Abstract

**IMPORTANCE** National injury surveillance systems use administrative data to collect information about severe fall-related trauma and mortality. Measuring milder injuries in ambulatory clinics would improve comprehensive outcomes measurement across the care spectrum.

**OBJECTIVES** To assess a flexible set of administrative data–only algorithms for health systems to capture a greater breadth of injuries than traditional fall injury surveillance algorithms and to quantify the algorithm inclusiveness and validity associated with expanding to milder injuries.

**DESIGN, SETTING, AND PARTICIPANTS** In this longitudinal diagnostic study of 13,939 older adults (≥65 years) in the nationally representative Health and Retirement Study, a survey was conducted every 2 years and was linked to hospital, emergency department, postacute skilled nursing home, and outpatient Medicare claims (2000-2012). During each 2-year observation period, participants were considered to have sustained a fall-related injury (FRI) based on a composite reference standard of having either an external cause of injury (E-code) or confirmation by the Health and Retirement Study patient interview. A framework involving 3 algorithms with *International Classification of Diseases, Ninth Revision* codes that extend FRI identification with administrative data beyond the use of fall-related E-codes was developed: an acute care algorithm (head and face or limb, neck, and trunk injury reported at the hospital or emergency department), a balanced algorithm (all acute care algorithm injuries plus severe nonemergency outpatient injuries), and an inclusive algorithm (almost all injuries). Data were collected from January 1, 1998, through December 31, 2012, and statistical analysis was performed from August 1, 2016, to March 1, 2019.

**MAIN OUTCOMES AND MEASURES** Validity, measured as the proportion of potential FRI diagnoses confirmed by the reference standard, and inclusiveness, measured as the proportion of reference-standard FRIs captured by the potential FRI diagnoses.

**RESULTS** Of 13,939 participants, 1,672 (42.4%) were male, with a mean (SD) age of 77.56 (7.63) years. Among 50,310 observation periods, 9,270 potential FRI diagnoses (18.4%) were identified; these were tested against 8,621 reference-standard FRIs (17.1%). Compared with the commonly used method of E-coded–only FRIs (2-year incidence, 8.8% [95% CI, 8.6%-9.1%]; inclusion of 51.5% [95% CI, 50.4%-52.5%] of the reference-standard FRIs), FRI inclusion was increased with use of the study framework of algorithms. With the acute care algorithm (2-year incidence, 12.6% [95% CI, 12.4%-12.9%]), validity was prioritized (88.6% [95% CI, 87.4%-89.8%]) over inclusiveness (62.1% [95% CI, 61.1%-63.1%]). The balanced algorithm showed a 2-year incidence of 14.6% (95% CI, 14.3%-14.9%), inclusion of 65.3% (95% CI, 64.3%-66.3%), and validity of 83.2% (95% CI, 81.9%-84.6%). With the inclusive algorithm, the number of potential FRIs increased compared with the E-code–only method (2-year incidence, 17.4% [95% CI, 17.1%-17.8%]; inclusion, 68.4% [95% CI, 67.4%-69.3%]; validity, 75.2% [95% CI, 73.7%-76.6%]).

Key Points

**Question** What are the tradeoffs between inclusiveness and validity when expanding the external mechanism-of-injury codes (E-codes) for fall-related injury to include *International Classification of Diseases, Ninth Revision* (ICD-9)–coded injuries in older adults?

**Findings** In this diagnostic study of 13,939 older adults (≥65 years) in the nationally representative Health and Retirement Study, an external reference standard of patient interview (E-codes) was used as evidence that a fall caused the injury. With use of hospital and emergency department ICD-9 codes, the acute care algorithm maximized validity and the inclusive algorithm prioritized milder injuries seen in outpatient clinic care, doubling the number of fall-related injuries captured compared with E-codes alone.

**Meaning** The findings suggest that health care systems can increase inclusion of fall-related injury by adding ICD-9-coded injuries to the existing method of using only fall-related E-codes.

Supplemental content

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JAMA Network Open. 2019;2(8):e199679. doi:10.1001/jamanetworkopen.2019.9679

August 21, 2019

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CONCLUSIONS AND RELEVANCE The findings suggest that use of algorithms with International Classification of Diseases, Ninth Revision codes may increase inclusion of FRIs by health care systems compared with E-codes and that these algorithms may be used by health systems to evaluate interventions and quality improvement efforts.

Introduction

Falls among older adults are associated with serious morbidity, mortality, and cost but are preventable. From a population health perspective, fall surveillance can bolster prevention efforts by targeting high-risk individuals. However, existing surveillance systems rely heavily on external cause of injury codes (E-codes) which are used by the US trauma health care system to determine that an injury was caused by a fall (as opposed to another traumatic cause). While accurate, this injury identification approach is limited in nonemergency outpatient clinic settings where E-codes are not required and hampers efforts to gain a complete picture of fall-related injury (FRI).

