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BRIEF COMMUNICATION

Temporal Trends in Characteristics and Outcomes Associated With In-Hospital Cardiac Arrest: A 20-Year Analysis (1999–2018)

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BACKGROUND: Despite advances in resuscitation medicine, the burden of in-hospital cardiac arrest (IHCA) remains substantial. The impact of these advances and changes in resuscitation guidelines on IHCA survival remains poorly defined. To better characterize evolving patient characteristics and temporal trends in the nature and outcomes of IHCA, we undertook a 20-year analysis of a national database.

METHODS AND RESULTS: We analyzed the National Inpatient Sample (1999–2018) using *International Classification of Diseases*, *Ninth Revision* and *Tenth Revision, Clinical Modification* (*ICD-9-CM* and *ICD-10-CM*) codes to identify all adult patients suffering IHCA. Subgroup analysis was performed based on the type of cardiac arrest (ie, ventricular tachycardia/ventricular fibrillation or pulseless electrical activity-asystole). An age- and sex-adjusted model and a multivariable risk-adjusted model were used to adjust for potential confounders. Over the 20-year study period, a steady increase in rates of IHCA was observed, predominantly driven by pulseless electrical activity-asystole arrest. Overall, survival rates increased by over 10% after adjusting for risk factors. In recent years (2014–2018), a similar trend toward improved survival is noted, though this only achieved statistical significance in the pulseless electrical activity-asystole cohort.

CONCLUSIONS: Though the ideal quality metric in IHCA is meaningful neurological recovery, survival is the first step toward this. As overall IHCA rates rise, overall survival rates are improving in tandem. However, in more recent years, these improvements have plateaued, especially in the realm of ventricular tachycardia/ventricular fibrillation-related survival. Future work is needed to better identify characteristics of IHCA nonsurvivors to improve resource allocation and health care policy in this area.

Key Words: cardiac arrest ■ populational studies ■ resuscitation ■ survival ■ trends

The annual incidence of in-hospital cardiac arrest (IHCA) is estimated to be approximately 300 000 in the United States.[1] This ranges from 1.6 to 2.85 per 1000 hospital admissions based on data from the United Kingdom and United States, respectively.[2,3] Shockable rhythms (pulseless ventricular tachycardia/ventricular fibrillation [VT/VF]) account for 15.3% of these events, with the remaining composed of pulseless electrical activity (PEA)-asystole arrest.

The past decade has witnessed significant improvements in rates of survival, which range from 18.4% to 25.6% in the United Kingdom and the United States registry, respectively.[4] However, population-level data from recent years with regard to these trends remain

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limited. The American Heart Association resuscitation guidelines have witnessed many modifications over the past 2 decades along with substantial improvements in emergency and intensive-care therapeutics such as early and standardized chest compression techniques, prompt use of capnography, mechanical ventilation, and target temperature management, as well as early revascularization when indicated.[5] However, the temporal impact of these interventions on IHCA survival remains poorly defined.

In an attempt to better understand the evolving patient characteristics as well as temporal trends in the nature and outcomes of IHCA, we undertook a long-term, 20-year analysis of a US national database. This population-level analysis could provide insight into the implications of changes in clinical practice and guide future health policy.

METHODS

The current trend analysis was conducted using the National Inpatient Sample (NIS) from 1999 to 2018. The NIS is the largest publicly available in-hospital database in the United States, with data covering over 30 million hospitalizations.[6] Local institutional review board approval was waived in lieu of the deidentified nature of the data. The data that support the findings of this study are available from the corresponding author upon reasonable request.

International Classification of Diseases, Ninth and Tenth Revision, Clinical Modification (*ICD-9-CM* and *ICD-10-CM*) codes (Table S1) were used to identify all adult patients suffering an IHCA (9960, 9963; 5A12012).[3,7,8] Out-of-hospital cardiac arrests (4275; I46) were excluded before analysis.[8] This coding approach has yielded an 83.3% positive predictive value in the identification of IHCA based on prior studies.[9] VT/VF were identified using secondary diagnosis codes (427.4x, I472, I490), and the remainder of cases without these codes were considered to have PEA-asystole cardiac arrest.[7,8] A General Equivalence Mapping tool published by the Centers for Medicare and Medicaid Services was used to assist the conversion of *ICD-9-CM* to *ICD-10-CM* codes. Demographics, including age, sex, race, income, insurance, and Charlson Combiditiy Index scores (Table S2), as well as hospital characteristics, were analyzed in four 5-year groups to assess the temporal trends in event rates as well as outcomes. We used discharge trend weights files provided by the Agency for Healthcare Research and Quality to account for changes in the NIS over time.[6] A further separate trend analysis was performed from years 2014 to 2018 to better reflect recent trends and the impact of changes in societal guidelines.[5] The methodological standard of the Healthcare Cost and Utilization Project were adhered to throughout the analysis.[10]

