Validity of Myocardial Infarction Diagnoses in Administrative Databases: A Systematic Review

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Abstract

Background: Though administrative databases are increasingly being used for research related to myocardial infarction (MI), the validity of MI diagnoses in these databases has never been synthesized on a large scale.

Objective: To conduct the first systematic review of studies reporting on the validity of diagnostic codes for identifying MI in administrative data.

Methods: MEDLINE and EMBASE were searched (inception to November 2010) for studies: (a) Using administrative data to identify MI; or (b) Evaluating the validity of MI codes in administrative data; and (c) Reporting validation statistics (sensitivity, specificity, positive predictive value (PPV), negative predictive value, or Kappa scores) for MI, or data sufficient for their calculation. Additional articles were located by handsearch (up to February 2011) of original papers. Data were extracted by two independent reviewers; article quality was assessed using the Quality Assessment of Diagnostic Accuracy Studies tool.

Results: Thirty studies published from 1984–2010 were included; most assessed codes from the International Classification of Diseases (ICD)-9th revision. Sensitivity and specificity of hospitalization data for identifying MI in most (≥50%) studies was ≥86%, and PPV in most studies was ≥93%. The PPV was higher in the more-recent studies, and lower when criteria that do not incorporate cardiac troponin levels (such as the MONICA) were employed as the gold standard. MI as a cause-of-death on death certificates also demonstrated lower accuracy, with maximum PPV of 60% (for definite MI).

Conclusions: Hospitalization data has higher validity and hence can be used to identify MI, but the accuracy of MI as a cause-of-death on death certificates is suboptimal, and more studies are needed on the validity of ICD-10 codes. When using administrative data for research purposes, authors should recognize these factors and avoid using vital statistics data if hospitalization data is not available to confirm deaths from MI.

Introduction

Cardiovascular diseases (CVD), including myocardial infarction (MI), are associated with physical disability, reduced quality-of-life, economic hardship, and death. In 2008 CVD accounted for 30% of all deaths globally [1], and annual cost estimates for CVD have recently exceeded €169 billion for the European Union [2] and $400 billion in the United States [3]. Although age is one of the primary risk factors for CVD, growing evidence suggests that chronic conditions including inflammatory rheumatic diseases [4–9], osteoarthritis [10], diabetes [11], and clinical depression [12] are also associated with an increased risk of CVD, independent of age.

Alongside, there is increasing recognition of the value of administrative data for use in disease surveillance [13–19], and this data source has been key in identifying the associations between chronic diseases and CVD as mentioned above. Administrative databases provide easy access to data for a large number of patients attending multiple centres, with longer follow-up periods at relatively low cost. For example, the universal provision of publicly-funded health care in Canada allows the patient-level linkage of health resource utilization data (including hospital separations, outpatient visits, procedures and tests, and, in some provinces, dispensed prescriptions) for nearly every resident of each province to demographic and vital statistics data. Consequently, both selection and recall bias are minimized.

Despite these advantages, much uncertainty exists around the validity of diagnoses recorded in administrative data since most databases are not established for research purposes. Instead, using administrative data for research purposes, authors should recognize these factors and avoid using vital statistics data if hospitalization data is not available to confirm deaths from MI.
and hospital staff primarily to obtain reimbursement. Thus, not all conditions may be recorded in the databases, and those recorded may not correspond to the date of disease onset or reflect the true diagnosis and assessment made by the treating physician. These errors and inconsistencies in diagnostic codes may lead to misclassification bias, impacting the quality of research using these sources and, in turn, any changes in health policy and care practices stemming from it. For example, failure to adequately capture the number of people affected by CVD may underestimate the burden of these diseases, thus limiting the health resources allocated to address them. Alternatively, when studying long-term health outcomes, capturing an excess number of false-positive cardiovascular events could overestimate the risks associated with an otherwise beneficial therapy or intervention.

While several assessments of the validity of cardiovascular codes have been published [20–23], most concerned a single CVD and were conducted within a limited geographic area, restricting their generalizability. Much inconsistency exists with regards to the methods (including the source of the population and gold standards) adopted by these studies and the way in which results are reported. To our knowledge data on the validity of these codes have not yet been synthesized on a larger scale.

As part of a Canadian Rheumatology Network for establishing best practices in the use of administrative data for health research and surveillance (CANRAD) [13,19,24], our objective was to conduct a systematic review of studies reporting on the validity of diagnostic codes for identifying CVD in administrative data. Data from these studies were used to compare the validity of these codes, and to evaluate whether administrative health data can accurately identify CVD for the purpose of identifying these events as covariates, outcomes, or complications in future research. We focus on MI in this paper, and will discuss two other CVD, congestive heart failure and cerebrovascular accident, in subsequent reports.

Methods

Literature Search

Comprehensive searches of the MEDLINE and EMBASE databases from inception (1946 and 1974, respectively) to November 2010 for all available peer-reviewed literature were conducted by an experienced librarian (M-DW). Two search strategies were employed: (1) all studies where administrative data was used to identify CVD; (2) all studies reporting on the validity of administrative data for identifying CVD. Our MEDLINE and EMBASE search strategies are available as supplementary materials (Text S1 and S2). To find additional articles, the authors hand-searched the reference lists of the key articles located through the database search. The Cited-By tools in PubMed and Google Scholar were also used to find relevant articles that had cited the articles located through the database search (up to February 2011). The titles and abstracts of each record were screened for relevance by two independent reviewers. No protocol for this systematic review has been published, though the review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement; our completed PRISMA checklist is provided as supplementary material (Checklist S1). More information about the CANRAD project is available here [13].

Inclusion Criteria

We selected full-length peer-reviewed articles published in English that used administrative data and reported validation statistics for the International Classification of Diseases (ICD) codes of interest or provided sufficient data enabling us to calculate them. We included studies evaluating particular diagnostic codes for acute MI (being ICD-8 & ICD-9 code 410 and ICD-10 codes I21&I22) and excluded studies that evaluated umbrella diagnoses. This means we did not include validity statistics from studies where other codes were included in the algorithm for MI (ie. 410–411 or 410–414). For example, the MI statistics in one study [25] were not included because the algorithm included a code for cardiac arrest (ICD-9 427.5); those in three others [26–28] were not included because those algorithms contained codes for old MI (ICD-9 412 and ICD-10 code I25.2). Any discrepancies were discussed until consensus was reached. When the conflict persisted a third reviewer (JAA-Z) was consulted.

