A pilot study for long-term outcome assessment after aortic aneurysm repair using Vascular Quality Initiative data matched to Medicare claims

Andrew W. Hoel, MD,[a] Adrienne E. Faerber, PhD,[b] Kayla O. Moore, MS,[b] Niveditta Ramkumar, MS,[b] Benjamin S. Brooke, MD, PhD,[c] Salvatore T. Scali, MD,[d] Art Sedrakyan, MD, PhD,[e] *and* Philip P. Goodney, MD, MS,[b,f] *Chicago, Ill; Lebanon, NH; Salt Lake City, Utah; Gainesville, Fla; and New York, NY*

ABSTRACT

Objective: Accurate and complete long-term postoperative outcome data are critical to improving value in health care delivery. The Society for Vascular Surgery Vascular Quality Initiative (VQI) is an important tool to achieve this goal in vascular surgery. To improve on the capture of long-term outcomes after vascular surgery procedures for patients in the VQI, we sought to match VQI data to Medicare claims for comprehensive capture of major clinical outcomes in the first several years after vascular procedures.

Methods: Patient and procedure characteristics for abdominal aortic aneurysm procedures captured in the Society for Vascular Surgery VQI between January 1, 2002, and December 31, 2013, were matched to Medicare claims data using an indirect identifier methodology. Late outcomes captured in the VQI and in Medicare claims were compared.

Results: Matching procedures yielded 9895 endovascular aneurysm repair (EVAR) patients (82.4% of eligible VQI patients) and 3405 open aneurysm repair (OAR) patients (74.4% of eligible). Comparison of patients who did and did not match to a Medicare claim demonstrated similar patient and procedure characteristics. Evaluation of late outcomes revealed good patient-level agreement on mortality for both EVAR (κ, 0.64) and OAR (κ, 0.82). Postoperative reintervention rates demonstrated lower agreement for both EVAR (κ, 0.26) and OAR (κ, 0.16).

Conclusions: This work demonstrates the feasibility of an algorithm using indirect identifiers to match VQI patients and procedures to Medicare claims data. The refinement of this strategy will focus on establishing and improving algorithms related to identifying and categorizing late events after EVAR and may serve as a mechanism to ensure that the best quality follow-up information is achieved within the VQI. (J Vasc Surg 2017;66:751-9.)

The Society for Vascular Surgery Vascular Quality Initiative (SVS VQI) is an Agency for Healthcare Research and Quality (AHRQ) Patient Safety Organization (PSO) with restrictions and protections on the use of patient, procedure, and outcome information for the express use of quality improvement and research.[1] Data are prospectively collected by participating centers within the PSO and composed in a secure setting, allowing deidentified outcome comparisons between participating provider groups. VQI data are collected for the perioperative period and at 1 year in follow-up, giving the ability to evaluate perioperative and late outcomes.[2]

The emphasis on outcomes beyond the perioperative period represents a unique element of the VQI and reflects the chronic nature of vascular disease. However, comprehensive collection of long-term outcome data is time-consuming and problematic. For example, prior research has shown considerable variation in follow-up at 1 year within the VQI for patient, provider, and center-specific reasons.[3] Whereas the explicit goal is to provide at least 80% follow-up for all procedures entered in the VQI, recent review of data entered suggests that the rate of 1-year follow-up is substantially below this threshold.[4]

Vascular disease affects older Americans, many of whom are 65 years and older and are enrolled in Medicare. The comprehensive data available in Medicare claims afford an opportunity to track outcomes for patients undergoing procedures tracked by VQI regardless of location and time of follow-up. The strategy of matching specific patient data to Medicare claims has been used by institutions[5-7] and by registries such as the Surveillance, Epidemiology, and End Result Program,[8-11] National Cardiovascular Data Registry,[12,13] and National Surgical Quality Improvement Program[14] with various strategies. In particular, many have used an

From the Division of Vascular Surgery, Northwestern University Feinberg School of Medicine, Chicago[a]; The Dartmouth Institute, Lebanon[b]; the Division of Vascular Surgery, University of Utah School of Medicine, Salt Lake City[c]; the Division of Vascular Surgery, University of Florida School of Medicine, Gainesville[d]; the Weill Cornell Medical College, New York[e]; and the Section of Vascular Surgery, Geisel School of Medicine at Dartmouth, Lebanon.[f]

P.P.G. and A.S. were supported by U01 FD005478 (A.S., principal investigator) from the U.S. Food and Drug Administration for creation of the Vascular Implant Surveillance and Interventional Outcomes Network (VISION).

Author conflict of interest: none.

Additional material for this article may be found online at www.jvascsurg.org.

Correspondence: Andrew W. Hoel, MD, Division of Vascular Surgery, Northwestern University Feinberg School of Medicine, 676 N St. Clair St, Ste 650, Chicago, IL 60611 (e-mail: awhoel@nm.org).

The editors and reviewers of this article have no relevant financial relationships to disclose per the JVS policy that requires reviewers to decline review of any manuscript for which they may have a conflict of interest.

0741-5214

http://dx.doi.org/10.1016/j.jvs.2016.12.100

indirect identifier strategy whereby patient information available in both registry data and Medicare claims are the data fields for linkage, including date and location of the procedure and birth date and gender of the patient.[7,12,13]

Here we describe our efforts to evaluate the feasibility and potential of using indirect identifiers to match VQI data with Medicare claims data. Whereas matching efforts have been performed for nearly all procedures entered in the VQI data set, as a descriptive model herein we describe the treatment of infrarenal abdominal aortic aneurysm by either endovascular aneurysm repair (EVAR) or open aneurysm repair (OAR).