As health care systems develop fall injury reduction programs, monitoring of programs’ effectiveness requires surveillance of both severe and moderate injuries (ie, including those in which a fall E-code was not used but instead involving diagnostic codes in claims data only). There are important tradeoffs involved in broadening surveillance systems beyond the use of only E-codes. On the one hand, such injuries as hip fracture and head trauma are likely to be FRIs because falls are the most common cause of severe, traumatic injury among older adults. The inclusion of mild injuries in surveillance systems may reduce the validity of those FRI diagnoses that are identified because mild injuries may be due to nonfall causes. On the other hand, including mild injury (eg, sprains and contusions) would favorably increase the power to detect intervention associations, which depended heavily on the rate of outcomes. In addition, mild injuries are important causes of pain and accelerated disability in older people. The inclusion of mild injuries in surveillance systems may reduce the validity of the FRI diagnoses while increasing the total number of FRIs identified because not all mild injuries are fall related.

Earlier research involving fall surveillance has extended claims-based diagnoses beyond E-codes without explicitly considering tradeoffs of inclusiveness and validity. We enhanced this work by examining inclusiveness and validity across a spectrum of potential inpatient and outpatient FRI diagnoses.

Methods

Data

This longitudinal diagnostic study used Health and Retirement Study (HRS) Core and Exit (postmortem) surveys (biennially from January 1, 2000, through December 31, 2012) and linked Medicare claims from inpatient hospital, ambulatory (emergency department and outpatient clinics), and nursing home claims files from January 1, 1998, through December 31, 2012. We included older (age ≥65 years) HRS respondents who consented to providing their Medicare beneficiary numbers for linking their interviews to fee-for-service Medicare (Parts A and B) claims data. The study was approved by the University of Michigan institutional review board; informed consent was waived because this study was a secondary analysis of deidentified data. Data were collected from January 1, 1998, through December 31, 2012, and statistical analysis was performed from August 1, 2016, to March 1, 2019. The study followed the Standards for Reporting of Diagnostic Accuracy (STARD) reporting guideline.
Reference Standard Used for Validating FRIs

To develop a set of International Classification of Diseases, Ninth Revision (ICD-9) FRI diagnoses beyond fall-related E-codes, patient-reported FRIs (indicating an injurious fall in the previous 2 years) were added to E-coded FRIs (eTable 1 in the Supplement) to create a composite of the 2 FRI identifiers. A composite reference standard is 1 approach to evaluating a new diagnostic test in the absence of an external criterion standard. In a data set of this size and scope, a large sample of ICD-9 codes were tested against both internal (E-codes) and external (interview) data validation sources. By adopting this next best reference standard, test properties were calculated and they prioritized the injury codes by validity. Because this ICD-9-based algorithm was intended to measure FRIs in future practice, the primary criterion for prioritizing ICD-9 codes as more valid was higher positive predictive value (proportion of tests events confirmed by the reference standard). Thus, further references to validity in this report were synonymous to positive predictive value. Validity was operationalized as a tradeoff with inclusiveness (proportion of the reference standard captured by the test, synonymous to sensitivity) as the scope of injuries considered to include milder injuries was broadened. This approach was only possible by considering the reference standard, even if imperfect, as a true measure of FRI.

Injury Diagnoses to Be Tested

Using all claims from Medicare hospital, nursing home, and outpatient (emergency department and clinic) encounters, we identified all injuries (ICD-9 diagnosis codes 800-999) excluding burns, splinters, bites, and fractures associated with metastatic bone disease. The remaining diagnoses were considered as potential FRIs to be tested against the reference standard. Next, we created a matrix of potential FRI categories consisting of 3 injury types by 4 anatomic regions. Injury types were bone fractures, sprains, strains, dislocations, and superficial skin injuries. Regions were the head, neck or trunk, upper limb, and lower limb. Finally, a nonspecific and internal injury category was created (eTable 2 and eTable 3 in the Supplement).

To identify potential FRIs treated exclusively in emergency department and outpatient clinics, a UCLA/RAND algorithm was extended that requires a casting or splinting procedure on the same day or an imaging study in less than 10 days. We further included superficial injuries such as bruises and abrasions as potential FRIs (eTables 4-8 in the Supplement) and added suturing to these inclusion criteria.

Potential FRIs were grouped into episodes, with claims across health care settings that occurred within fewer than 180 days in the same anatomic region and injury type combined into single episodes of care (Figure 1); this served as a look-back period to prevent preexisting injury from counting as a new event. Potential FRI episodes beginning with a non-FRI E-code (eg, motor vehicle crash) were excluded.