Data Extraction

The full text of each selected record was examined by two independent reviewers (NM and VB) who abstracted data using a standardized collection form (a copy is provided in Text S3) developed for the CANRAD investigations. While extracting data, particular attention was given to the study population, administrative data source, algorithm used to identify the CVDs, validation method and gold standard. Validation statistics comparing the MI codes listed above to definite, probable, or possible cases were abstracted. These statistics included sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and kappa scores. Because hospital separations typically contain multiple diagnoses, with the primary or principle diagnosis in the first position followed by one or more secondary diagnoses, we abstracted statistics for each of these positions, where available. Data were independently abstracted by each reviewer, who subsequently compared their forms to correct any errors and resolve discrepancies.

The design and methods used by each study (for example, whether or not the diagnosis recorded in the administrative database formed part of the reference standard) can directly influence the validity statistics produced. Thus, all studies were evaluated for quality, and the validation statistics were stratified by level of study quality. We used the Quality Assessment of Diagnostic Accuracy Studies (QUADAS) tool [29] (available as a part of Text S3), used previously by the CANRAD network in assessing the validity of codes for osteoporosis and fractures [30]. Briefly, it is a 14-item evidence-based quality assessment tool used in systematic reviews of diagnostic accuracy studies. Each item, phrased as a question, addresses one or more aspects of bias or applicability; however, there is no overall score. Instead, as done previously [30], items were independently answered by each reviewer and used to qualitatively assess each study as High, Medium, or Low quality. Any disagreements were resolved by consensus.

Statistical Analysis

All validation statistics were abstracted as reported. Where sufficient data were available we calculated 95% confidence intervals (95% CI) and additional validity statistics not directly reported in the original publication. For each CVD these were evaluated on aggregate, and, as pre-specified, stratified by administrative data source (ie. hospitalization vs. vital statistics). Sensitivity (the ability of the codes to identify true positive cases) was equal to the number of true positives divided by the sum of true positives and false negatives (all those who are diseased). Specificity (the ability of the codes to exclude false-positive cases) was equal to the number of true negatives divided by the sum of true negatives and false positives (all those who are non-diseased). PPV (the likelihood that the code corresponds to a true-positive
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Results

Literature Search

After the removal of duplicates, 1,587 citations were identified through MEDLINE and EMBASE searches and screened for relevance to our study objectives. We then assessed 98 full-text articles for eligibility (Figure 1), of which 22 were selected for inclusion. We also assessed 30 full-text articles for eligibility that were identified from other sources, and selected 8 additional articles therein. This meant a total of 128 articles were assessed for eligibility, from which 96 were excluded, mainly because they reported on the validity of other CVD (n = 41), or did not actually validate MI diagnoses in administrative data (n = 20). Six articles were excluded because they were not published in English; their languages of publication were Danish, German, Italian, Japanese, Portuguese, and Spanish. Ultimately, 30 articles were included for the systematic review of MI.

Study Characteristics

Of the 30 studies evaluating MI diagnoses that were included in the final review, 12 (40%) were from Europe, 8 (27%) were from the United States (USA), 7 (23%) were from Canada, 2 (7%) were from New Zealand, and 1 (3%) was from Australia. Characteristics of these studies are presented in Table 1. Validation was the primary research objective in 26 (87%) of them. Altogether data were collected over a 34-year period (1970 to 2003) that covered three revisions of the ICD system (ICD-8, ICD-9, and ICD-10). Nearly all administrative data sources pertained to hospitalizations with algorithms consisting of ICD diagnostic codes but no procedure codes. Five studies evaluated the validity of MI as a cause-of-death on death certificates, but none of the studies evaluated diagnoses for outpatient encounters. National and regional disease registries and surveillance systems served as the gold standards in 10 (33%) studies [20,21,34-41]. In the 20 remaining studies, the gold standards were based on chart reviews, often in consultation with established diagnostic criteria. Just two studies [42,43] reported on the validity of ICD-10 codes separately from ICD-9 codes.

Study quality was evaluated based on the QUADAS tool [29], with 26 of 30 studies (87%) categorized as high quality, and four (13%) as medium quality. A detailed breakdown of the evaluations for each study is provided in Table S1. In one of the medium-quality studies [44] the validation process was not adequately described, while the gold standard in another [45] was considered less-reliable because charts of potential MI cases were not evaluated by a clinician. The two other medium-quality studies employed a select source population – male smokers aged 50–69 years in one [46], and those aged 65 years or older in another [47] - which limited their generalizability.

PPV data were available from all but one study [39] while the kappa statistic was reported in only two studies [21,48]. Sensitivity, specificity, and NPV were less-frequently reported by authors, but sufficient data to allow calculation of these statistics were often available and included when the source population was sufficiently broad (ie. when it was not confined to cases receiving codes of ICD-9 410–414, which correspond to a more general category of coronary heart diseases that includes MI).

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The validation statistics reported by each of the included studies are provided in Table 2. Sensitivity was reported by 12 studies, and was at least 86% in half of them. PPV, obtained from 29 studies, was ≥93% in the majority (n = 15) of them. Specificity and NPV were available only from three studies [22,40,48] and in these ranged from 89-99%, and 75–99%, respectively. Five studies [34–36,43,45] provided sex-stratified statistics and in four of these [35,36,43,45] sensitivity and PPV values were higher for males (Table 2). Twenty-six of the 30 studies on MI (87%) were of high quality and the PPV was ≥80% in 20 of 25 (80% of the high-quality studies). One high-quality study [39] did not report PPV. One of the medium-quality studies reported a PPV of 81% [44], while in the three others [45–47] this value ranged from 95–98%. None of the medium-quality studies reported on sensitivity, specificity, NPV, or kappa.