ARTICLE HIGHLIGHTS

- **Type of Research:** Retrospective case-control pilot study
- **Take Home Message:** This work demonstrates the feasibility of an algorithm using indirect identifiers to match Vascular Quality Initiative (VQI) patients and procedures to Medicare claims data.
- **Recommendation:** The authors suggest additional methodologic refinements before the validity and accuracy of currently available outcomes data can be determined.

METHODS

Data source. Procedure and perioperative data for patients undergoing EVAR and OAR are entered by each participating center into the VQI registry using a web-based system maintained by M2S, Inc (Lebanon, NH). At the time of 1-year follow-up (defined as 9 to 21 months after the procedure), additional outcome data are collected and similarly maintained and protected. Patient-specific, perioperative VQI data contain presurgical, surgical, and in-hospital postoperative information. Follow-up data include death, reinterventions, and procedure-specific outcomes. Data collection in the VQI began in 2003.

The Medicare inpatient claims data set contains reimbursed inpatient hospital claims for Medicare beneficiaries. Hospitals, providers, and beneficiaries were identifiable with unique identification numbers that allowed linking across annual data sets. Until December 31, 2005, a random 20% of claims were available, and afterward 100% of claims were available. Longitudinal data were not available for Medicare beneficiaries who are enrolled in non-fee-for-service health maintenance organization programs, such as Medicare Part C or a Medicare Advantage plan. Patients who left Medicare fee-for-service and entered any of these alternative programs were censored at the time of their switch. The Medicare Denominator File was used to identify death dates. To reduce computational burden of matching with VQI data, the Medicare data set was restricted to patients with a hospital admission containing International Classification of Diseases, Ninth Revision (ICD-9) procedure codes for open or endovascular aortic aneurysm repair.

Data protection. Data collected within the VQI are compiled on servers secured and maintained by M2S, Inc. As a provision of the PSO designation of the SVS VQI, all unique identifiers of patient, provider, and center are prohibited from dissemination. Mortality data are derived from center reporting and supplemented by linkage to the Social Security Death Index (SSDI) database.

Medicare inpatient claims data are secured and maintained within The Dartmouth Institute-Data Analytic Core (TDI-DAC). Matching of VQI and Medicare claims data is performed within the TDI-DAC with VQI data provided from M2S, Inc, through secure crosswalk that maintains data integrity and confidentiality as outlined in the SVS PSO charter (Fig 1). The data security, data use, and analytic plan were all evaluated by the SVS VQI and TDI-DAC, and this work was approved by the Dartmouth College Institutional Review Board.

Matching. Because direct patient and provider identifiers were not legally permissible by AHRQ PSO rules to be exchanged between the VQI and Medicare data sets, matching was performed using an indirect identifier methodology similar to that described previously.[2,7,13] We maximized our matching efficiency through three rounds of a two-step matching process (Fig 2). This two-step process was developed after pilot testing of several one-step processes to determine which combinations would yield the highest number of direct matches, without the occurrence of duplicative matching (ie, matching of more than one patient to the same Medicare claim record).

In the first step, matching was performed by matching ICD-9 procedure code (Appendix, online only), date of surgery, patient's date of birth and gender, and three-digit zip code prefix of residence on the date of surgery. Exact correlation of all five criteria constitutes a positive match. The second step substituted the National Provider Identifier number of the surgeon or interventionalist for the ICD-9 code; the same strategy was applied to the remaining unmatched patients. These two steps were repeated for two additional rounds of matching. In the second round of matching, zip code was eliminated from the matching process. In the third round, the procedure date was broadened to ±3 days. This strategy of successively less-restrictive matching criteria on a progressively smaller cohort of patients was performed to maximize matching efficiency. Sensitivity analyses revealed that this hierarchical approach among unmatched patients garners additional matches without resulting in duplicative matching.