Figure 1. Construction of Fall-Related Injury (FRI) Episodes of Care From Claims

Claims for external cause of injury-coded (E-coded) reference standard or International Classification of Diseases, Ninth Revision (ICD-9)–coded potential FRIs were grouped into episodes of care during 2-year observation windows (the unit of analysis) before the interviews. Left, a potential FRI episode, an initial hip fracture (HF) ICD-9 code, and multiple subsequent same-injury diagnoses for follow-up care within 180 days. Middle, a skull fracture (SF) ICD-9 was excluded because of an E-code for nonfall (motor vehicle crash). Right, a single diagnosis code indicates a potential FRI involving an ankle dislocation (AD).
Statistical Analysis
Potential FRI episodes occurring during the 2 years preceding each HRS survey interview were identified (ie, corresponding to the period covered by the interview question). These 2-year observation windows were the unit of analysis for testing whether potential FRI episodes were validated by the reference standard, (ie, if a reference standard FRI was present during the same period). The earliest date within the FRI episode was used to determine which observation window to use (Figure 1). The use of these episodes ensured that codes appearing multiple times in claims over time (ie, for follow-up care of the same injury) would not count as a new injury in the next observation period. Further details (along with annotated SAS code [SAS, version 9.4; SAS Institute]) are provided in eTables 4-8 in the Supplement.

Validity of each category of ICD-coded injury diagnoses was calculated by ascertaining the copresence of a reference-standard FRI with the test FRI episode within the same observation window (Figure 1) (Table 1). Then, using these true-positives (number of test FRI episodes confirmed by the reference standard) as the numerator, we divided by all the potential FRI episodes (the denominator; ie, all the test-positives). In this initial descriptive analysis, validity was calculated within each of the consolidated categories of potential FRIs.

To explore differences in validity by level of health care acuity, potential FRI episodes were stratified by presence of any acute hospital data (total hospital plus any postacute nursing home care ≥3 days), any emergency department or short hospital stay (<3 days), and outpatient clinic only data.

Within each level of health care acuity, injury categories were consolidated to simplify the matrix of injuries and reduce categories with low sample sizes. We screened the least-valid categories (in which <60% of potential FRIs were validated) for outlier diagnoses with poor validity (in which <50% were validated). These diagnoses were removed from their original categories and placed into a distinct, generalized category of nonvalidated injuries.

The results were used to develop a framework involving 3 algorithms that extend FRI identification with administrative data beyond the use of FRI E-codes: (1) an acute care algorithm identifying the most valid and severe injuries, (2) a balanced algorithm occupying a middle ground in validity and inclusion, and (3) an inclusive algorithm, which maximizes inclusion of FRIs found across the health care system. To develop the framework, we sorted the consolidated injury categories from the most to the least valid within each health care acuity level and sequentially included the categories according to their validity. In this way, we quantified the loss in validity (and gain in inclusiveness) as additional, less-valid FRI categories were added. Specifically, E-coded FRIs were the first category to be included in each algorithm because they were, by definition, the most valid administrative data (100% valid because they were part of the reference standard). Then, beginning with acute care settings, we sequentially added the next most valid of the potential FRI categories to E-coded FRIs, reporting the loss in validity and increase in inclusiveness of the resulting cumulative FRI algorithm at each step.

Table 1. Composite Reference Standard for FRIs vs Potential FRIs in 2-Year Observation Windows

| Level of Health Care for All Potential ICD-9-Coded FRIs | Reference Standard, Cases, No. (%) (N = 50 310) |
|----------------------------------------------------------|--------------------------------------------------|
| Acute hospital or postacute nursing home care for >3-d stay (n = 2264)* | Only E-coded FRI 295 (13.0) Only Self-reported FRI 432 (19.1) Both E-coded and Self-reported FRI 1013 (44.7) Neither E-coded nor Self-reported FRI 524 (23.1) |
| Any emergency department visit, hospital, or postacute nursing home care, any length of stay (n = 5836)* | 1141 (19.6) 1023 (17.5) 2155 (36.9) 1517 (26.0) |
| All levels of inpatient or outpatient care (n = 9270)* | 1425 (15.4) 1617 (17.4) 2379 (25.7) 3849 (41.5) |
| No potential ICD-9 test FRIs (n = 41 040) | 400 (1.0) 2566 (6.3) 234 (0.6) 37 840 (92.2) |

Abbreviations: E-code, external cause of injury code; FRIs, fall-related injuries; ICD-9, International Classification of Diseases, Ninth Revision.

* Row 1 is nested in row 2, which is nested in row 3.
* True-positives.
* False-positives.
* False-negatives.
* True-negatives.
These steps were then sequentially repeated for consolidated FRI categories across less acute health care settings until all data were considered in the algorithm framework. To address known recall bias resulting from interviewing patients about FRIs,\textsuperscript{18-22} validity of the final algorithms was presented among the FRIs less than 6 months before the interviews.

Results

Descriptive Results

There were 20,334 participants (aged $\geq 65$ years) in the HRS who participated in 83,769 biennial interviews from 2000 through 2012. Of these, 13,939 individuals allowed HRS to link their survey data with fee-for-service Medicare data, resulting in a final analytic sample of 50,310 two-year