In order to examine secular trends in the validity of MI codes, the studies in Tables 2 and 3 have been ordered chronologically by publication year. Half of the MI studies were published between 1984 and 1998, and the other half from 1999 to 2010. No clear trends in sensitivity were observed amongst the twelve studies reporting this statistic. However, at least amongst studies providing statistics on hospitalization data, we did observe somewhat of a trend towards higher PPV's in later years: the PPV was $89% in eight of the ten most-recent studies (from 2002 to 2010) while only four out of the 10 earlier studies (from 1984 to 1995) reported PPV≥89%. Of interest, Rosamond et al [36] analysed the validity of MI diagnoses recorded from 1987 to 2000, with no secular
trends overall in sensitivity or PPV. We were unable to directly evaluate any secular trends in specificity or NPV as there were very few studies (n = 3) reporting these statistics.

As expected, there was also some variability in results with regards to the selection of gold standard and specific diagnostic criteria. The MONICA criteria, described above, were used in 12 studies [20,21,34,35,37–39,41,46,49–51], and the sensitivity and PPV in these was lower than in studies using the current criteria. For example, the reported sensitivity of ICD 410 for detecting cases of definite or possible MI using the MONICA was 43% [20] in one study and ranged from 56–72% [34] in another. However, the PPV was noticeably higher (94–95% in the primary or secondary admission position) [47] in one article where levels of an additional biomarker of cardiac damage, troponin, were considered in addition to the standard MONICA criteria. In one study comparing the PPV’s associated with two gold standards, the PPV for definite MI was 56% using American Heart Association (AHA) criteria but only 53% using MONICA criteria [49]. Finally, while it wasn’t consistent across all studies using the MONICA criteria, the PPV’s were generally higher in those that were part of an actual MONICA registry [20,21,34,35,37,38,41] than in other investigations that simply used the MONICA criteria to evaluate potential cases of MI [46,49–51].

The PPV values from studies that reported on hospitalization data and incorporated a formal set of diagnostic criteria in their gold standard are plotted in Figure 2. The studies are ordered chronologically by year of publication. Figure 2a contains the estimates pertaining to the stricter parameter of “Definite MI”, and Figure 2b contains the estimates pertaining to the broader parameter of “Definite or Probable or Possible MI”, as estimates for these two parameters cannot be directly compared. If no parameter was specified in the study (ie. the MI code was compared to a diagnosis of simply “myocardial infarction”), we include that estimate in both figures. To allow for visual inspection of the impact of cardiac troponin measurement on the PPV of MI diagnoses, the PPV’s in Figure 2 are colour-coded as to whether

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)-style Flowchart of Study Selection and Review. ICD = International Classification of Diseases; MI = myocardial infarction. doi:10.1371/journal.pone.0092286.g001
### Table 1. Characteristics of included studies.