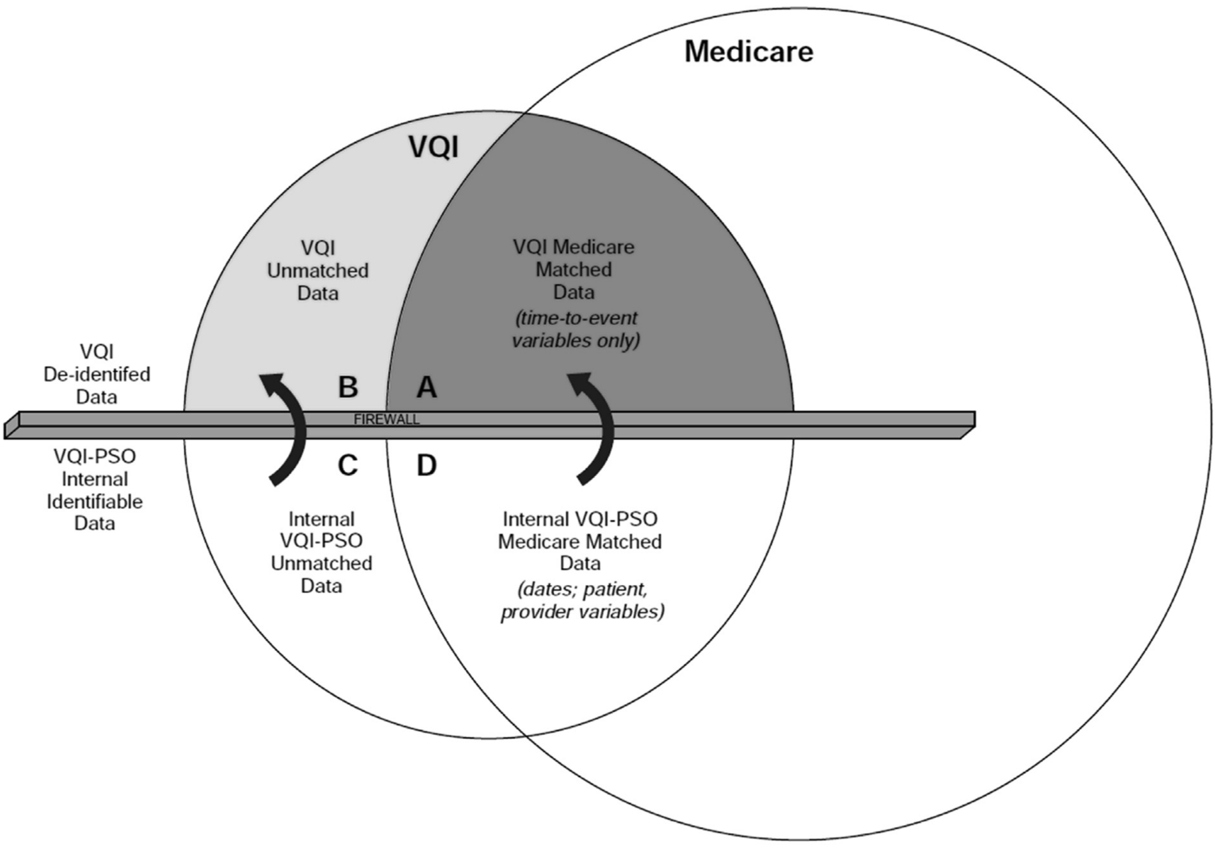

Fig 1. Graphical representation of data security and matching process. All patient and physician identifiers are securely maintained within the Vascular Quality Initiative (*VQI*) and The Dartmouth Institute (TDI) data sets (group C and group D). Only deidentified matched (group A) and unmatched (group B) data leave the secure environment for review, including quality improvement and research work. *PSO,* Patient Safety Organization.

This matching strategy was applied to a cohort of VQI patients 65 years and older who underwent EVAR or OAR between January 2003 (the earliest VQI data) and December 31, 2013 (the latest Medicare data available). Follow-up rates for patients in the VQI registry were between 70% and 75% during the time intervals considered in this study.

Outcomes. Once we had matched cases between the VQI data and the Medicare data, we measured outcomes across all available years (2003-2013) of Medicare inpatient claims data. Outcomes were measured starting on the date of discharge after the hospital admission for the index procedure. Outcomes that occurred during the index hospital admission were not recorded because those are captured in detail in the VQI data set. Late outcomes were defined as within 2 years after the procedure because the 1-year VQI follow-up window between 2003 and 2013 was defined as 9 to 21 months after the procedure.

We identified four outcomes in the Medicare data: death, aortic aneurysm rupture, repeated aortic aneurysm repair procedures, and 90-day hospital readmissions. Death was identified in the Medicare Denominator File. Cause of death is not available in this data set. Aortic aneurysm rupture was recorded as an outcome when inpatient hospital claims indicated that primary diagnosis on a subsequent admission was aortic rupture. However, if someone came to the emergency department with a ruptured aorta and died before admission, that was recorded as a death.

VQI data are linked to mortality data from the SSDI on a biannual basis. Repeated procedures were any secondary abdominal aortic aneurysm repair or intervention for aneurysm-related complications after the index procedure. Ninety-day hospital readmissions were measured for 90 days after discharge from the index hospitalization. Using the array of diagnostic codes that accompany each admission, we categorized the reasons for readmission as being related to the surgery (eg, vascular complication, postoperative infection, cardiac complications; complete list in the Appendix, online only).

As a provision of the PSO designation for the SVS VQI, sharing of potential patient or provider identifying data is prohibited. Therefore, postoperative events were

