, No. (%)						
Henry Ford	498 (15%)	283 (22%)		498 (15%)	76 (21%)	
Kaiser	2011 (62%)	844 (67%)		2011 (62%)	222 (61%)	0.02
Harvard Vanguard	714 (22%)	137 (11%)	<0.001	714 (22%)	68 (19%)	
Race, No. (%)						
Black/African American	490 (15%)	176 (14%)		490 (15%)	67 (18%)	
Asian	125 (3.9%)	56 (4.5%)		125 (3.9%)	11 (3.0%)	
Caucasian	2351 (74%)	937 (75%)	0.55	2351 (74%)	265 (73%)	0.39
Other/Multiple	221 (6.9%)	81 (6.5%)		221 (6.9%)	22 (6.0%)	
Hispanic, No. (%)	195 (6.1%)	76 (6.0%)	0.96	195 (6.1%)	19 (5.2%)	0.51
Education, No. (%)						
< High school	172 (5.3%)	88 (7.0%)		172 (5.3%)	27 (7.4%)	
High school, trade school, or some college	1650 (51%)	702 (56%)	0.001	1650 (51%)	193 (53%)	0.28
College graduate	824 (26%)	263 (21%)		824 (26%)	84 (23%)	
Graduate degree	570 (18%)	208 (16%)		570 (18%)	60 (16%)	
Married/Living with partner, No. (%)	1966 (61%)	740 (59%)	0.15	1966 (61%)	221 (61%)	0.88
Smoking status, No. (%)						
Never smoked	1772 (55%)	691 (55%)		1772 (55%)	201 (55%)	
Quit>1 year ago	1254 (39%)	488 (39%)	0.81	1254 (39%)	141 (39%)	

Variable	No-Early Radiograph (n=3223)	Early Radiograph ^a (n=1264)	P-value ^b : Radiograph vs none	No-Early MRI/CT (n=3223)	Early MRI/CT ^a (n=366)	P-Value ^b : MRI/CT vs None
Current smoker	190 (5.9%)	81 (6.4%)		190 (5.9%)	21 (5.8%)	0.99
Quan Comorbidity, No (%)						
0 Comorbidities	481 (15%)	228 (18%)		481 (15%)	46 (13%)	
1 Comorbidity	1205 (37%)	418 (33%)	0.005	1205 (37%)	135 (37%)	0.40
>1 Comorbidity	1537 (48%)	618 (49%)		1537 (48%)	185 (51%)	
Baseline Diagnosis, No. (%)						
Non-Specific Back Pain Only	2235 (69%)	867 (69%)		2235 (69%)	180 (49%)	
Back and Leg Pain	603 (19%)	292 (23%)	<0.001	603 (19%)	146 (40%)	<0.001
Lumbar Stenosis	197 (6.1%)	29 (2.3%)		197 (6.1%)	29 (7.9%)	
Other	188 (5.8%)	76 (6.0%)		188 (5.8%)	11 (3.0%)	
Pain Duration, No. (%)						
<1 month	1087 (34%)	458 (36%)		1087 (34%)	96 (26%)	
1-3 months	553 (17%)	305 (24%)		553 (17%)	91 (25%)	
3-6 months	182 (5.7%)	114 (9.0%)		182 (5.7%)	30 (8.2%)	
6-12 months	165 (5.1%)	88 (7.0%)	<0.001	165 (5.1%)	33 (9.0%)	<0.001
1-5 years	519 (16%)	144 (11%)		519 (16%)	50 (14%)	
>5 years	714 (22%)	155 (12%)		714 (22%)	65 (18%)	
Confidence pain will improve in 3 months, No. (%)						
0 (not at all confident)	734 (23%)	207 (16%)		734 (23%)	55 (15%)	
1-4	437 (14%)	202 (16%)		437 (14%)	61 (17%)	
5	490 (15%)	199 (16%)	<0.001	490 (15%)	76 (21%)	<0.001
6-9	827 (26%)	407 (32%)		827 (26%)	98 (27%)	
10 (extremely confident)	730 (23%)	246 (20%)		730 (23%)	73 (20%)	

Variable	No-Early Radiograph (n=3223)	Early Radiograph ^a (n=1264)	P-value ^b : Radiograph vs none	No-Early MRI/CT (n=3223)	Early MRI/CT ^a (n=366)	P-Value ^b : MRI/CT vs None
Prior Imaging ^e , No. (%)	296 (9.2%)	47 (4.5%)	<0.001	296 (9.2%)	51 (14%)	0.004
Baseline RMDQ ^f mean (SD)	8.8 (6.4)	10.8 (6.0)	<0.001	8.8 (6.4)	12.7 (5.9)	<0.001
Baseline BPI, ^g mean (SD)	3.0 (2.4)	3.7 (2.4)	<0.001	3.0 (2.4)	4.6 (2.5)	<0.001
Baseline EQ5D Index, ^h mean (SD)	0.77 (0.17)	0.73 (0.18)	<0.001	0.77 (0.17)	0.67 (0.19)	<0.001
Baseline EQ5D VAS, ⁱ mean (SD)	76 (18)	73 (18)	<0.001	76 (18)	70 (19)	<0.001
Baseline PHQ4, ^j mean (SD)	1.4 (2.4)	1.8 (2.6)	<0.001	1.4 (2.4)	2.2 (3.0)	<0.001
Baseline ≥1 fall past 3 weeks, No. (%)	206 (6.4%)	120 (9.5%)	<0.001	206 (6.4%)	34 (9.3%)	0.03
Baseline back pain NRS ^k (0-10), mean (SD)	4.8 (2.8)	5.5 (2.7)	<0.001	4.8 (2.8)	5.2 (3.2)	<0.001
Baseline leg pain NRS ^k (0-10), mean (SD)	3.2 (3.2)	3.7 (3.3)	<0.001	3.2 (3.2)	5.2 (3.2)	<0.001
Total RVUs ^l prior year, mean (SD)	36 (84)	38 (87)	0.58	36 (84)	41 (95)	0.31

^aRadiograph group could have received subsequent MRI or CT in days 0-42 (n=138); MRI/CT group could have received same day or subsequent radiograph in days 0-42 (n=37). In both analyses, controls could not have received radiograph or MRI/CT in days 0-42.

^b Chi-Square test used to obtain p-values

^cSD= standard deviation

^d No.=number

^e Defined as spine imaging at the healthcare site in 365 days prior to index visit.

^fRMDQ: Roland-Morris Disability Questionnaire. Range is 0 (no pain-related limitations) - 24 (maximum pain-related limitations).

^gBPI: Brief Pain Inventory Interference. Range is 0 (no pain interference)-10 (maximum pain interference)

^hEQ-5D Index:EuroQuol Group Index score. Range is 0 (death)-1 (perfect health)

ⁱEQ-5D VAS:EuroQuol Group Visual Analog Scale. Range is 0 (worst imaginable health state)-100 (best imaginable health state)

^jPHQ-4:Patient Health Questionnaire. Range is 0 (no depression/anxiety)-12 (most severe depression/anxiety)

^kNRS: Numeric Rating Scale. Range is 0 (no pain)-10 (pain as bad as you can imagine)

^l RVU: Relative value unit