Table 2. Administrative Data Sources of Injuries Among Older US Adults, 1998-2012\textsuperscript{a}

| Description of Data                                | Claims, No. (%) (N = 2.8 Million) |
|---------------------------------------------------|-----------------------------------|
| Data source for all health care encounter claims   |                                   |
| Hospital                                          | 40,120 (1.4)                      |
| Nursing home                                      | 15,906 (0.6)                      |
| Emergency department                              | 33,818 (1.2)                      |
| Outpatient clinic                                 | 2,731,571 (96.8)                  |
| E-coded fall-related injuries                     |                                   |
| Motor vehicle crash                               | 803 (0)                           |
| Accidental falls                                  | 9,685 (0.3)                       |
| Other                                             | 8,642 (0.3)                       |
| Potential FRIs tested                             |                                   |
| Head and face                                     |                                   |
| Fracture of skull and head trauma                 | 2,391 (0.1)                       |
| Open wound, superficial injury, or contusion      | 4,618 (0.2)                       |
| Dislocation of jaw                                | 6 (0)                             |
| Sprains and strains                               | 61 (0)                            |
| Injury to blood vessels or nerve, crushing injury  | 29 (0)                            |
| Neck and trunk                                    |                                   |
| Fracture                                          | 5,358 (0.2)                       |
| Open wound, superficial injury, or contusion      | 2,173 (0.1)                       |
| Dislocation                                       | 424 (0)                           |
| Sprains and strains                               | 2,084 (0.1)                       |
| Internal injury                                   | 378 (0)                           |
| Injury to blood vessels or nerve, crushing injury  | 158 (0)                           |
| Upper extremity                                   |                                   |
| Fracture                                          | 10,135 (0.4)                      |
| Open wound, superficial injury, or contusion      | 3,557 (0.1)                       |
| Dislocation                                       | 630 (0)                           |
| Sprains and strains                               | 1,638 (0.1)                       |
| Injury to blood vessels or nerve, crushing injury  | 54 (0)                            |
| Lower extremity                                   |                                   |
| Fracture                                          | 17,324 (0.6)                      |
| Open wound, superficial injury, or contusion      | 4,054 (0.1)                       |
| Dislocation                                       | 1,316 (0.1)                       |
| Sprains                                           | 2,570 (0.1)                       |
| Injury to blood vessels or nerve, crushing injury  | 58 (0)                            |

Abbreviations: E-code, external cause of injury code; FRIs, fall-related injuries.

\textsuperscript{a} Medicare injury encounter data for participants in the 1998-2012 Health and Retirement Study before consolidating E-codes and potential FRIs claims into episodes of care. There were 19,130 E-coded FRIs (0.68% of all claims) and 52,060 potential FRIs tested (1.85% of all claims).
observation windows. The sample of 13,939 participants was 42.4% male (1,672 participants), with a mean (SD) age of 77.56 (7.63) years.

In the Medicare data, more than 2.8 million claims across all levels of acuity were identified, of which 0.68% included E-coded FRIs and 1.85% included ICD-9-coded potential FRIs (Table 2). After we linked E-coded FRI encounters into episodes, 4438 (8.8%) were found in 50,310 unique 2-year observation windows. After including patient-reported interviews, the number of observation windows containing a reference standard FRI increased to 8621 (17.1% of observations). Using 52,060 eligible ICD-9 diagnoses (Table 2), we constructed 9,270 potential FRI episodes (18.4% of 50,310 observation windows) to test against the reference standard FRIs (Table 1).

Validity in High-Acuity Care Settings
The overall validity of ICD-9 injuries was similar in the 2 high-acuity care categories, and therefore the categories were combined (any hospital, nursing home, or emergency department care). After consolidating injury types, the most valid injury category from higher-acuity care settings (Figure 2) was head and face injuries (1,602 FRI episodes; 86.0% validity).

Validation Across All Inpatient and Outpatient Health Care Settings
Among all potential FRIs (Figure 2), the most valid category remained head and face injury (2,332 episodes; 83.7% validity), whereas the invalid injury category (injuries with <50% validity) consisted of upper and lower extremity sprains (2,405 episodes; 42.7% validity).

Most superficial injuries (contusions, lacerations, and abrasions) were validated at more than 70%. A post hoc sensitivity analysis (eTable 9 in the Supplement) showed that this high validity was not a function of superficial injuries occurring during the same observation window as more severe injuries.

Validity and Inclusiveness of Cumulative Diagnosis-Based Algorithms
Our final framework of 3 nested FRI algorithms revealed trade-offs between validity and inclusiveness (Figure 3). For comparison, as a baseline reference, each algorithm was compared with one only including E-coded FRIs (2-year incidence, 8.8% [95% CI, 8.6%-9.1%]; validity, 100%; inclusiveness, 51.5% [95% CI, 50.4%-52.5%]). The acute care algorithm (Figure 3) revealed an incidence of FRIs of 12.6% (95% CI, 12.4%-12.9%) and a 43% increase in test-positive cases.
compared with E-coded FRIs only, the baseline reference. The acute care algorithm was 88.6% (95% CI, 87.4%-89.8%) valid and 62.1% (95% CI, 61.1%-63.1%) inclusive (a 21% increase).

The balanced algorithm revealed an incidence of FRIs of 14.6% (95% CI, 14.3%-14.9%), which was a 65.7% increase compared with E-codes only, and was 83.2% (95% CI, 81.9%-84.6%) valid and 65.3% (95% CI, 64.3%-66.3%) inclusive (a 27% increase compared with E-codes only).