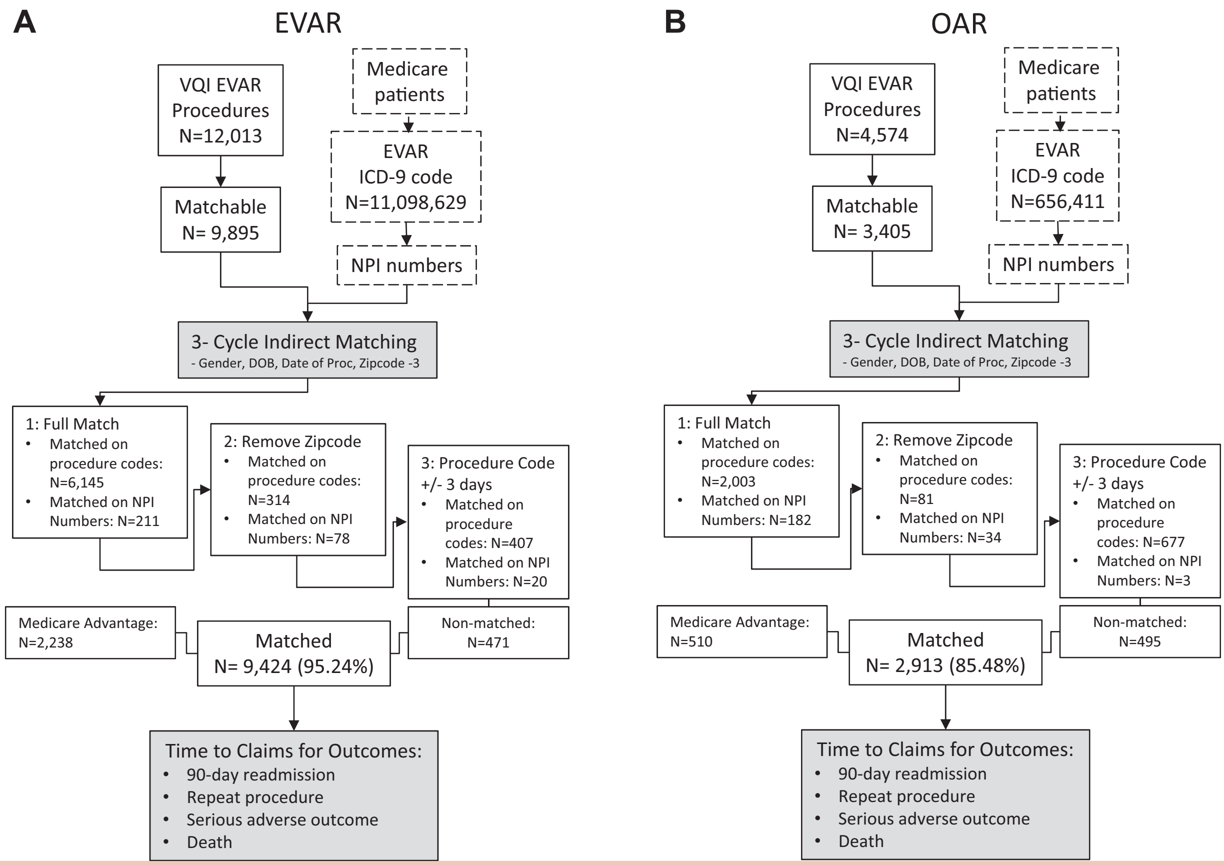

Fig 2. Flow diagram for matching procedures for patients who have undergone endovascular aneurysm repair (*EVAR*; **A**) and open aneurysm repair (*OAR*; **B**). *DOB,* Date of birth; *ICD-9,* International Classification of Diseases, Ninth Revision; *NPI,* National Provider Identifier; *VQI,* Vascular Quality Initiative.

converted to time to event variables. For each outcome, we calculated days to the outcome after the discharge from the index admission. Also for each event, we provided the ICD-9 codes for the outcome.

Validation. Raw match rate was calculated for EVAR and OAR by dividing matched patient numbers by the total VQI cohort with potential to match in fee-for-service Medicare based on age of the patient (65 years and older), U.S. citizenship, and procedure within the available range of our Medicare Denominator File. Patients determined to be in a non-fee-for-service program (eg, Medicare Advantage) were included in the match rate calculation but did not have data available for determination of outcomes. Patient characteristics were compared between those who matched to Medicare claims data and those who did not using χ^2 for categorical variables and two-way unpaired *t*-test for continuous variables. Fidelity of outcome measurement was evaluated in matched subjects by comparing postoperative reinterventions that were captured by both VQI and Medicare. (See the Appendix, online only, for complete list of events and corresponding ICD-9 codes.) Similarly, mortality in matched subjects was compared between VQI and Medicare data. These analyses were limited only to the successfully matched patients.

Outcome agreement for reintervention and mortality between VQI and Medicare data was determined using Cohen κ. The κ for rare events was adjusted using the correction of Cicchetti and Feinstein.[15,16] Additional time-to-event comparisons were performed with Kaplan-Meier estimates. We obtained Institutional Review Board approval from the Center for the Protection of Human Subjects at Dartmouth for this work, and no individual patient informed consent was deemed necessary.

RESULTS

Between January 1, 2003, and December 31, 2013, there have been 12,013 EVAR procedures and 4574 OAR procedures captured in the VQI. Our study cohort of patients aged 65 years and older undergoing procedures in this time frame included 9895 EVAR patients and 3405 OAR patients. Of these, there were 9424 (95.2%) matched EVAR patients and 2913 (85.5%) matched OAR patients (Fig 2).

Table. Characteristics of Vascular Quality Initiative (*VQI*) patients 65 years and older who were matched and unmatched to Medicare claims for endovascular aneurysm repair (*EVAR*; *left columns*) and open aneurysm repair (*OAR*; *right columns*)

Characteristics of patients	EVAR			OAR		
	VQI-Medicare matched (n = 7159)	VQI unmatched (n = 3035)	*P* value[a]	VQI-Medicare matched (n = 2399)	VQI unmatched (n = 1095)	*P* value[a]
Age, years, median (IQR)	76 (66-86)	75 (65-85)	.001	74 (65-83)	72 (62-82)	.001
Male sex	5646/7159 (78.9)	2444/3033 (80.6)	.050	1676/2395 (70.0)	808/1095 (73.8)	.014
White race	6748/7158 (94.3)	2714/3029 (89.6)	<.001	2291/2394 (95.7)	979/1091 (89.7)	<.001
Smoking			.001			.005
Prior smoking	4092/7131 (57.4)	1613/2999 (53.8)		1205/2363 (51.0)	485/1077 (45.0)	
Current smoking	1894/7131 (26.6)	897/2999 (29.9)		872/2363 (36.9)	442/1077 (41.0)	
HTN	6019/7133 (84.4)	2521/3009 (83.8)	.449	1974/2380 (82.9)	928/1086 (85.5)	.063
Diabetes	1424/7132 (20.0)	591/3006 (19.7)	.725	377/2377 (15.9)	154/1083 (14.2)	.214
CAD	2185/7129(30.7)	925/3003 (30.8)	.879	713/2369 (30.1)	284/1083 (26.2)	.020
COPD	2342/7127 (32.9)	994/3006 (33.1)	.840	855/2375 (36.0)	368/1085 (33.9)	.234
CHF	867/7131 (12.2)	334/3008 (11.1)	.133	194/2370 (8.2)	89/1084 (8.2)	.980
Dialysis	85/7145 (1.2)	26/3009 (0.9)	.150	15/2387 (0.6)	6/1086 (0.6)	.789
Prior CABG or PCI	1378/3741 (36.8)	672/1900 (35.4)	.279	714/2365 (30.2)	305/1080 (28.2)	.245
Positive preoperative stress test	766/7106 (10.8)	323/2996 (10.8)	.998	298/2377 (12.5)	108/1083 (10.0)	.030
Living at home	7019/7129 (98.5)	2959/3005 (98.5)	.964	2360/2387 (98.9)	1079/1084 (99.5)	.056
Prior aortic surgery (any)	307/7122 (4.3)	148/3002 (4.9)	.169	204/2377 (8.6)	81/1084 (7.5)	.271
Urgency			<.001			.001
Symptomatic	563/7130 (7.9)	253/3011 (8.4)		236/2393 (9.9)	126/1088 (11.6)	
Ruptured	330/7130 (4.6)	199/3011 (6.6)		433/2393 (18.1)	247/1088 (22.7)	
Unfit for open repair	1461/7124 (20.5)	657/3001 (21.9)	.118	N/A	N/A	N/A
Unfit for general anesthesia	218/7124 (3.1)	90/3002 (3.0)	868	N/A	N/A	N/A

