ORIGINAL ARTICLE

The impact on relative risk estimates of inconsistencies between ICD-9 and ICD-10

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Appendix I is available on the *OEM* website

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Background: The 10th revision of the International Classification of Diseases (ICD) represents a major change in the ICD system. This paper investigates the impact on relative risk estimates of inconsistencies in outcome classification between ICD-9 and ICD-10, including scenarios in which occupational exposure levels are correlated with year of death (and therefore with the ICD revision in effect at death). The setting of interest is a cohort mortality study in which follow up spans the periods during which ICD-9 and ICD-10 were in effect. The relative risk estimate obtained when death certificates are coded to the ICD revision in effect at time of death is compared to the relative risk estimate that would be obtained if all death certificates were coded to a consistent ICD revision (that is, ICD-10). The ratio of these relative risks is referred to as the coefficient of bias.
Methods: Simple equations relate the coefficient of bias to the sensitivity and specificity of the classification of decedents into categories of cause of death via ICD-9 (treating classifications based upon ICD-10 as the standard). Bridge coded mortality data for 2 296 922 decedents (that is, death certificates coded to ICD-9 and ICD-10) are used to derive estimates of sensitivity and specificity by category of cause of death. Numerical examples illustrate the application of these equations.
Results: Estimates of the sensitivity of classification of decedents into categories of death defined by ICD-9 ranged from 0.26–1.00. Specificity was above 0.98 for all categories of cause of death. Numerical examples illustrate that inconsistencies in outcome classification between ICD-9 and ICD-10 may have substantial impact on relative risk estimates if there is a strong relation between exposure status and the proportion of deaths coded to a given ICD revision.
Conclusions: For analyses of mortality outcomes that exhibit poor comparability between ICD-9 and -10, it may be prudent to recode cause of death information to a standard ICD revision in order to avoid bias that can occur when exposures are correlated with the proportion of deaths coded to a given ICD revision.

Mortality outcomes for occupational cohort research often are defined in terms of underlying causes of death coded according to the International Classification of Diseases (ICD). The use of ICD coding of cause of death information allows investigators to conduct analyses using a standardised methodology for coding the textual cause of death information on the death certificate and it provides investigators a standardised methodology for selection of a single underlying cause of death from a set of listed causes.[1]

However, roughly once every decade a new revision of the ICD is adopted. As a result, methodologies for coding cause of death information change over time, as do rules for selection of the underlying cause of death. The adoption of the 10th revision of the ICD is particularly noteworthy, as ICD-10 marks a significant departure from the previous revisions both in form and structure.[2] Consequently, the rationale that use of the ICD permits the conduct of epidemiological analyses following a standardised methodology for coding (and selection) of underlying cause of death information may be undermined by the periodic revisions to ICD, particularly substantial revisions such as that from ICD-9 to ICD-10.

One way for epidemiologists to address this problem is to code all death certificates for decedents in a study population to a standard revision of the ICD (for example, ICD-10). Such an approach ensures that death certificates with the same listed causes of death are assigned to the same categories of death regardless of the ICD revision in effect at the time of death. However, there are often good reasons for not coding all death certificates to a single revision of the ICD. For example, for analyses that compare mortality rates in a study population to an external referent population via the standardised mortality ratio, cause of death information is preferably tabulated to contemporaneous revisions of the ICD (as is done for calculation of referent rates at the state and national level). Furthermore, there are practical obstacles to coding all death certificates to a standard ICD revision. The investigator must obtain copies of all death certificates so that these may be coded by a trained nosologist to a standard ICD revision. The collection of death certificates for epidemiological research has become less common as access to national databases of cause of death information, such as the US National Death Index, have made it more efficient to obtain cause of death information from a national death registry. Since cause of death information in the US national death registry is coded to the contemporaneous revision of the ICD, the investigator may not have the ability to recode cause of death information to different versions of the ICD.