The inclusive algorithm, which extends beyond hospitals and emergency department care into outpatient clinic care, revealed an incidence of FRIs of 17.4% (95% CI, 17.1%-17.8%), which was a 98.2% increase compared with E-codes only, and was 75.2% (95% CI, 73.7%-76.6%) valid and 68.4% (95% CI, 67.4%-69.3%) inclusive (a 32.8% increase compared with E-codes only).

Validity of all 3 algorithms was improved with use of the UCLA/RAND method (requiring procedure codes as inclusion criteria to identify FRIs exclusively diagnosed in outpatient emergency departments and clinics), with the greatest improvement observed for the inclusive algorithm (from 53.2% to 75.2%) (eTable 10 in the Supplement).

The category of low-validity injuries (upper and lower limb sprains from both inpatient and outpatient care settings) was not included in any of the 3 final algorithms. Adding these remaining injuries would have identified more cases (19.7% incidence and 70.2% inclusiveness) but would have reduced validity (68.6%) (Figure 3).

Discussion

In this study, we developed and validated an administrative approach using injury diagnostic data sets from across health settings to identify older adults with FRIs ranging from high to low acuity, improving on existing methods that rely on E-codes for detection of fall-related health care. The result was a flexible framework of algorithms that traded off in validity and inclusiveness, with implications for surveillance and quality improvement measurement. Using only high-acuity FRIs, the acute care algorithm was the most valid but least inclusive, with 88.6% of its test FRIs confirmed by the reference standard and approximately 62.1% of all reference-standard FRIs captured by test FRIs. By examining outpatient clinical care diagnoses, the inclusive algorithm had a 32.8% increase in reference-standard FRIs captured by test FRIs with a decrease in validity (from 90% to 75%). Together, these results suggest that by balancing validity with inclusiveness, FRIs of varying severity...
can be broadly identified using commonly used administrative databases that go beyond the use of E-codes.23

Previous work24-27 used FRI algorithms that were limited to only E-coded injuries, patient interview, or medical record review (limited by cost). In comparison with previous algorithms,13-16 we developed more comprehensive algorithms, including less severe injuries (abrasions, contusions, and lacerations) while removing less valid injury diagnoses. This was achieved by leveraging the thousands of injuries in Medicare data that were validated against E-codes and interviews from the nationally representative HRS—a process not possible in other data sets. The large sample of injuries also allowed us to identify injury categories within health care acuity levels to refine the algorithms. This study was also the first, to our knowledge, to offer its algorithm codes for public use.

We propose that this algorithm framework can facilitate assessment of interventions28-30 to reduce fall risk among individuals31-33 and within communities.34-38 The acute care algorithm identified 43% more FRIs compared with the E-code only approach while maintaining strong validity; thus, it may be a valid tool for increasing statistical power to detect significant changes resulting from an intervention (eg, a resource-intensive polypharmacy review to reduce fall risk). Because of its broader scope but reduced validity, the balanced algorithm can serve to identify fall outcomes for lower-risk quality improvement initiatives in primary care, such as promoting use of the Medicare annual medical wellness visit or for improving care of older persons who fall.39,40 The inclusive algorithm was the most comprehensive approach (doubling the number of FRIs compared with E-codes only) and included more superficial injuries. By excluding the least-valid injuries while maintaining most other injuries, it captured the most FRIs of the 3 algorithms and therefore may be the most useful for public health monitoring. For individuals who are more frail, this measure captures even the minor injuries that lead to fear of falling and loss of independence.

Each of these surveillance tools can contribute to ongoing efforts in fall prevention. For population-based efforts41-44 and clinical practice improvement efforts to reduce falls45-49 to work, valid tools to measure their effectiveness will be required. However, although large health care systems are increasingly responsible for monitoring quality and outcomes, they often lack the tools to do so. Medicare also does not have critical population-wide fall surveillance for older adults, although falls are one of the leading causes of death among older adults.3,7,50 Instead, present approaches to monitoring fall injuries and their costs,1,12,14,15,24,51 including data from the US trauma system,52 focus on fall-related death and more severe injury and ignore falls treated in outpatient clinics, which represent a large proportion of older adult falls. Our algorithms can be considered a step toward addressing these limitations and improve monitoring.

As increasing attention is paid to falls in an aging US population, one direction is to capture clinical events in electronic health records. Next steps include developing methods to capture falls reported by patients by telephone, email, or electronic visits either by requiring diagnoses for these alternative means of accessing health care or by using natural language processing to read clinical notes.53 In addition, triangulating diagnostic codes with both patient report and clinician notes would be a resource-intensive but rigorous way to further develop an administrative algorithm for FRI identification.53 These approaches may not be as broadly generalizable as our present claims-based approach given the intersystem differences in electronic health record use, type, and data availability but may be a step toward more accurate monitoring of falls.