CABG, Coronary artery bypass graft; *CAD*, coronary artery disease; *CHF*, congestive heart failure; *COPD*, chronic obstructive pulmonary disease; *HTN*, hypertension; *IQR*, interquartile range; *N/A*, not applicable; *PCI*, percutaneous coronary intervention.
Values are reported as n/N (%) unless otherwise indicated. Observations with missing values for each variable were not included in the analysis. Percentage refers to column percentage.
[a]*P* value for categorical/dichotomous variables from χ^2 test, Student *t*-test for continuous variables.

Patient characteristics. Medicare-matched and unmatched patients 65 years and older were compared for both EVAR and OAR. Demographics and patient characteristics were similar for patients undergoing both EVAR and OAR. Differences between matched and unmatched cohorts included a slightly higher likelihood of male sex, white race, preoperative living at home, and nonurgent/emergent procedure in the Medicare-matched cohort. In addition, unmatched patients who underwent EVAR were slightly more likely to be unfit for open surgical repair. Prior work has suggested that this subjective assessment of patient functional status is associated with long-term outcomes.[17] There were no significant differences between cohorts in comorbidities, smoking status, or prior vascular procedures (Table).

Mortality. In Medicare-matched subjects who underwent EVAR, we compared mortality rates between the VQI data and Medicare claims data. The positive percentage agreement between VQI and Medicare data for death was 63%; negative percentage agreement was 92%. This resulted in a Cohen κ of 0.55 for all post-procedure time points. Because the VQI specifically tracks 1-year outcomes, we also determined a 70% positive percentage agreement and 94% negative percentage agreement for death for patients with late follow-up in the VQI and a 2-year time window after discharge in Medicare, resulting in κ of 0.64. The Kaplan-Meier estimates for survival after EVAR comparing VQI and Medicare claims data demonstrated statistically significant divergence of mortality rates between the two data sets, with a higher mortality rate for Medicare claims data compared with the SSDI-linked VQI data ($P < .001$; Fig 3, *A*).

Mortality rates between the VQI data and Medicare claims data for patients who underwent OAR also had

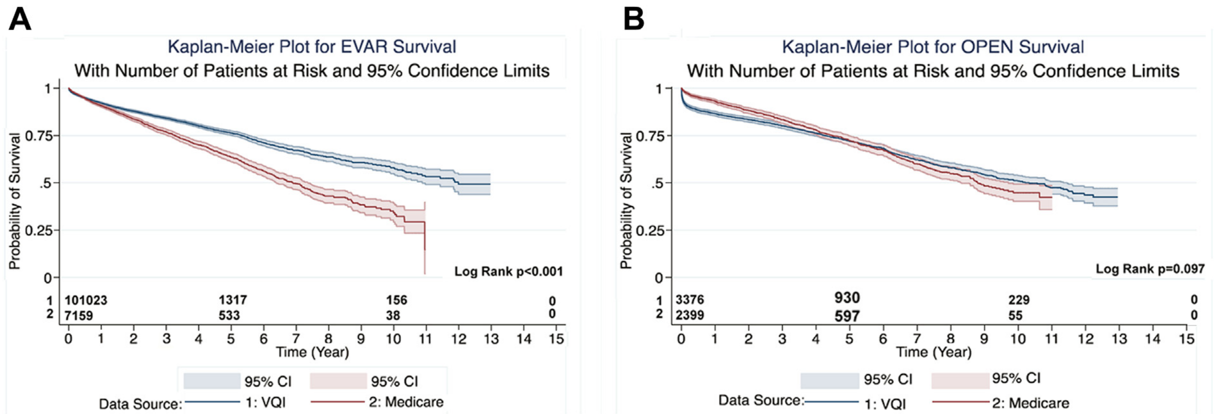

Fig 3. Kaplan-Meier estimate for survival after endovascular aneurysm repair (*EVAR*; **A**) and open aneurysm repair (OAR; **B**) as collected in the Vascular Quality Initiative (*VQI*; *blue*) and in Medicare claims data (*red*). *CI*, Confidence interval.

moderate agreement. The positive percentage agreement between VQI and Medicare data for death was 64%; negative percentage agreement was 86% in the VQI data. This resulted in a Cohen κ of 0.51 for all postprocedure time points. The 1-year mortality after OAR demonstrated 86% positive percentage agreement and 96% negative percentage agreement for the VQI data to detect death for patients with late follow-up in the VQI and a 2-year time window after postprocedure discharge in Medicare, resulting in κ of 0.82. The Kaplan-Meier estimates for survival after OAR comparing VQI and Medicare claims data demonstrated statistically significant divergence of mortality rates between the two data sets, with a higher mortality rate for Medicare claims data compared with the SSDI-linked VQI data at 1 year after the procedure ($P < .001$; Fig 3, *B*), but these differences had disappeared by 5 years after the procedure among the matched VQI-Medicare patients.