The objective of this paper is to evaluate the impact on relative risk estimates of the transition from ICD-9 to ICD-10. Data from a large comparability study are used to assess the classification of decedents into categories of death defined by ICD-9 and -10 codes. Simple equations relate the impact on relative risk estimates to the sensitivity and specificity of the classification of decedents into categories of cause of death via ICD-9 (treating classifications based upon ICD-10 as the standard); numerical examples illustrate the impact on relative risk estimates of coding death certificates to contemporaneous revisions of ICD-9 and ICD-10, rather than coding all certificates to a standard ICD revision.

METHODS

Consider a hypothetical study comparing disease risk in two groups within a closed cohort followed to extinction. Let's say that study outcomes are classified in terms of categories of

cause of death using information on underlying cause of death coded to ICD-10; we can denote the observed risk in the exposed subgroup as r_1, and the observed risk in the unexposed group as r_0, where r_1 and r_0 denote incidence proportions.

Now, consider the scenario in which some of the decedents have their underlying cause of death information coded to ICD-9 rather than ICD-10. Let's say that a proportion, P_1, of those in the exposed subcohort is coded to ICD-9, while the remainder is coded to ICD-10; similarly, a proportion, P_0, of those in the unexposed subcohort is coded to ICD-9. If outcome classifications based upon ICD-10 serves as our standard then we can refer to the sensitivity (Se) and specificity (Sp) of outcome classifications that occur when using cause of death information coded to ICD-9.

Among the exposed subcohort, therefore, the sensitivity of case classification will be $Se_1 = (1-P_1)+Se^* P_1$; the specificity of case classification among the exposed can be expressed as $Sp_1 = (1-P_1)+Sp^* P_1$. Similarly, among the unexposed the sensitivity and specificity of case classification can be expressed as $Se_0 = (1-P_0)+Se^* P_0$ and $Sp_0 = (1-P_0)+Sp^* P_0$, respectively.

An analysis of these data would yield an estimate of risk in the exposed subgroup, $r'_1 = Se_1(r_1)+(1-Sp_1)(1-r_1)$; an estimate of risk among the unexposed, $r'_0 = Se_0(r_0)+(1-Sp_0)(1-r_0)$; and a risk ratio estimate of $RR' = r'_1/r'_0$.

Given that RR reflects the relative risk estimate that would be observed if all deaths were coded to ICD-10, and RR′ reflects the relative risk estimate obtained when proportions P_1 and P_0 of the deaths in the exposed and unexposed subgroups, respectively, are coded to ICD-9, the ratio, RR′/RR, may be referred to as a coefficient of bias in the relative risk estimate due to inconsistencies in outcome classification between ICD-9 and ICD-10.

Estimates of Se and Sp are shown in table 1. These values were obtained via analyses of comparability (that is, bridge coding) data. All US death certificates for 1996 were originally coded and classified according to ICD-9; a comparability file was created by appending ICD-10 codes to each record in the 1996 mortality file. 99.1% of the 2 318 212 records are coded by both ICD-9 and ICD-10. For the purposes of the comparability study 130 mortality outcomes were defined along with comparable ranges of ICD-9 and ICD-10 codes for each mortality outcome.[2] The list of outcomes and associated ICD-9 and ICD-10 codes is shown in the online Appendix I (see http://www.occenvmed.com/supplemental). Table 1 reports the numbers of decedents classified into disease categories by ICD-9 only, ICD-10 only, ICD-9 and -10, as well as estimates of Se and Sp (rounded to three decimal places) for 130 outcomes.

Numerical example

Numerical examples are provided for three categories of cause of death: lung cancer, renal failure, and essential hypertension. Coefficients of bias are derived under assumptions that P_0 and P_1 took values equal to 0.0, 0.2, 0.4, 0.6, 0.8, and 1.0. For the purposes of these examples, the baseline risk (r_0) for each outcome was specified as 0.05 and RR (that is, r_1/r_0) was specified as 2.0. Results are easily computed for alternative assumptions; however, estimates of the coefficient of bias are not influenced by assumptions about RR, and, for categories of cause of death with Sp near unity, estimates of the coefficient of bias are minimally influenced by assumptions about the magnitude of the baseline risk (see Appendix II).