Limitations

We noted 3 limitations. First, because of the HRS design, we could only examine patient reports of FRIs every 2 years. Instead of being contemporaneous, patient report of fall injuries involved a 2-year recall period. Previous research suggested that accuracy of recall using falls calendars declined after 6 months18,19,21,22 and a modest decline in reporting accuracy 1 year after an FRI. In the present analysis, we used relative ranking of injury types to develop the algorithms. Given that the injury types were randomly distributed in time, the 2-year time frame should not bias our results. Second, use of International Statistical Classification of Diseases and Related Health Problems, Tenth Revision
ICD-10 diagnosis codes became mandatory as of 2015, with expansion of both cause of injury and diagnostic injury codes. We believe that these changes will not increase the validity of reported FRIs because there have been no concomitant changes in the mandates for reporting of falls by clinicians. To facilitate future use of the algorithms, we provided proposed ICD-10 codes corresponding to our ICD-9-based algorithms (eTable 11 in the Supplement). Further research is needed to revalidate the ICD-10 algorithms. Third, the validity of our algorithms may be biased downward because of unreported FRIs occurring within nursing homes and hospitals. One future improvement would be to identify additional reference-standard FRIs in the minimum data set given standard reporting requirements for falls that are mandatory in nursing facilities.

Conclusions

The findings suggest that fall injury data should be collected broadly in health systems and for use in public health monitoring by leveraging both the validity of E-codes and ICD codes for injuries. By accounting for variability in the validity but also the contribution to overall inclusiveness when adding ICD codes, this research organized the codes into algorithms that can be tailored to the measurement needs of health systems.
Langa) from the National Institute on Aging, and grant NIA AG024824 (Dr Hoffman) from the University of Michigan Older Americans Independence Center Research Education Core and pilot grant. The Health and Retirement Survey is funded by grant U01 AG009740 from the National Institute on Aging and performed at the Institute for Social Research, University of Michigan, Ann Arbor.

Role of the Funder/Sponsor: The funding agencies had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

REFERENCES

1. Hoffman GJ, Hays RD, Shapiro MF, Wallace SP, Ettner SL. The costs of fall-related injuries among older adults: annual per-faller, service component, and patient out-of-pocket costs. *Health Serv Res*. 2017;52(5):1794-1816. doi: 10.1111/1475-6773.12554

2. Owens PL, Russo CA, Spector W, Mutter R. *Healthcare Cost and Utilization Project (HCUP) Statistical Brief #80: Emergency Department Visits for Injurious Falls Among the Elderly*, 2006. Rockville, MD: Agency for Health Care Policy and Research; 2009.

3. Cigolle CT, Ha J, Min LC, et al. The epidemiologic data on falls, 1998-2010: more older Americans report falling. *JAMA Intern Med*. 2015;175(3):443-445. doi: 10.1001/jamainternmed.2014.7533

4. Florence CS, Bergen G, Atherly A, Burns E, Stevens J, Drake C. Medical costs of fatal and nonfatal falls in older adults. *J Am Geriatr Soc*. 2018;66(4):693-698. doi: 10.1111/jgs.15304

5. Tricco AC, Cogo E, Holroyd-Leduc J, et al. Efficacy of falls prevention interventions: protocol for a systematic review and network meta-analysis. *Syst Rev*. 2013;2:38. doi: 10.1186/2046-4053-2-38

6. Ganz DA, Alkema GE, Wu S. It takes a village to prevent falls: reconceptualizing fall prevention and management for older adults. *Inj Prev*. 2008;14(4):266-271. doi: 10.1136/ip.2008.018549

7. Bergen G, Stevens MR, Burns ER; Centers for Disease Control and Prevention. Falls and fall injuries among adults aged ≥65 years—United States, 2014. *MMWR Morb Mortal Wkly Rep*. 2016;65(37):993-998. doi: 10.15585/mmwr.mm6537a2

8. McKenzie K, Enrigh-Moony EL, Walker SM, McClure RJ, Harrison JE. Accuracy of external cause-of-injury coding in hospital records. *Inj Prev*. 2009;15(1):60-64. doi: 10.1136/ip.2008.019935

9. Centers for Disease Control and Prevention. Injury prevention and control. Leading causes of nonfatal injury reports, 2000–2017. [https://www.webappa.cdc.gov/sasweb/ncipc/nfilead.html](https://www.webappa.cdc.gov/sasweb/ncipc/nfilead.html). Accessed July 13, 2019.

10. Abellera J, Annest JL, Conn JC, Kohn M. *How States Are Collecting and Using Cause of Injury Data: 2004 Update to the 1997 Report*. Atlanta, GA: Council of State and Territorial Epidemiologists; 2005.

11. Annest JL, Conn JC, McLoughlin E, Finghert LA, Pickett D, Gallagher S. *How States Are Collecting and Using Cause of Injury Data: Injury Control and Emergency Health Services Section*. Washington, DC: American Public Health Association; 1997.