Reintervention. Comparison of reintervention rates after EVAR between VQI and Medicare claims data demonstrated a positive percentage agreement of 29% and negative percentage agreement of 92% with a κ of 0.23. Pearson $r = 0.20$ for the correlation between counts of reinterventions in Medicare and the VQI at all time points. Reintervention rates in the patients with late follow-up in the VQI and a 2-year time window after discharge in Medicare demonstrated a positive percentage agreement of 33% and negative percentage agreement of 91% for a κ of 0.26. Pearson $r = 0.20$ for the correlation between counts of reinterventions among VQI patients with late follow-up and Medicare claims 2 years after the procedure. The low κ is driven by reinterventions present in one data source but not present in the other. For example, 524 of 647 reinterventions (81%) captured in Medicare claims data were not captured in the VQI, whereas 82 of 205 reinterventions (40%) captured in the VQI did not have an associated Medicare claim. The Kaplan-Meier estimates for reintervention after EVAR comparing VQI and Medicare claims data demonstrate clear differences at early time points that disappear at late time points as the number at risk in the VQI data drops ($P < .001$; Fig 4, *A*).

Similar results were obtained after OAR, with reintervention rate comparison between the VQI and Medicare yielding a positive percentage agreement of 12% and negative percentage agreement of 96% for a κ of 0.07 at all time points. Pearson $r = 0.06$ for the correlation between counts of reinterventions in Medicare and the VQI. The reintervention rates in patients with late follow-up in the VQI and a 2-year time window after discharge in Medicare demonstrated a positive percentage agreement of 21% and negative percentage agreement of 95% with a κ of 0.16. Pearson $r = 0.13$ for the correlation between counts of reinterventions among VQI patients with long-term follow-up and Medicare claims 2 years after the procedure. As with the EVAR data, there were 70 of 79 reinterventions (89%) captured in Medicare claims data that were not captured in the VQI, and 68 of 77 (88%) captured in the VQI did not have an associated Medicare claim. However, the Kaplan-Meier estimates for reintervention after OAR comparing VQI and Medicare claims data demonstrate no difference in intervention capture at late time points in the VQI ($P = .497$; Fig 4, *B*).

DISCUSSION

For patients facing vascular treatments, understanding of surgical outcomes beyond the perioperative period is essential for measuring the value of our interventions. To this end, we have developed and described herein a methodology for determining postoperative events in

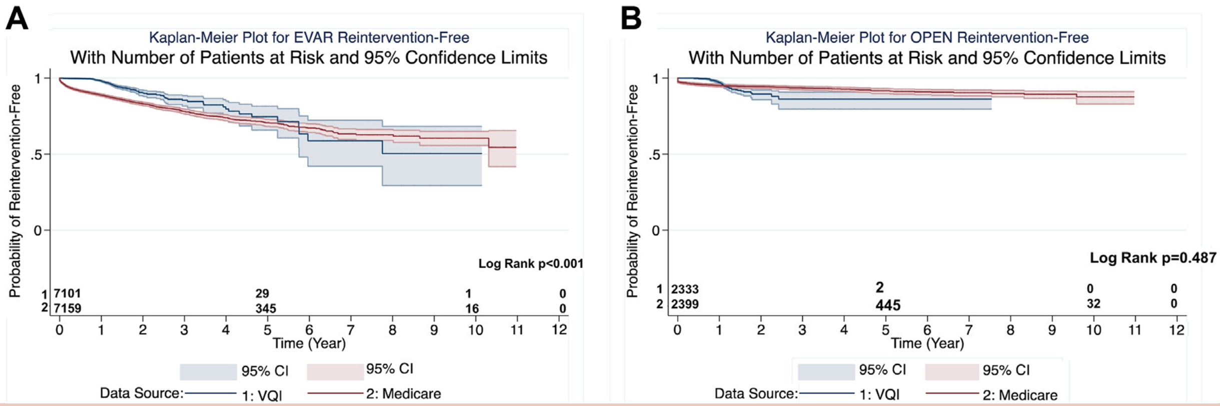

Fig 4. Kaplan-Meier estimate for freedom from reintervention after endovascular aneurysm repair (*EVAR*; **A**) and open aneurysm repair (OAR; **B**) as collected in the Vascular Quality Initiative (*VQI*; *blue*) and in Medicare claims data (*red*). *CI*, Confidence interval.