RESULTS

Table 1 reports estimates of sensitivity and specificity of outcome classifications made via ICD-9 relative to classifications made via ICD-10 coding of underlying cause of death information. The sensitivity of classification of decedents into categories of death defined by underlying cause of death coded according to ICD-9 ranged from 0.26–1.00. For deaths due to external causes and infectious diseases sensitivity ranged from 0.26–1.00 and 0.6 –1.00, respectively; for cancer deaths, sensitivity tended to be fairly high (that is, greater than 0.90). Specificity was above 0.98 for all categories of cause of death.

Table 2 presents estimates of the coefficient of bias for estimates of the relative risk of lung cancer. The rows and columns of the table define various assumptions about the proportions of decedents for whom cause of death information was coded to ICD-9. By definition, the coefficient of bias equals 1.00 for the cell defined by $P_0 = 0.0$ and $P_1 = 0.0$ (that is, no decedents were coded to ICD-9 in either the exposed or unexposed subgroups).

In an occupational setting, exposure status may be related to the proportion of deaths coded to ICD-9 versus ICD-10. For example, if occupational exposures tended to be higher in earlier calendar periods than in later calendar periods then exposure status may be related to year of death (and consequently, P_1 may be greater than P_0). An extreme scenario is one in which all deaths among the exposed are coded to ICD-9 ($P_1 = 1$) and all deaths among the unexposed are coded to ICD-10 ($P_0 = 0$). Under this scenario, the estimate of the association between exposure and death due to lung cancer is very comparable to the relative risk estimate that would be obtained if all deaths were coded to ICD-10 (coefficient of bias = 1.00). An alternative, equally extreme scenario is one in which all deaths among the exposed are coded to ICD-10 ($P_1 = 0$) and all deaths among the unexposed are coded to ICD-9 ($P_0 = 1$). Under the latter scenario, the estimate of the association between exposure and death due to lung cancer is only modestly attenuated when compared to the relative risk estimate that would be obtained if all deaths were coded to ICD-10 (coefficient of bias = 0.98). Such calculations illustrate how maximal and minimal values for the coefficient of bias may be obtained, permitting an investigator to evaluate the magnitude of bias potentially attributable to coding death certificates to contemporaneous revisions of the ICD rather than coding all certificates to a standard ICD revision.

Table 3 presents coefficient of bias for estimates of the relative risk of death due to essential hypertension. From table 3, maximal and minimal values for the coefficient of bias may be obtained. The minimal value for the coefficient of bias is 0.82 (for the scenario $P_1 = 1$ and $P_0 = 0$), while the maximal value for the coefficient of bias is 1.22. Table 4 presents coefficient of bias for estimates of the relative risk of death due to renal failure. Under the scenario ($P_1 = 1$ and $P_0 = 0$) the minimal value for the coefficient of bias is 0.72 while under the scenario ($P_1 = 0$ and $P_0 = 1$) the coefficient of bias is 1.39.

DISCUSSION

Over the last century, there have been 10 revisions of the ICD. Information about the degree of consistency in disease classification when cause of death information is coded to different revisions of the ICD is of direct relevance to understanding of potential bias in results obtained from epidemiological research on mortality outcomes. This paper focuses on the period spanned by ICD revisions 9 and 10;[3] this encompasses the period of coverage of the US National Death Index (NDI) and therefore is of direct relevance to US researchers who rely upon the NDI for collection of cause of death information. ICD-10 is much more detailed than ICD-9. Three additional chapters have been added to the ICD and some chapters rearranged, and cause of death titles (and some coding rules) have been changed.[2] The use of bridge coded data offers a way to assess the sensitivity and specificity of outcome classification using categories of death

Table 1 Classification of 2 296 922 deaths into categories defined by underlying cause of death coded to ICD-9 and ICD-10