| First Author, Year of Publication | Year(s) of Data Collection | Primary Validation Study? | Country | Records Evaluated (N) | Source Population | Type of Administrative Data | Gold Standard | Cardiac Troponin Levels Included in the Reference Standard? |
|----------------------------------|-----------------------------|---------------------------|---------|-----------------------|-------------------|-----------------------------|---------------|----------------------------------------------------------|
| Ainla [42], 2006                 | 2001                        | no                        | Estonia | 520                   | general hospitalized population | ICD-10 inpatient records | CRDC - Joint European Society of Cardiology/American College of Cardiology Committee criteria | yes          |
| Austin [48], 2002               | 1996–2000                   | yes                       | Canada (Ontario) | 20,048                | consecutive patients 20 years+ admitted to in coronary care units from ER (excluded patients transferred from another institution, with urgent or emergent admission, if most responsible diagnosis didn’t occur during hospital stay) | ICD-9 inpatient records | disease registry - diagnosis of bedside nurse (as recorded in Fastrak II prospective acute coronary syndromes registry) | n/a          |
| Barchielli [49], 2010            | 2003                        | yes                       | Italy   | 372                   | from population-based Tosc-AMI registry in Tuscany, hospitalized patients, all out-of-hospital deaths | ICD-9 inpatient records | CRDC - American Heart Association (AHA) and MONICA criteria | AHA = yes, MONICA = no |
| Beaglehole [37], 1987           | 1983                        | yes                       | New Zealand | 604                  | general hospitalized population from 3 general hospitals (aged 25–64) | ICD-9 inpatient records | disease registry - MONICA project | no          |
| Boyle [20], 1995                | 1986–1991                   | yes                       | Australia | 2,492                | all residents of 5 communities aged 25–69 years | ICD-9 inpatient records; death certificates | disease registry - MONICA project | no          |
| De Henauw [39], 1998            | 1983–1991                   | yes                       | Belgium | 1,675                 | general population of two Belgian cities | ICD-9 death certificates | disease registry - MONICA project | no          |
| Hammar [64], 2001               | 1987, 1995                  | no                        | Sweden  | 1,848                 | all hospitalized patients and all deaths in the country | ICD-9 inpatient records; death certificates | CRMD | yes          |
| Heckbert [65], 2004             | 1994–2000                   | yes                       | USA (national) | 807                  | women participating in the Women’s Health Initiative clinical and observational studies | ICD-9 inpatient records | CRDC - Women’s Health Initiative criteria | yes          |
| Jackson [38], 1988              | 1983–1984                   | yes                       | New Zealand | 411                  | general population < 65 years residing in Auckland | ICD-9 death certificates | disease registry - MONICA project | no          |
| Kennedy [40], 1984              | not provided                | yes                       | USA (Texas) | 110                  | hospitalized patients at large urban teaching hospital | ICD-9 inpatient records | disease registry - Cardiology Surveillance System (cardiology service) | n/a          |
| Kiyota [47], 2004               | 1999–2000                   | yes                       | USA (Pennslyvania) | 2,022                | hospitalized elderly Medicare beneficiaries in one US state | ICD-9 inpatient records | CRDC – modified WHO criteria | yes          |
| Levy [45], 1999                 | 1994                        | yes                       | Canada  | 234                   | individuals ≥65 years hospitalized with MI (primary diagnosis) | ICD-9 inpatient records | chart review: mentioned in records | n/a (no formal diagnostic criteria) |
| Lindblad [66], 1993             | 1977–1987                   | yes                       | Sweden  | 413                   | participants in hypertension registry (hypertensive cases, normotensive participants, randomly-selected controls), recruited from a geographical half of one Swedish county, aged 40–70 years at registration | ICD-9 inpatient records | CRMD | no          |
| First Author, Year of Publication | Year(s) of Data Collection | Primary Validation Study? | Country | Records Evaluated (N) | Source Population | Type of Administrative Data | Gold Standard | Cardiac Troponin Levels Included in the Reference Standard? |
|----------------------------------|----------------------------|---------------------------|---------|----------------------|------------------|-----------------------------|---------------|---------------------------------------------------------|
| Lowel [41], 1991                 | 1985–1986                  | yes                       | Germany | 753                  | hospitalized patients aged 25–74 | ICD-9 inpatient records, death certificates | disease registry - MONICA project | no |
| Mahonen [35], 1997               | 1983–1990                  | yes                       | Finland | 4,836                | from general population 25–64 years, all hospitalized patients residing in FINMONICA study areas; also screened hospitalized stroke cases to calculate sensitivity for MI | ICD 8,9 inpatient records | disease registry - FINMONICA project | no |
| Mahonen [34], 1999               | 1983–1992                  | yes                       | Finland | 3,182                | general population aged 35–64 years residing in FINMONICA study areas | ICD-8,9 death certificates | disease registry - MONICA project | no |
| McCarthy [44], 2000             | 1994                       | yes                       | USA (California, Connecticut) | 485       | hospitalized Medicare beneficiaries 65 years+ | ICD-9 inpatient records | CRMD | unknown |
| Merry [62], 2009                 | 1987–2003                  | yes                       | Netherlands | 417       | residents of one regions in the Netherlands born between 1927–1977 (aged 20–59 years at registration) participating in two large monitoring projects | ICD-9 inpatient records | disease registry - diagnosis listed in Cardiology Information System (hospital cardiology service) | n/a |
| Nova Scotia-Saskatchewan Cardiovascular Disease Epidemiology Group [51], 1989 | 1974–1977                  | no                        | Canada (Nova Scotia & Saskatchewan) | 813       | general hospitalized population (from all residents aged 25–74) | ICD-8 inpatient records | CRDC - MONICA criteria | no |
| Nova Scotia-Saskatchewan Cardiovascular Disease Epidemiology Group [50], 1992 | 1977, 1981, 1985            | no                        | Canada (Nova Scotia & Saskatchewan) | 1,810     | general hospitalized population (from all residents aged 25–74) | ICD inpatient records | CRDC - MONICA criteria | no |
| Pajunen [43], 2005              | 1988–2002                  | yes                       | Finland | 37,062               | general population (all hospitalizations and deaths) residing in FINMONICA study areas | ICD-9 and ICD-10 inpatient records; death certificates | chart review: using American Heart Association criteria | yes |
| Palomaki [21], 1994             | 1987–1990                  | yes                       | Finland | 1,565                | people aged 35–64 years hospitalized for suspected CHD | ICD-9 inpatient records | disease registry - FINMONICA and MONICA project | no |
| Petersen [67], 1999             | 1994–1995                  | yes                       | USA     | 4,712                | hospitalized male veterans | ICD-9 inpatient records | CRDC - Cooperative Cardiovascular Project criteria | no |
| Pladevall [22], 1996            | 1988–1990                  | yes                       | USA (Texas) | 734       | hospitalized participants in Corpus Christi Heart Project (MONICA-affiliated surveillance program in one Texas county) aged 25–74 years, Mexican-American and non-Hispanic white | ICD-9 inpatient records | CRDC - Cardiovascular Community Surveillance Project criteria | no |
| First Author, Year of Publication | Year(s) of Data Collection | Primary Validation Study? | Country | Records Evaluated (N) | Source Population | Type of Administrative Data | Gold Standard | Cardiac Troponin Levels Included in the Reference Standard? |
|---------------------------------|-----------------------------|---------------------------|---------|----------------------|-------------------|-----------------------------|---------------|---------------------------------------------------|
| Rapola [46], 1997              | 1985–1993                  | yes                       | Finland | 408                  | male smokers aged 50–69 years at registration participating in cancer prevention study | ICD-8,9 inpatient records; death certificates/death register | CRDC - FINMONICA criteria | no |
| Rawson [68], 1995              | 1986                       | yes                       | Canada (Saskatchewan) | 224                  | general hospitalized population | ICD-9 inpatient records | CRMD | unknown |
| Rosamond [36], 2004            | 1987–2000                  | yes                       | USA (North Carolina, Mississippi, Minnesota, Maryland) | 17,900               | from general population (participants in population-based ARIC study), all hospitalized patients aged 35–74, excluded non-whites or blacks | ICD-9 inpatient records | disease registry - Atherosclerosis Risk in Communities project | yes, 1996-onwards |
| van Walraven [69], 1990        | 1987–1988                  | yes                       | Canada (Ontario) | 209                  | hospitalized patients at tertiary hospital | ICD-9 inpatient records | CRMD | no |
| Varas-Lorenzo [70], 2008       | 1999–2001                  | yes                       | Canada (Saskatchewan) | 193                  | as part of a population-based cohort study, hospitalized patients aged 40–84 years | ICD-9 inpatient records | CRDC - American Heart Association/European Society of Cardiology criteria | yes |
| Wahl [71], 2010                | 2002–2004                  | yes                       | USA     | 200                  | commercially-insured individuals in large health claims database | ICD-9 inpatient records | CRMD | unknown |

CRDC = Chart Review, Diagnostic Criteria – the charts of potential cases were reviewed, and a formal set of diagnostic criteria were applied when evaluated cases.
CRMD = Chart Review, Medical Doctor – the charts of potential cases were reviewed by a physician, who evaluated cases using their clinical judgement or an otherwise unspecified set of criteria.
AHA = American Heart Association; MONICA = MONItoring Trends and Determinants in CArdiovascular Disease; WHO = World Health Organization.