Medicare beneficiaries treated with procedural interventions such as aortic surgery. Our match rate was 95.2% for EVAR and 85.5% for OAR. These rates are similar to those described by others using indirect identifier methodology. Specifically, two studies used patient gender, patient date of birth, hospital admission date, and hospital ID to match Medicare claims to the National Cardiovascular Data Registry, with match rates of 75.2% for percutaneous coronary intervention[12] and 56% for implantable cardioverter-defibrillator implantation.[13] In surgery, the addition of Current Procedural Terminology (CPT) and ICD-9 coding to the matching algorithm resulted in an 80.5% match rate in the National Surgical Quality Improvement Program database to Medicare claims.[7]

Other studies have achieved higher rates of matching by use of a direct identifier match based on Social Security Number,[1,9,10,12] with match rates between 91% and 98%. However, because the VQI collects data within an AHRQ PSO, data sharing is strictly regulated and, at this time, precludes use of direct patient identifiers. Efforts to develop the pathways necessary to preserve patient anonymity yet still allow direct Medicare matching "within the PSO" are under way and will be used for future renditions of this work. Other large cardiovascular registries, such as those of the American College of Cardiology and the Society of Thoracic Surgeons, have reported similar success rates using a variety of matching strategies.[12,18] Similarly, national registries for transplantation have been successfully linked to Medicare for evaluation of long-term outcomes.[19]

We achieved a moderate degree of accuracy in detection of late mortality in our matched patients with a Cohen κ of 0.64 for EVAR and 0.82 for OAR. However, agreement decreased when all time points were evaluated. This is further demonstrated by Kaplan-Meier analysis for survival, which demonstrated a statistically significant divergence in mortality curves based on the source data set. Interestingly, the rate of mortality was higher in the Medicare data set compared with the VQI, even though the VQI data were linked to SSDI before being matched to Medicare.

In contrast, in our evaluation, detection of reintervention was less effective in considering potentially disparate data sources of VQI and Medicare claims. We noted that 81% of reinterventions after EVAR and 89% of reinterventions after OAR had a Medicare claim but were not captured in the VQI. Similarly, 40% of EVAR reinterventions and 89% of OAR reinterventions captured in the VQI lacked an associated Medicare claim. Many of these differences, we hypothesize, are likely due to differences between the Medicare events we used to define reintervention (generally ICD-9 procedure codes indicative of an inpatient stay) and much broader VQI-based definitions, which may be indicative of outpatient procedures, such as an endoleak embolization. Improvement and harmonization of our coding algorithms, especially outpatient procedures, will be the focus of our future work in an effort to improve the ability of our linked data sets to successfully describe the long-term outcomes of aortic aneurysm repair using linked clinical claims data sets. Furthermore, additional work needs to be done to determine if these reflect true missed events or simply an error in the correlation of late events between Medicare and the VQI.

A number of limitations are present within our analysis, largely due to the deidentified nature of our data. We are unable to directly identify patients, and therefore sensitivity analysis is limited to specific outcomes captured in both data sets. Furthermore, because of the potential for errors within either data set, no "gold standard" is easily determined, and future validation efforts will necessitate chart-level validation of both registry and claims data sets. Prior analyses examining the weaknesses of claims-based data sets have shown that different coding algorithms can affect the absolute rates of important outcomes, such as stroke after carotid revascularization.[20] Furthermore, characterization of patient-level events using administrative claims can result in differences that may not accurately reflect true patient risk strata.[21]

Our future work will focus on revising and optimizing our matching algorithm without sacrificing fidelity, ensuring complete and reliable capture of late events in the Medicare claims data across data sets including but not limited to EVAR. Improving our matching algorithm will entail development of a multistep matching algorithm balancing maximum matching efficiency with accurate capture. Continuing to develop the ICD-9 code selection for reintervention and readmission will improve the quality of our capture of late events. Subsequent to algorithm optimization, we intend to apply these strategies to all procedures captured by the VQI. Eventually, as regulatory mechanisms allow transmission of patient identifiers between a PSO and Medicare claims, we look forward to the opportunity to perform direct, nonprobabilistic matching between patients in the VQI and their respective Medicare claims.

CONCLUSIONS

Matching of patient-level VQI and Medicare claims data has the potential to be a powerful tool for the evaluation of long-term postoperative outcomes for patients undergoing vascular procedures. Our initial work has demonstrated feasibility of matching procedures, and future work will focus on refinement and broad application of this methodology to provide comprehensive outcome data with the ultimate goal of improving care for all patients undergoing vascular procedures.

AUTHOR CONTRIBUTIONS

Conception and design: AH, AF, KM, NR, BB, SS, AS, PG
Analysis and interpretation: AH, AF, KM, NR, BB, SS, AS, PG
Data collection: AH, AF, KM, NR, BB, SS, PG
Writing the article: AH, AF, BB, SS, PG
Critical revision of the article: AH, AF, KM, BB, SS, AS, PG
Final approval of the article: AH, AF, KM, NR, BB, SS, AS, PG
Statistical analysis: AH, AF, NR, BB, AS, PG
Obtained funding: AH, AF, BB, SS, AS, PG
Overall responsibility: PG