Category of death	Number of decedents classified into disease category by ICD-9 and ICD-10	Number of decedents classified into disease category by ICD-9 only	Number of decedents classified into disease category by ICD-10 only	Sensitivity*	Specificity*
Salmonella infections	46	12	6	0.885	1.000
Shigellosis and amebiasis	6	2	1	0.857	1.000
Certain other intestinal infections	458	361	246	0.651	1.000
Respiratory tuberculosis	753	159	104	0.879	1.000
Other tuberculosis	169	120	32	0.841	1.000
Whooping cough	4	0	2	0.667	1.000
Scarlet fever and erysipelas	1	2	0	1.000	1.000
Meningococcal infection	270	18	15	0.947	1.000
Septicemia	20074	1262	5316	0.791	0.999
Syphilis	39	34	18	0.684	1.000
Acute poliomyelitis	0	0	1	–	1.000
Arthropod-borne viral encephalitis	2	1	0	1.000	1.000
Measles	1	0	0	1.000	1.000
Viral hepatitis	2567	1202	126	0.953	0.999
Human immunodeficiency virus (HIV) disease	30631	273	2810	0.916	1.000
Malaria	5	0	0	1.000	1.000
Other and unspecified infectious and parasitic diseases and their sequelae	3402	2876	2314	0.595	0.999
Malignant neoplasms of lip, oral cavity, and pharynx	7179	656	340	0.955	1.000
Malignant neoplasm of oesophagus	10914	285	225	0.980	1.000
Malignant neoplasm of stomach	12983	309	402	0.970	1.000
Malignant neoplasms of colon, rectum, and anus	54833	1458	1388	0.975	0.999
Malignant neoplasms of liver and intrahepatic bile ducts	10911	631	215	0.981	1.000
Malignant neoplasm of pancreas	26776	392	313	0.988	1.000
Malignant neoplasm of larynx	3706	201	221	0.944	1.000
Malignant neoplasms of trachea, bronchus, and lung	147147	4426	2059	0.986	0.998
Malignant melanoma of skin	6732	527	160	0.977	1.000
Malignant neoplasm of breast	42474	853	1170	0.973	1.000
Malignant neoplasm of cervix uteri	4394	140	123	0.973	1.000
Malignant neoplasms of corpus uteri and uterus, part unspecified	6054	238	390	0.939	1.000
Malignant neoplasm of ovary	12825	300	218	0.983	1.000
Malignant neoplasm of prostate	33044	964	1453	0.958	1.000
Malignant neoplasms of kidney and renal pelvis	10720	348	308	0.972	1.000
Malignant neoplasm of bladder	10926	480	424	0.963	1.000
Malignant neoplasms of meninges, brain, and other parts of central nervous system	11667	664	385	0.968	1.000
Hodgkin's disease	1309	95	99	0.930	1.000
Non-Hodgkin's lymphoma	21730	1135	647	0.971	1.000
Leukaemia	19674	622	833	0.959	1.000
Multiple myeloma and immunoproliferative neoplasms	9965	258	700	0.934	1.000
Other and unspecified malignant neoplasms of lymphoid, haematopoietic, and related tissue	0	0	72	–	1.000
All other and unspecified malignant neoplasms	54700	2261	10106	0.844	0.999
In situ neoplasms, benign neoplasms, and neoplasms of uncertain or unknown behaviour	6517	1090	5894	0.525	1.000
Anaemias	3574	743	497	0.878	1.000
Diabetes mellitus	59674	1811	2999	0.952	0.999
Malnutrition	2492	1015	1043	0.705	1.000
Other nutritional deficiencies	117	54	187	0.385	1.000
Meningitis	681	64	73	0.903	1.000
Parkinson's disease	11263	534	653	0.945	1.000
Alzheimer's disease	20597	695	13070	0.612	1.000
Acute rheumatic fever and chronic rheumatic heart diseases	3911	1065	476	0.891	1.000
Hypertensive heart disease	20405	5568	334	0.984	0.998
Hypertensive heart and renal disease	2017	473	789	0.719	1.000
Acute myocardial infarction	207911	5081	2005	0.990	0.998
Other acute ischaemic heart diseases	2329	547	755	0.755	1.000
Atherosclerotic cardiovascular disease, so described	64335	3815	7896	0.891	0.998
All other forms of chronic ischaemic heart disease	251673	7037	6159	0.976	0.997
Acute and subacute endocarditis	735	103	129	0.851	1.000
Diseases of pericardium and acute myocarditis	650	64	100	0.867	1.000
Heart failure	45832	1220	3044	0.938	0.999
All other forms of heart disease	89569	16104	8577	0.913	0.993
Essential (primary) hypertension and hypertensive renal disease	11814	1070	2567	0.822	1.000
Cerebrovascular diseases	154524	4331	12313	0.926	0.998
Atherosclerosis	15363	1292	723	0.955	0.999
Aortic aneurysm and dissection	16011	350	360	0.978	1.000
Other diseases of arteries, arterioles, and capillaries	8119	2627	1014	0.889	0.999