doi:10.1371/journal.pone.0092286.t001
Table 2. Results of studies validating diagnoses of myocardial infarction (MI) in administrative data (in ascending order of publication).

| First Author, Year | Diagnostic Codes | Parameter | Sensitivity (95% CI) | Specificity (95% CI) | PPV (95% CI) | NPV (95% CI) | Kappa (95% CI) | Quality |
|--------------------|------------------|-----------|----------------------|----------------------|--------------|--------------|---------------|---------|
| Kennedy, 1984 [40] | ICD9 410         |           | 94.37 (85.46–98.18)  | 99.79 (99.71–99.85) | 60.91 (51.11–69.93) | 99.98 (99.95–99.99) | High          |
| Beaglehole, 1987 [37] | ICD9 410       | definite MI | 85.99 (82.45–88.93)  | 67.05 (63.12–70.76) | 48.66 (41.74–53.60) | High          |
| Jackson, 1988 [38]  | ICD9 410         | definite MI | 84.03 (76.61–88.32)  | 48.66 (41.74–53.60) | High          |
| Nova Scotia-Saskatchewan Cardiovascular Disease Epidemiology Group, 1989 [51] | ICD8 410 or ICD9 410 (primary or secondary hospital diagnosis, or underlying COD) | definite MI, overall | 57.56 (54.08–60.98) | High          |
| van Walraven, 1990 [69] | ICD9 410        | primary discharge diagnosis | 80.44 (77.57–83.02) | High          |
| Lowel, 1991 [41]    | ICD9 410         | nonfatal definite MI | 79.43 (73.18–84.56) | High          |
| Nova Scotia-Saskatchewan Cardiovascular Disease Epidemiology Group, 1992 [50] | ICD 410         | definite or possible MI | 85.47 (83.74–87.04) | High          |
| Lindblad, 1993 [66] | ICD8 410.00 or 410.99; or ICD9 410A-X | definite MI | 95.64 (93.07–97.32) | High          |
| Palomaki, 1994 [21] | ICD9 410.0       | definite MI, vs. MONICA | 98.79 (97.03–99.55) | High          |
| 410.0 or 410.9      | definite MI, vs. MONICA | 86.40 (83.23–89.06) | 0.81 (0.76–0.86) | High          |
| 410.0 or 410.9      | definite or possible MI, vs. MONICA | 93.46 (91.36–95.09) | 0.25 (0.21–0.29) | High          |
| 410.0               | definite MI, vs. FINMONICA | 91.96 (89.69–93.78) | 0.60 (0.55–0.65) | High          |
| 410.0               | definite MI, vs. FINMONICA | 96.47 (94.50–97.77) | High          |
| Palomaki, 1994 [21] | ICD9 410.0       | definite MI, vs. FINMONICA | 95.94 (93.87–97.35) | High          |
| Rawson, 1995 [68]   | ICD9 410         | primary discharge diagnosis | 96.88 (93.40–98.62) | High          |
| Boyle, 1995 [20]    | ICD9 410         | definite MI (hospital) | 78.90 (77.10–80.77) | High          |
| Boyle, 1995 [20]    | ICD9 410         | definite or possible MI (hospital) | 65.57 (63.66 – 67.43) | High          |
| Boyle, 1995 [20]    | ICD9 410         | definite MI (death certificate) | 43.18 (41.77–44.61) | High          |
| Boyle, 1995 [20]    | ICD9 410         | definite or possible MI (death certificate) | 72.66 (70.09–75.09) | High          |
| First Author, Year | Diagnostic Codes | Parameter | Sensitivity (95% CI) | Specificity (95% CI) | PPV (95% CI) | NPV (95% CI) | Kappa (95% CI) | Quality |
|--------------------|------------------|-----------|----------------------|----------------------|--------------|--------------|----------------|---------|
| Pladevall, 1996 [22] | ICD9 410 | definite MI | 80.9 (77.4–84.4) | 93.1 (92.4–93.8) | 54.6 (53.2–56.0) | 97.9 (96.7–99.2) | High |
|                    |                  | definite or possible MI | 36.3 (34.1–38.5) | 97.5 (97.0–98.0) | 87.7 (86.6–88.8) | 75.4 (73.4–77.4) | |
| Mahonen, 1997 [35]  | ICD8 410 | definite MI: men | 84.4 (83.2–86.3) | 79.5 (77.8–81.1) | 90.7 (89.6–91.8) | 87.5 (86.8–90.0) | High |
|                    |                  | definite or possible MI: men | 72.0 (74.3–79.7) | 72.5 (68.8–76.2) | 87.5 (85.0–90.0) | 72.0 (65.1–85.5) | Medium |
|                    | ICD9 410 | definite MI: women | 85.5 (82.3–88.7) | 62.2 (59.2–65.3) | 85.9 (84.2–87.5) | 93.3 (92.3–94.4) | High |
|                    |                  | definite or possible MI: women | 66.8 (65.1–68.5) | 81.3 (77.6–85.0) | 80.7 (77.0–84.4) | 89.6 (87.1–92.2) | Medium |
|                    | ICD8 410 | definite nonfatal MI | 77.88 (71.65–83.10) | 49.13 (46.72–51.56) | 45.31 (36.58–54.33) | 93.55 (89.19–96.30) | Medium |
|                    |                  | definite or possible nonfatal MI | 54.27 (51.48–57.04) | 88.19 (84.71–89.88) | 58.11 (51.99–64.75) | 80.7 (77.0–84.4) | Medium |
|                    |                  | definite fatal MI | 54.95 (52.39–57.48) | 91.08 (88.99–92.81) | 55.01 (52.37–57.61) | 75.8 (74.3–77.3) | High |
|                    |                  | definite or possible fatal MI | 95.31 (89.64–90.08) | 89.14 (86.85–91.09) | 65.80 (60.49–70.74) | 94.20 (91.05–96.33) | High |
|                    |                  | definite fatal & nonfatal MI | 55.01 (52.37–57.61) | 90.00 (84.23–93.89) | 59.07 (52.80–65.07) | 49.13 (46.72–51.56) | Medium |
|                    |                  | definite or possible fatal & nonfatal MI | 55.01 (52.37–57.61) | 89.28 (87.21–91.06) | 55.84 (53.22–58.03) | 49.13 (46.72–51.56) | Medium |
| Hennauw, 1998 [39] | ICD9 410 | definite or possible MI, as underlying cause of death | 95.73 (93.9–98.9) | 71.96 (69.76–74.07) | 97.07 (95.95–97.90) | 95.73 (93.9–98.9) | High |
|                    |                  | definite MI, men | 91.34 (89.04–93.21) | 74.59 (69.27–79.29) | 95.02 (91.25–97.28) | 97.07 (95.95–97.90) | Medium |