REFERENCES

1. AHRQ. Patient safety rule. Rockville, Md: Agency for Healthcare Research and Quality; 2009.
2. Cronenwett JL, Kraiss LW, Cambria RP. The Society for Vascular Surgery Vascular Quality Initiative. J Vasc Surg 2012;55:1529-37.
3. Judelson DR, Simons JP, Flahive JM, Patel VI, Nolan BW, Bachman M, et al. Determinants of follow-up failure in patients enrolled in the Vascular Study Group of New England (VSGNE). J Vasc Surg 2015;61:154-5.
4. Vascular Study Group of New England semi-annual meeting. Worcester, MA; November 13, 2015.
5. Weiner M, Stump TE, Callahan CM, Lewis JN, McDonald CJ. A practical method of linking data from Medicare claims and a comprehensive electronic medical records system. Int J Med Inform 2003;71:57-69.
6. Hammill BG, Hernandez AF, Peterson ED, Fonarow GC, Schulman KA, Curtis LH. Linking inpatient clinical registry data to Medicare claims data using indirect identifiers. Am Heart J 2009;157:995-1000.
7. Mark TL, Lawrence W, Coffey RM, Kenney T, Chu BC, Mohler ER 3rd, et al. The value of linking hospital discharge and mortality data for comparative effectiveness research. J Comp Eff Res 2013;2:175-84.
8. Potosky AL, Riley GF, Lubitz JD, Mentnech RM, Kessler LG. Potential for cancer related health services research using a linked Medicare-tumor registry database. Med Care 1993;31:732-48.
9. Bradley CJ, Given CW, Luo Z, Roberts C, Copeland G, Virnig BA. Medicaid, Medicare, and the Michigan Tumor Registry: a linkage strategy. Med Decis Making 2007;27:352-63.
10. Nadpara PA, Madhavan SS. Linking Medicare, Medicaid, and cancer registry data to study the burden of cancers in West Virginia. Medicare Medicaid Res Rev 2012;2.
11. Setiawan VW, Virnig BA, Porcel J, Henderson BE, Le Marchand L, Wilkens LR, et al. Linking data from the Multiethnic Cohort Study to Medicare data: linkage results and application to chronic disease research. Am J Epidemiol 2015;181:917-9.
12. Brennan JM, Peterson ED, Messenger JC, Rumsfeld JS, Weintraub WS, Anstrom KJ, et al; Duke Clinical Research Institute DEcIDE Team. Linking the National Cardiovascular Data Registry CathPCI Registry with Medicare claims data: validation of a longitudinal cohort of elderly patients undergoing cardiac catheterization. Circ Cardiovasc Qual Outcomes 2012;5:134-40.
13. Setoguchi S, Zhu Y, Jalbert JJ, Williams LA, Chen CY. Validity of deterministic record linkage using multiple indirect personal identifiers: linking a large registry to claims data. Circ Cardiovasc Qual Outcomes 2014;7:475-80.
14. Lawson EH, Ko CY, Louie R, Han L, Rapp M, Zingmond DS. Linkage of a clinical surgical registry with Medicare inpatient claims data using indirect identifiers. Surgery 2013;153:423-30.
15. Feinstein AR, Cicchetti DV. High agreement but low kappa: I. The problems of two paradoxes. J Clin Epidemiol 1990;43:543-9.
16. Cicchetti DV, Feinstein AR. High agreement but low kappa: II. Resolving the paradoxes. J Clin Epidemiol 1990;43:551-8.
17. De Martino RR, Brooke BS, Robinson W, Schanzer A, Indes JE, Wallaert JB, et al. Designation as "unfit for open repair" is associated with poor outcomes after endovascular aortic aneurysm repair. Circ Cardiovasc Qual Outcomes 2013;6:575-81.
18. Jacobs JP, Edwards FH, Shahian DM, Haan CK, Puskas JD, Morales DL, et al. Successful linking of the Society of Thoracic Surgeons adult cardiac surgery database to Centers for Medicare and Medicaid Services Medicare data. Ann Thorac Surg 2010;90:1150-6; discussion: 1156-7.

19. Massie AB, Kucirka LM, Segev DL. Big data in organ transplantation: registries and administrative claims. Am J Transplant 2014;14:1723-30.
20. Fokkema M, Hurks R, Curran T, Bensley RP, Hamdan AD, Wyers MC, et al. The impact of the present on admission indicator on the accuracy of administrative data for carotid endarterectomy and stenting. J Vasc Surg 2014;59:32-8. e31.
21. Finlayson EV, Birkmeyer JD, Stukel TA, Siewers AE, Lucas FL, Wennberg DE. Adjusting surgical mortality rates for patient comorbidities: more harm than good? Surgery 2002;132:787-94.

Submitted Oct 10, 2016; accepted Dec 5, 2016.

Additional material for this article may be found online at www.jvascsurg.org.

APPENDIX (online only).

International Classification of Diseases, Ninth Revision (ICD-9) diagnostic and procedure codes used for matching and identification of outcomes

An x in the code indicates that any number 0-9 could go in that place.

Matching: Open abdominal aortic aneurysm repair
- 38.34, 38.44, 38.64, 39.52, 39.7x, 44.22

Matching: Endovascular abdominal aortic aneurysm repair
- 38.04, 38.06, 38.08, 38.14, 38.16, 38.18, 38.34, 38.36, 38.38, 38.44, 38.46, 38.48, 38.64, 38.66, 38.68, 38.84, 38.86, 38.88, 38.91, 38.93, 39.25, 39.26, 39.29, 39.30, 39.31, 39.50, 39.51, 39.52, 39.54, 39.56, 39.57, 39.58, 39.59, 39.71, 39.72, 39.73, 39.74, 39.75, 39.76, 39.77, 39.78, 39.79, 39.90

Outcome: Aortic rupture diagnostic codes
- 441.3x

Outcome: Open abdominal aortic aneurysm reintervention
- 38.34, 38.44, 38.64, 39.52, 39.7x, 44.22 (procedures)
- 996.1, 996.59, 996.6, 441.3, 441.5, 440.0, 995.7, 444.2x, 444.8x (diagnosis of postsurgical complications)

Outcome: Categories for 90-day readmissions (ICD-9 diagnostic codes anywhere in the admission code string)
- Vascular complications: 997.71, 997.72, 997.79
- Postoperative infection: 998.5x, 998.51, 998.59
- Postoperative stroke: 997.02
- Cardiac complications: 997.1x, 428.0x, 428.1x, 428.2x, 428.3x, 428.4x, 428.9x, 427.0x, 427.3x, 427.4x, 427.5x, 427.8x, 427.9x
- Urinary/renal complications: 997.5x, 593.3x, 593.9x
- Gastrointestinal complications: 997.4x, 560.9x, 557.0x, 557.9x
- Respiratory complications: 997.3x, 518.4x, 518.5x