Table 1 Continued

Category of death	Number of decedents classified into disease category by ICD-9 and ICD-10	Number of decedents classified into disease category by ICD-9 only	Number of decedents classified into disease category by ICD-10 only	Sensitivity*	Specificity*
Other disorders of circulatory system	2379	1828	1726	0.580	0.999
Influenza	712	31	31	0.958	1.000
Pneumonia	55687	26615	1485	0.974	0.988
Acute bronchitis and bronchiolitis	302	172	40	0.883	1.000
Unspecified acute lower respiratory infection	0	0	119	–	1.000
Bronchitis, chronic and unspecified	1066	2061	141	0.883	0.999
Emphysema	15457	1722	1064	0.936	0.999
Asthma	4687	927	284	0.943	1.000
Other chronic lower respiratory diseases	77435	2056	9612	0.890	0.999
Pneumoconioses and chemical effects	1074	61	80	0.931	1.000
Pneumonitis due to solids and liquids	9685	579	1653	0.854	1.000
Other diseases of respiratory system	16293	2328	4383	0.788	0.999
Peptic ulcer	4748	379	231	0.954	1.000
Diseases of appendix	367	54	43	0.895	1.000
Hernia	1257	134	151	0.893	1.000
Alcoholic liver disease	10420	1542	1551	0.870	0.999
Other chronic liver disease and cirrhosis	11972	927	1716	0.875	1.000
Cholelithiasis and other disorders of gall bladder	2565	251	141	0.948	1.000
Acute and rapidly progressive nephritic and nephrotic syndrome	182	138	26	0.875	1.000
Chronic glomerulonephritis, nephritis, and nephropathy not specified as acute or chronic, and renal sclerosis unspecified	603	1026	67	0.900	1.000
Renal failure	21255	969	8232	0.721	1.000
Other disorders of kidney	29	13	7	0.806	1.000
Infections of kidney	796	89	109	0.880	1.000
Hyperplasia of prostate	428	27	34	0.926	1.000
Inflammatory diseases of female pelvic organs	91	21	9	0.910	1.000
Pregnancy with abortive outcome	32	7	9	0.780	1.000
Other complications of pregnancy, childbirth, and the puerperium	214	32	70	0.754	1.000
Certain conditions originating in the perinatal period	12555	361	1337	0.904	1.000
Congenital malformations, deformations, and chromosomal abnormalities	9525	2215	989	0.906	0.999
Symptoms, signs, and abnormal clinical and laboratory findings, not elsewhere classified	22496	3010	2381	0.904	0.999
All other diseases (residual)	128432	32240	18414	0.875	0.985
Motor vehicle accidents	40525	2512	476	0.988	0.999
Other land transport accidents	678	51	1932	0.260	1.000
Water, air and space, and other and unspecified transport accidents and their sequelae	1967	320	208	0.904	1.000
Falls	10215	3701	528	0.951	0.998
Accidental discharge of firearms	1026	6	23	0.978	1.000
Accidental drowning and submersion	3312	128	230	0.935	1.000
Accidental exposure to smoke, fire, and flames	3539	110	108	0.970	1.000
Accidental poisoning and exposure to noxious substances	7859	94	377	0.954	1.000
Other and unspecified nontransport accidents and their sequelae	10107	489	5705	0.639	1.000
Intentional self-harm (suicide) by discharge of firearms	17791	93	114	0.994	1.000
Intentional self-harm (suicide) by other and unspecified means and their sequelae	11927	96	142	0.988	1.000
Assault (homicide) by discharge of firearms	13809	46	72	0.995	1.000
Assault (homicide) by other and unspecified means and their sequelae	6207	78	92	0.985	1.000
Legal intervention	297	31	10	0.967	1.000
Discharge of firearms, undetermined intent	220	2	2	0.991	1.000
Other and unspecified events of undetermined intent and their sequelae	2482	78	41	0.984	1.000
Operations of war and their sequelae	5	7	2	0.714	1.000
Complications of medical and surgical care	1136	1897	776	0.594	0.999