12. Hoffman GJ, Hays RD, Shapiro MF, Wallace SP, Ettner SL. Claims-based identification methods and the cost of fall-related injuries among US older adults. *Med Care*. 2016;54(7):664-671. doi: 10.1097/MLR.0000000000000531

13. Bohl AA, Fishman PA, Ciol MA, Williams B, Logerfo J, Phelan EA. A longitudinal analysis of total 3-year healthcare costs for older adults who experience a fall requiring medical care. *J Am Geriatr Soc*. 2010;58(5):853-860. doi: 10.1111/j.1532-5415.2010.02816.x

14. Bohl AA, Phelan EA, Fishman PA, Harris JR. How are the costs of care for medical falls distributed? the costs of medical falls by component of cost, timing, and injury severity. *Gerontologist*. 2012;52(5):664-675. doi: 10.1093/geront/gnt151

15. Roudsari BS, Ebel BE, Corso PS, Molinari NA, Koepsell TD. The acute medical care costs of fall-related injuries among the US older adults. *Injury*. 2005;36(11):1316-1322. doi: 10.1016/j.injury.2005.05.024

16. Kim SB, Zingmond DS, Keeler EB, et al. Development of an algorithm to identify fall-related injuries and costs in Medicare data. *Inj Epidem*. 2016;3(1):1. doi: 10.1186/s40621-015-0066-z

17. Rutjes AW, Reitsma JB, Coomarasamy A, Khan KS, Bossuyt PM. Evaluation of diagnostic tests when there is no gold standard: a review of methods. *Health Technol Assess*. 2007;11(S0):iii, ix-ix.

18. Peel N. Validating recall of falls by older people. *Accid Anal Prev*. 2000;32(3):371-372. doi: 10.1016/S0001-4575(99)00066-4

19. Hale WA, Delaney MJ, Cable T. Accuracy of patient recall and chart documentation of falls. *J Am Board Fam Pract*. 1993;6(3):239-242.
20. Hoffman GJ, Ha J, Alexander NB, Langa KM, Tinetti M, Min LC. Underreporting of fall injuries of older adults: implications for wellness visit fall risk screening. *J Am Geriatr Soc*. 2018;66(6):1195-1200. doi:10.1111/jgs.15360
21. Ganz DA, Higashi T, Rubenstein LZ. Monitoring falls in cohort studies of community-dwelling older people: effect of the recall interval. *J Am Geriatr Soc*. 2005;53(12):2190-2194. doi:10.1111/j.1532-5415.2005.00509.x
22. Cummings SR, Nevitt MC, Kidd S. Forgetting falls: the limited accuracy of recall of falls in the elderly. *J Am Geriatr Soc*. 1988;36(7):613-616. doi:10.1111/j.1532-5415.1988.tb06155.x
23. Bossuyt PM, Reitsma JB, Bruns DE, et al; STARD Group. STARD 2015: an updated list of essential items for reporting diagnostic accuracy studies. *BMJ*. 2015;351:h5527. doi:10.1136/bmj.h5527
24. Finkelstein E, Prabhu M, Chen H. Increased prevalence of falls among elderly individuals with mental health and substance abuse conditions. *Am J Geriatr Psychiatry*. 2007;15(7):611-619. doi:10.1097/JGP.Ob013e318033ed97
25. Finkelstein EA, Chen H, Miller TR, Corso PS, Stevens JA. A comparison of the case-control and case-crossover designs for estimating medical costs of nonfatal fall-related injuries among older Americans. *Med Care*. 2005;43(11):1087-1091. doi:10.1097/01.mlr.0000182513.35595.60
26. Corso P, Finkelstein E, Miller T, Fiebelkorn I, Zaloshnja E. Incidence and lifetime costs of injuries in the United States. *Inj Prev*. 2006;12(4):212-218. doi:10.1136/inp.2005.010983
27. Alexander BH, Rivara FP, Wolf ME. The cost and frequency of hospitalization for fall-related injuries in older adults. *Am J Public Health*. 1992;82(7):1020-1023. doi:10.2105/AJPH.82.7.1020
28. Tinetti ME. Clinical practice: preventing falls in elderly persons. *N Engl J Med*. 2003;348(1):42-49. doi:10.1056/NEJMcp020719
29. Tinetti ME, Baker DI, King M, et al. Effect of dissemination of evidence in reducing injuries from falls. *N Engl J Med*. 2008;359(3):252-261. doi:10.1056/NEJMoA0801748
30. Titler MG, Conlon P, Reynolds MA, et al. The effect of a translating research into practice intervention to promote use of evidence-based fall prevention interventions in hospitalized adults: a prospective pre-post implementation study in the US. *Appl Nurs Res*. 2016;31:52-59. doi:10.1016/j.apnr.2015.12.004
31. Chang JT, Morton SC, Rubenstein LZ, et al. Interventions for the prevention of falls in older adults: systematic review and meta-analysis of randomised clinical trials. *BMJ*. 2004;328(7441):680. doi:10.1136/bmj.328.7441.680
32. Gillespie LD, Robertson MC, Gillespie WJ, et al. Interventions for preventing falls in community-dwelling older adults. *Cochrane Database Syst Rev*. 2012;(9):CD004441.
33. Chase CA, Mann K, Wasek S, Arbesman M. Systematic review of the effect of home modification and fall prevention programs on falls and the performance of community-dwelling elderly adults. *Am J Occup Ther*. 2012;66(3):284-291. doi:10.5014/ajot.2012.005017
34. Lindqvist K, Timpka T, Schelp L. Evaluation of an inter-organizational prevention program against injuries among the elderly in a WHO Safe Community. *Public Health*. 2001;115(5):308-316. doi:10.1016/S0033-3506(01)00468-1
35. Ytterstad B. The Harstad injury prevention study: community based prevention of fall-fractures in the elderly evaluated by means of a hospital based injury recording system in Norway. *J Epidemiol Community Health*. 1996;50(5):551-558. doi:10.1136/jech.50.5.551
36. Lin MR, Hwang HF, Wang YW, Chang SH, Wolf SL. Community-based tai chi and its effect on injurious falls, balance, gait, and fear of falling in older people. *Phys Ther*. 2006;86(9):1189-1201. doi:10.2522/ptj.20040408
37. Poulstrup A, Jeune B. Prevention of fall injuries requiring hospital treatment among community-dwelling elderly. *Eur J Public Health*. 2000;10(1):45-50. doi:10.1093/eurpub/10.1.45
38. McClure R, Turnier C, Peal N, Spinks A, Eakin E, Hughes K. Population-based interventions for the prevention of fall-related injuries in older people. *Cochrane Database Syst Rev*. 2005;(1):CD004441.
39. Min L, Wenger N, Walling AM, et al. When comorbidity, aging, and complexity of primary care meet: development and validation of the Geriatric Complexity of Care Index. *J Am Geriatr Soc*. 2013;61(4):542-550. doi:10.1111/jgs.12160
40. Min LC, Reuben DB, Adams J, et al. Does better quality of care for falls and urinary incontinence result in better participant-reported outcomes? *J Am Geriatr Soc*. 2011;59(8):1435-1443. doi:10.1111/j.1532-5415.2011.03517.x
41. Ganz DA, Kim S-B, Zingmond DS, et al. Effect of a falls quality improvement program on serious fall-related injuries. *J Am Geriatr Soc*. 2015;63(1):63-70. doi:10.1111/jgs.13154
42. Rose DJ, Alkema GE, Choi IH, Nishita CM, Pynoos J. Building an infrastructure to prevent falls in older Californians: the Fall Prevention Center of Excellence. Ann N Y Acad Sci. 2007;1114:170-179. doi:10.1196/annals.1396.035