|                    |                  | definite MI, women | 89.81 (83.71–93.88) | 73.87 (70.35–77.30) | 96.74 (95.68–97.56) | 97.07 (95.95–97.90) | Medium |
|                    | ICD9 410 | definite MI, overall | 91.08 (88.99–92.81) | 84.23 (83.71–93.88) | 98.96 (96.33–98.31) | 97.07 (95.95–97.90) | Medium |
|                    |                  | definite MI, men | 89.14 (86.85–91.09) | 89.28 (87.21–91.06) | 96.74 (95.68–97.56) | 97.07 (95.95–97.90) | Medium |
|                    |                  | definite MI, women | 90.00 (84.23–93.89) | 71.96 (69.76–74.07) | 97.07 (95.95–97.90) | 97.07 (95.95–97.90) | Medium |
| Levy, 1999 [45]    | ICD9 410, as primary discharge diagnosis | overall | 95.73 (93.9–98.9) | 97.47 (96.3–98.9) | 97.07 (95.95–97.90) | 97.07 (95.95–97.90) | Medium |
|                    |                  | men | 97.74 (93.05–99.42) | 97.74 (93.05–99.42) | 97.74 (93.05–99.42) | 97.74 (93.05–99.42) | High |
| Petersen, 1999 [67] | ICD9 410 | primary discharge diagnosis | 96.88 (96.33–97.35) | 71.96 (69.76–74.07) | 97.07 (95.95–97.90) | 97.07 (95.95–97.90) | Medium |
| First Author, Year  | Diagnostic Codes | Parameter                                | Sensitivity (95% CI) | Specificity (95% CI) | PPV (95% CI) | NPV (95% CI) | Kappa (95% CI) | Quality |
|---------------------|------------------|------------------------------------------|----------------------|----------------------|--------------|--------------|---------------|---------|
| McCarthy, 2000 [44] | ICD9 410         | compare w/objective clinical evidence    | 81.08 (64.29–91.45)  |                      |              |              | Medium        |         |
| Hammar, 2001 [64]  | ICD9 410         | definite MI                              | 85.83 (83.01–88.27)  |                      |              |              | High          |         |
| Austin, 2002 [48]  | ICD9 410         | primary position                         | 88.83 (88.41–89.24)  | 92.84 (92.57–93.11)  | 88.54 (88.12–88.95) | 93.03 (92.76–93.29) | 0.82          | High    |
| Rosamond, 2004 [36]| ICD9 410         | definite MI                              | 67.99 (67.23–68.75)  |                      |              |              | High          |         |
|                    |                  | definite or probable MI                 | 63.26 (62.61–63.91)  |                      |              |              | High          |         |
|                    |                  | primary or secondary position            | 92.8                 | 89.2                 |              |              | High          |         |
| Heikkila, 2004 [65]| ICD9 410 only    | MI                                       | 83.02 (80.21–85.51)  |                      |              |              | High          |         |
| Kiyota, 2007 [47]  | ICD9 410.01, 410.11, 410.21, 410.31, 410.41, 410.51, 410.61, 410.71, 410.81, 410.91 | primary or secondary admission position, 3≤LOS≤180 days | 94.11 (92.92–95.12) |                      |              |              | Medium        |         |
|                    |                  | primary admission position, 3≤LOS≤180 days |                      | 95.1 (94.1–96.2)     |              |              |                |         |
|                    |                  | ICD9 410.x0, 410.x1, and 410.x2         |                      | 92.45 (91.13–93.59)  |              |              |                |         |
| Pajunen, 2005 [43]| ICD9 410 or ICD10 I21-22             | definite/probable/possible nonfatal MI  | 61–81                |                      |              |              | High          |         |
| Ainla, 2006 [42]   | ICD10 I21-22     | tertiary care hospitals                  | 93.3                 |                      |              |              | High          |         |
|                    |                  | secondary care hospitals                 | 83.5                 |                      |              |              |               |         |
| Varas-Lorenzo, 2008 [70]| ICD9 410 | definite MI                              | 72.02 (65.03–78.11)  |                      |              |              | High          |         |
| Merry, 2009 [62]   | ICD9 410 for hospital; ICD10 I21-22 as COD | definite or probable/possible MI          | 83.99 (80.34–87.09)  |                      | 96.88 (94.59–98.26) |              | High          |         |
| Wahl, 2010 [71]    | ICD9 410xx (excluding 410.x2)        | true or probable MI overall              | 88.50 (83.05–92.42)  |                      |              |              | High          |         |
| Barchielli, 2010 [49]| ICD9 410 as primary discharge diagnosis | definite MI, vs. AHA criteria           | 86.02 (81.98–89.30)  |                      |              |              | High          |         |
|                    |                  | definite or probable MI, vs. AHA criteria | 87.37 (83.46–90.48)  |                      |              |              | High          |         |
|                    |                  | definite or probable or possible MI, vs. AHA criteria | 94.62 (91.68–96.60) |                      |              |              | High          |         |
|                    |                  | definite MI, vs. MONICA criteria          | 52.69 (47.48–57.84)  |                      |              |              | High          |         |
or not levels of cardiac troponin were included in the diagnostic criteria.