*Treating classifications based upon ICD-10 as the standard.

defined in relation to ICD-9 and 10 codes, specifically evaluating how events defined via death certificate information coded to ICD-9 would be classified if the death certificate information were coded to ICD-10. As illustrated via numerical examples in this paper, maximal and minimal values for the coefficient of bias may be obtained, providing a sense of the magnitude of bias potentially attributable to coding death certificates to contemporaneous revisions of the ICD.

It can be shown (Appendix II) that the maximal and minimal bounds for the coefficient of bias are approximately *Se* and 1/*Se*, corresponding to the extreme scenarios in which there is perfect concordance between exposure status and ICD revision. For most cancer outcomes, as illustrated by the numerical example for lung cancer, there is minimal potential for bias due to outcome misclassification. Even in scenarios where there is a strong correlation between exposure status and the proportion of deaths coded to a

Table 2 Hypothetical data. Coefficients of bias* for analyses of the relative risk of lung cancer mortality under varying assumptions about the proportion of exposed decedents (P_1) coded to ICD-9 rather than ICD-10 and the proportion of unexposed decedents (P_0) coded to ICD-9 rather than ICD-10

	P_0					
P_1	0.0	0.2	0.4	0.6	0.8	1.0
0.0	1.00	1.00	1.00	1.00	1.00	1.00
0.2	1.00	1.00	1.00	1.00	1.00	1.00
0.4	0.99	0.99	0.99	0.99	0.99	0.99
0.6	0.99	0.99	0.99	0.99	0.99	0.99
0.8	0.98	0.98	0.98	0.98	0.98	0.99
1.0	0.98	0.98	0.98	0.98	0.98	0.98

*The ratio of the relative risk estimate obtained when death certificates are coded to the ICD revision in effect at time of death to the relative risk estimate that would be obtained if all death certificates were coded to ICD-10.

Table 3 Hypothetical data. Coefficients of bias* for analyses of the relative risk of mortality due to essential hypertension under varying assumptions about the proportion of exposed decedents (P_1) coded to ICD-9 rather than ICD-10 and the proportion of unexposed decedents (P_0) coded to ICD-9 rather than ICD-10

	P_0					
P_1	0.0	0.2	0.4	0.6	0.8	1.0
0.0	1.00	0.96	0.93	0.89	0.86	0.82
0.2	1.04	1.00	0.96	0.93	0.89	0.85
0.4	1.08	1.04	1.00	0.96	0.92	0.89
0.6	1.12	1.08	1.04	1.00	0.96	0.92
0.8	1.17	1.12	1.08	1.04	1.00	0.96
1.0	1.22	1.17	1.13	1.09	1.04	1.00

*The ratio of the relative risk estimate obtained when death certificates are coded to the ICD revision in effect at time of death to the relative risk estimate that would be obtained if all death certificates were coded to ICD-10.

given ICD revision, the coefficient of bias will be very near unity. For some non-cancer outcomes, in contrast, there is potential for substantial bias under scenarios in which exposure status is highly correlated with the proportion of deaths coded to ICD-9, as illustrated by the numerical examples for deaths due to essential hypertension and deaths due to renal disease.