43. Scott V, Wagar B, Sum A, Metcalfe S, Wagar L. A public health approach to fall prevention among older persons in Canada. Clin Geriatr Med. 2010;26(4):705-718. doi:10.1016/j.cger.2010.06.003

44. Murphy TE, Baker DI,leo-Summers LS, et al. Integration of fall prevention into state policy in Connecticut. Gerontology. 2013;53(3):508-515. doi:10.1093/geront/gns122

45. Clemson L. Prevention of falls in the community. BMJ. 2010;340:c2244. doi:10.1136/bmj.c2244

46. Tinetti ME, Gordon C, Sogolow E, Lapin P, Bradley EH. Fall-risk evaluation and management: challenges in adopting geriatric care practices. Gerontologist. 2006;46(6):717-725. doi:10.1093/geront/46.6.717

47. Wenger NS, Roth CP, Shekelle PG, et al. A practice-based intervention to improve primary care for falls, urinary incontinence, and dementia. J Am Geriatr Soc. 2009;57(3):547-555. doi:10.1111/j.1532-5415.2008.02128.x

48. Wenger NS, Roth CP, Hall WJ, et al. Practice redesign to improve care for falls and urinary incontinence: primary care intervention for older patients. Arch Intern Med. 2010;170(19):1765-1772. doi:10.1001/archinternmed.2010.387

49. Bhasin S, Gill TM, Reuben DB, et al. Strategies to Reduce Injuries and Develop Confidence in Elders (STRIDE): a cluster-randomized pragmatic trial of a multifactorial fall injury prevention strategy: design and methods. J Gerontol A Biol Sci Med Sci. 2018;73(8):1053-1061. doi:10.1093/gerona/glx190

50. Kramarow E, Chen LH, Hedegaard H, Warner M. Deaths from unintentional injury among adults aged 65 and over: United States, 2000-2013. NCHS Data Brief. 2015;(199):199.

51. Heinrich S, Rapp K, Rissmann U, Becker C, König HH. Cost of falls in old age: a systematic review. Osteoporos Int. 2010;21(6):891-902. doi:10.1007/s00198-009-1100-1

52. Orces CH. Emergency department visits for fall-related fractures among older adults in the USA: a retrospective cross-sectional analysis of the National Electronic Injury Surveillance System All Injury Program, 2001-2008. BMJ Open. 2013;3(1):e001722. doi:10.1136/bmjopen-2012-001722

53. McCart JA, Berndt DJ, Jarman J, Finch DK, Luther SL. Finding falls in ambulatory care clinical documents using statistical text mining. J Am Med Inform Assoc. 2013;20(5):906-914. doi:10.1136/amiajnl-2012-001334

SUPPLEMENT.
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