We also stratified results by geographic regions (Europe, the South Pacific [Australia and New Zealand], Canada, and the USA), and there was little difference in the sensitivity values reported in each region (Table 2). Similarly, there were few differences in the PPV’s from different regions; this value was >80% in most of the Canadian and US studies, and ≥89% in all 11 European studies reporting this statistic. However, the PPV’s in the three studies from the South Pacific were comparatively lower, with values ranging from 49 [30]–82% [20].

In most studies [≥50%] providing hospital statistics, PPV values were ≥93%, but the accuracy of MI as a cause-of-death on death certificates was much lower. For example, the PPV for definite MI amongst these studies was <60% (Table 3), while in many of the studies from hospitalization databases the PPV for definite MI was ≥86% when using the strictest category.

### Discussion

To our knowledge this is the first systematic review on the validity of MI diagnoses in administrative data. Overall, MI diagnostic codes from hospitalization data appear to be valid: in more than half of the studies, sensitivity and specificity exceeded 83%, and PPV exceeded 92%. Therefore, we believe hospitalization data can be used to identify MI either as a covariate or as an outcome. The accuracy of MI as a cause of death on death certificates was lower, with the highest PPV for definite fatal MI being 59% amongst the studies included. In comparison, the PPV was greater than 59% in three-quarters of the studies reporting on hospitalization data. Accordingly, caution should be taken when using vital statistics data to identify deaths from MI, and authors are encouraged to acknowledge this limitation.

It is possible that our findings on the accuracy of MI diagnoses were unduly influenced by publication bias or selective outcome reporting, wherein some authors who did assess the validity of MI codes in their study may have chosen not to report the statistics if they were low. But while our findings for MI in hospitalization data were generally positive, there were exceptions. For example, we observed that the accuracy of MI diagnoses was heavily influenced by the gold standard employed, with lower statistics when the previously-used, more conservative MONICA criteria [52] were applied. These criteria, developed in the 1970’s and 80’s from international standards, differ from more recent criteria with regards to the biomarkers of cardiac damage. The creatine kinase, lactate dehydrogenase, and aspartate transaminase enzymes are part of MONICA [33], used by 12 studies in this review [20,21,34,35,37–39,41,46,49–51]. Three studies [43,49,53] used the 2003 American Heart Association (AHA) criteria, which consider levels of cardiac troponin [32] - a component of cardiac muscle and a more sensitive and specific indicator of myocardial damage [54] – in addition to creatine kinase. Similarly, in the Joint European Society of Cardiology/American College of Cardiology (ESC/ACC) criteria [55] - used in two studies [42,53] - troponin levels take precedence over creatine kinase, and neither aspartate transaminase nor lactate dehydrogenase (the two other enzymes from MONICA) are considered markers of cardiac damage [56].

Support for the increased sensitivity of cardiac troponin is provided by many clinical and population-based studies [57–59] where more cases of MI were detected when applying the new criteria than when the MONICA. Consistent with this, some authors have shown that, when defined by the older criteria, the incidence of MI appears to have declined over the decades, but when the newer criteria are applied, the incidence appears to have

### Table 2. Cont.

| First Author, Year | Diagnostic Codes | Parameter | Kappa (95% Cl) | Sensitivity (95% Cl) | Specificity (95% Cl) | PPV (95% Cl) | NPV (95% Cl) | Quality |
|--------------------|------------------|-----------|---------------|---------------------|---------------------|--------------|-------------|---------|
|                     |                  |           |               |                     |                     |              |             |         |
|                     |                  |           |               |                     |                     |              |             |         |
remained steady [60] or even increased [61]. In other words, more cases will be classified as MI under the newer criteria than the old. Thus, given the increased sensitivity of the newer criteria, we expected to see greater sensitivity values amongst the more recently-published studies in this review, but we did not observe a trend in either direction. Amongst the ten studies reporting on the sensitivity of MI diagnoses in hospital data, sensitivity in the five earlier studies ranged from 80–94%, while in the five later studies it ranged similarly from 69–93%. This may simply be due to the comparatively small number of studies where sensitivity was reported, though heterogeneity in the study settings may also play a role. One study included in our review, by Rosamond et al [36], evaluated the sensitivity and PPV of ICD-9 410 over the period 1987–2000. They reported that while overall, these statistics remained relatively stable, amongst teaching hospitals they declined significantly (with sensitivity declining from 74% to 59%, and PPV from 80% to 71%). In contrast, in a study conducted at a university hospital in the Netherlands, both sensitivity and PPV were higher in the later period (years 1996–2003) than the earlier period 1987–1995 (with sensitivity increasing from 82% to 85%, and PPV from 94% to 99%) [62].

In addition to being more sensitive, cardiac troponin is also a more specific indicator of MI. Although few studies in this review reported specificity values directly, this statistic can be analysed by way of PPV. Specificity is equal to 1 - the number of false positives, so will increase as the number of false-positive cases decreases. PPV is the proportion of true-positives amongst all true-positive and false-positive cases, so will also increase as the number of false-positive cases decreases. The fact that the PPV’s for hospitalization data generally increased over time provides support for an increase in the specificity of MI diagnoses as well.

When comparing the performance of the newer diagnostic criteria to the MONICA, the contribution of other secular changes must be considered. One factor is the use of different revisions of the ICD coding system in different time periods. Mahonen et al [35] found that the sensitivity of ICD 410 was generally lower during the period 1987–1990 (ICD-9) than 1983–1986 (ICD-8), even though the same diagnostic criteria (FINMONICA, a Finnish adaptation of the MONICA criteria) were used through the study period. In contrast, those authors found that the PPV’s in the ICD-9 period were generally higher than in the ICD-8 period.

However, the impact that cardiac troponin testing has on the validity of MI diagnoses is difficult to ignore. For example, Pajunen et al [43] reported higher sensitivity during the ICD-10 period (1998–2002) than the ICD-9 period (1988–1997), but the authors attribute this difference to the use of cardiac troponin testing during the ICD-10 period. We believe the introduction of cardiac troponin testing and its increasing use over time may be mainly responsible for the improvements we observed in the PPV of MI codes over time.