For simplicity, our examples focused on the scenario of estimation of incidence proportions in a closed cohort followed to extinction. Often, of course, in a cohort mortality study incidence rates are estimated and a proportion of the cohort survives to the end of follow up. The equations presented in the Methods section are readily adapted from incidence proportions to incidence rates (Appendix III) accommodating the scenario in which a portion of the cohort remains alive at the end of follow up. Following the arguments in Appendix II, it can be shown that the maximal and minimal bounds for the coefficient of bias in analyses of incident rate ratios are approximately *Se* and 1/*Se*. Also for simplicity, this paper focused solely on evaluating the impact on relative risk estimates of inconsistencies in outcome classification between ICD-9 and ICD-10. It is not uncommon for the period of follow up in a cohort study to span several ICD revisions (for example, ICD-8, -9, and -10). While the transition from ICD-8 to ICD-9 was not as significant as the transition from ICD-9 to ICD-10, further work could be done to assess the impact on relative risk estimates of outcome misclassification when cause of death data are coded to a series of earlier ICD revisions. It is plausible that the sensitivity and specificity of classification of decedents (treating classifications based upon ICD-10 as the standard) would be progressively poorer as one considered deaths coded to progressively earlier ICD revisions. As observed in this paper, inconsistencies in outcome classification between ICD

Table 4 Hypothetical data. Coefficients of bias* for analyses of the relative risk of mortality due to renal failure under varying assumptions about the proportion of exposed decedents (P_1) coded to ICD-9 rather than ICD-10 and the proportion of unexposed decedents (P_0) coded to ICD-9 rather than ICD-10

	P_0					
P_1	0.0	0.2	0.4	0.6	0.8	1.0
0.0	1.00	0.94	0.89	0.83	0.78	0.72
0.2	1.06	1.00	0.94	0.88	0.82	0.76
0.4	1.13	1.06	1.00	0.94	0.87	0.81
0.6	1.20	1.13	1.07	1.00	0.93	0.87
0.8	1.29	1.22	1.14	1.07	1.00	0.93
1.0	1.39	1.31	1.23	1.15	1.08	1.00

*The ratio of the relative risk estimate obtained when death certificates are coded to the ICD revision in effect at time of death to the relative risk estimate that would be obtained if all death certificates were coded to ICD-10.

revisions might have the greatest impact on relative risk estimates if there is a strong relation between exposure status and the proportion of deaths coded to a given ICD revision.

One approach to assess potential bias due to inconsistencies in outcome classification between ICD-9 and ICD-10 is to stratify analyses into time periods during which deaths were coded to a single standard ICD revision. Under idealised conditions (including perfect specificity), stratification should control for this source of bias. In practice, of course, the results may be difficult to interpret because changes in effect estimates observed after stratification by calendar period of death (that is, ICD revision) may be due to factors other than bias induced by lack of comparability between ICD revisions. Therefore, the formulae in this paper (and the empirical data on sensitivity and specificity) are useful because they provide information on the potential magnitude of this bias without having to resort to stratified analyses. For example, this paper demonstrates that for most categories of cause of death, including most cancer outcomes, the potential magnitude of this source of bias is very small, and analyses that follow the standard practice of defining a mortality outcome in terms of ranges of ICD codes that span revisions (and not stratifying analyses by calendar period of death) should be appropriate. Stratification by calendar time may also constrain analytical exploration of other temporal factors (such as variation in exposure effect with time since exposure). Therefore, for epidemiological investigations that focus on categories of cause of death that exhibit poor comparability of outcome classification between ICD revisions, recoding cause of death information to a standard ICD revision may be the most straightforward approach to eliminating this potential source of bias.