When examining only studies that used the MONICA criteria, we observed that the PPV’s were usually higher in studies stemming from the original MONICA project compared to those just applying the MONICA criteria in other samples. This was especially apparent amongst the European studies from the MONICA project. One explanation for this may be some cross-referencing between the hospital databases and MONICA registries. It is acknowledged in these studies [21,35] how the MONICA project itself may have influenced local coding practices. For example, some of the same physicians that were involved with the MONICA study were also treating patients hospitalized for coronary events in local centres. However the potential influence these factors may have had in Europe, they did not appear to carry over in Australia and New Zealand, where the PPV’s in studies using the MONICA registries were much lower.

We observed that the accuracy of MI as a cause of death on death certificates was lower in comparison to hospitalization data. Death certificate diagnoses of MI may be less accurate because less information is available on these cases from which to determine a precise cause of death. Specifically, many deaths are not attended by medical personnel, resulting in a lack of comprehensive documentation [39]. In support of this, Lowel et al [41] found that the PPV’s were lower for cases who spent less time in hospital, and had less clinical data and test results (including electrocardiograms and enzyme levels) available, which could otherwise aid in establishing a more accurate cause of death [41].

Our review showed that the accuracy of hospitalization data for identifying MI cases is much higher than data from death certificates; consequently, we recommend that, when available, researchers attempt to confirm the cause of death by matching vital statistics death records for MI with administrative hospitalization data. At the very least, the limitations of vital statistics data
should be acknowledged by these authors.

Many of the findings presented in this paper are based on PPV, which was the most frequently-reported statistic amongst the studies included in this review. PPV is relatively easy for researchers to assess since they only need to evaluate cases who initially test positive for the condition (here being MI). However, a caveat of both PPV and NPV are their dependence on the prevalence of the condition in the study population [63]. The PPV will be lower for a rare condition than for a common condition. For example, amongst all testing positive in a rare condition (those in the denominator), few are likely to be true-positives (and appear in the numerator). In this review, we expected the PPV’s to be lower amongst the community-based studies than the clinic-based studies or those with otherwise more selected populations, and this was apparent in several studies. For instance, the PPV in a study of patients admitted to coronary care units was 89% [48] and in two studies that were restricted to individuals aged 65 years and older (amongst whom MI is more common) the PPV’s were 95% [47] and 98% [45]. In contrast, in another study which had a younger source population (aged between 25 and 64 years), the PPV was much lower (only 67%) [37]. Consequently, differences in the expected prevalence of MI in the different source populations may have contributed to variation in the PPV’s reported by the different studies in this review.

A significant research gap was identified in the course of this review, being a lack of studies reporting on the validity of codes from the ICD-10. This system has been in widespread use in Europe and Australia for at least a decade, but ICD-10 codes were evaluated in just three studies included in this review, and only two of these [42,43] reported on the validity of ICD-10 codes separately from ICD-9 codes. One of these studies reported that the PPV for ICD-10 I21-22 was good, especially in tertiary care hospitals (PPV = 93%) [42], and findings from the other suggest that ICD-10 I21-22 is more sensitive for MI than the equivalent ICD-9 code, 410 [43]. With ICD-10 codes now a key component of health research, assessments of the validity of ICD-9 codes are quickly losing their relevance, and clearly, more investigations into the accuracy of ICD-10 codes are needed to support ongoing research endeavours.

Our systematic review has some limitations. We could not consider articles whose full-text was not available in English, and this may have introduced a language bias. We were unable to include articles that did not report or reference the diagnostic algorithms being validated, or those that were published after the conclusion of our search period (February 2011). As well, although our MEDLINE and EMBASE searches were conducted by an experienced librarian, some relevant studies may have been missed since administrative databases are not well catalogued in these indexes (e.g., no MeSH term pertaining to “administrative database”). Most of the articles included in this review were located through database searches. In these, we searched for articles that were indexed under terms relating to Administrative Data, Validation, and Cardiovascular Disease. However, in our subsequent handsearch we located several relevant articles that were not indexed under these Administrative Data or Validation categories. Thus, while our handsearches were extensive, it is possible that we still missed some relevant articles if they were not indexed in the databases with a term relating to validation or administrative data, or were published in a journal not indexed in the MEDLINE or EMBASE databases.

In summary we conclude that, based on the evidence, hospitalization data can be used to identify MI as a covariate or outcome, but the accuracy of MI as a cause-of-death in vital statistics data is limited. Authors using vital statistics data to identify MI deaths are encouraged to compare such data with hospitalization data to confirm the cause of death or use sensitivity analyses excluding cases from this source. While most administrative databases are not established for research purposes, they are increasingly being used to study long-term patient outcomes and disease burden. Therefore, in order to maximize the sensitivity of these databases, physicians and hospital coders should be encouraged to record all significant complications and comorbidities. In the meantime, authors using administrative data to identify MI deaths should acknowledge the limitations of this data source. Finally, with ICD-10 coding now commonplace, more assessments of the validity of ICD-10 codes for MI are needed to ensure the quality of future research. We believe our findings will help to increase the rigour of population-based epidemiological and outcomes research and thus potentially improve health surveillance, resource allocation and patient care.

Supporting Information

Table S1 Item-by-item quadas breakdown for each study. (DOCX)
Text S1 MEDLINE search strategy. (DOCX)
Text S2 EMBASE search strategy. (DOCX)
Text S3 Data collection form. (DOC)
Checklist S1 PRISMA Checklist. (DOC)

Acknowledgments

The authors wish to thank members of the CANRAD network, librarian Mary-Doug Wright (B.Sc., M.L.S.) for conducting the literature search, Reza Torkjazi, and Lindsay Belvedere for their help during their administrative support and editing the manuscript.

Author Contributions

Conceived and designed the experiments: DL, JAAZ. Analyzed the data: NM DL VB JAAZ. Wrote the paper: NM DL VB JAAZ. Final approval of the version of the manuscript to be published: NM DL VB JAAZ.
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