The analyses in this paper consider a list of categories of cause of death (defined in terms of ICD-9 and ICD-10 codes) proposed by the US National Center for Health Statistics.[2] Some investigators have employed different definitions of mortality outcomes than those employed in this paper (for example, they have posited slightly different ranges of ICD-9 and/or ICD-10 codes associated with a category of cause of death). The LTAS program released by the US National Institute of Occupational Safety and Health, for example, defines 117 minor categories of cause of death in terms of ICD codes for revisions 7 through 10; and, the program OCMAP released by the University of Pittsburgh defines 60 categories of cause of death in terms of ICD codes for revisions 6 through 10.[4 5] The bridge coded data used in these analyses are publicly available (http://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/Comparability/icd9_icd10/); therefore, interested investigators can calculate sensitivities and specificities for different definitions of categories of cause of death. Use of different definitions of categories of cause of death could lead to estimates of sensitivity and specificity that differ from those values reported in table 1, and definitions of outcomes that exhibit greater consistency across ICD revisions should result in less overall bias. However, the general conclusions of this paper are unlikely to be substantially changed given that for many categories of death, such lung cancer and breast cancer, there is substantial consensus on the specified ranges of ICD codes associated with the category of death.

In addition to definitions of comparable ranges of ICD-9 and ICD-10 codes for a given category of cause of death, outcome classifications may differ depending upon the ICD revision used to code cause of death information as a result of changes between ICD revisions in rules for selection of the underlying cause of death.[1 6] Consequently, use of multiple cause coding of death information should lead to greater consistency in the classification of decedents into categories of death. We found that use of multiple cause coding slightly improved the consistency of classification of decedents into categories of death (results not shown).

The impact of using deaths coded to contemporaneous revisions of the ICD (and subsequently defining categories of cause of death via appropriate ranges of ICD-9 and ICD-10 codes) appears to be minimal for categories of cause of death that have high levels of comparability between ICD-9 and ICD-10 (that is, high sensitivity and specificity values in table 1). For such outcomes, even when exposures are correlated with the proportion of deaths coded to one of the ICD revisions a small degree of bias is expected. In contrast, for categories of cause of death that exhibit low levels of comparability between ICD revisions, the relative risk estimates obtained when death certificates are coded to the ICD revision in effect at time of death may diverge substantially from the relative risk estimate that would be obtained if all death certificates were coded to a consistent ICD revision (that is, ICD-10).

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APPENDIX II

If Sp very closely approximates unity (as is the case for the categories of cause of death shown in table 1) then the expression for RR' can be approximated as

$$RR' = \frac{Se_1(r_1)}{Se_0(r_0)}$$

The minimal value for the coefficient of bias occurs under the scenarios in which all deaths among the exposed study subjects are coded to ICD-9, while all deaths among the unexposed were coded to ICD-10 (that is, $P_1 = 1$ and $P_0 = 0$). In this case

$Se_1 = (1-P_1)+Se^* P_1 = Se$,
$Sp_1 = (1-P_1)+Sp^* P_1 = Sp$,
$Se_0 = (1-P_0)+Se^* P_0 = 1$,
$Sp_0 = (1-P_0)+Sp^* P_0 = 1$; therefore,

$$RR' = \frac{Se_1(r_1) + (1 - Sp)(1 - r_1)}{r_0}$$

which, as noted above, can be approximated by

$$\frac{Se_1(r_1)}{r_0}$$

when Sp~1. Therefore, the minimal value for the coefficient of bias,

$$\frac{RR'}{RR}$$

can be approximated by *Se*, the sensitivity of the outcome classification under ICD-9 relative to ICD-10. Following a similar argument, if *Sp* very closely approximates unity, the maximal value for the coefficient of bias can be approximated by

$$\frac{1}{Se}$$

APPENDIX III

Consider a study comparing mortality rates, rather than incidence proportions, in two groups. Let's denote the observed mortality rate for a specified category of cause of death in the exposed subgroup as r_1, and the observed rate in the unexposed group as r_0, where r_1 and r_0 denote incidence rates. Let us further denote d_1 and d_0 as the death rates from all other causes. An analysis of these data would yield a rate estimate in the exposed subgroup, $r'_1 = Se_1(r_1)+(1-Sp_1)(d_1)$; a rate estimate among the unexposed, $r'_0 = Se_0(r_0)+(1-Sp_0)(d_0)$; and, a rate ratio estimate of $RR' = r'_1/r'_0$.