Statistical Analysis

The Wilcoxon rank sum test was used to evaluate temporal trends for categorical variables and linear regression for continuous variables. To better assess changes in survival characteristics over time, we further developed an age- and sex-adjusted model as well as a multivariable risk-adjusted model using generalized estimation equations for the overall cohort.[11] The multivariable risk-adjusted model accounts for the age, sex, race, income, insurance, comorbidity burden, as well as hospital level variables including hospital bed size, geographical region, and teaching versus nonteaching status. Clustering effect was incorporated within the model using unique hospital identification numbers.

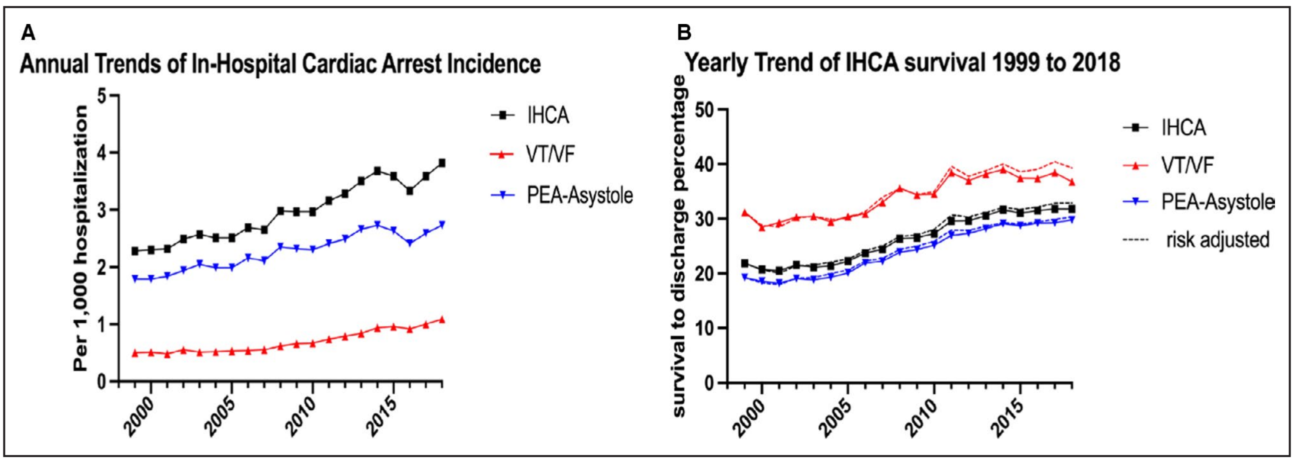

Figure. Yearly trends of in-hospital cardiac arrest (IHCA) incidence and survival from 1999 to 2018 in the United States.
A, Annualized incidence of IHCA demonstrating a steady increase over 20 years in all cohorts of patients. **B**, Crude and risk-adjusted annualized survival trends in IHCA patients demonstrating significant improvement in long-term survival rates, primarily driven by improved PEA-asystole survival. PEA indicates pulseless electrical activity; and VT/VF, ventricular tachycardia/ventricular fibrillation.

Table 1. Characteristics of IHCA

Variable	5-year trends 1999–2003, n=354 013	2004–2008, n=412 553	2009–2013, n=491 336	2014–2018, n=537 460	Overall *P* trend value
Patient characteristics					
Age, y, mean±SD	68.38±0.17	67.38±0.18	66.61±0.11	66.03±0.59	0.001
Age <65 y, %	34.39	38.54	41.24	42.11	0.001
Age 65–75 y, %	23.51	21.98	22.99	25.51	0.001
Age >75–85 y, %	28.57	26.20	22.93	21.23	0.001
Age >85 y, %	13.52	13.28	12.84	11.15	0.001
Women, %	46.28	45.54	44.40	42.70	0.001
Race and ethnicity, %					
White	68.71	65.50	63.00	62.13	0.001
Black	17.63	18.83	20.92	21.27	0.798
Hispanic	8.36	9.50	9.59	9.81	0.9
Other*	5.31	6.16	6.50	6.79	0.961
Charlson Comorbidity Index score, mean±SD	2.08±0.01	2.33±0.01	2.82±0.01	3.25±0.01	0.001
0, %	16.78	15.93	13.27	10.18	0.001
1, %	27.27	23.67	18.82	15.95	0.001
≥2, %	55.95	60.41	67.91	73.87	0.001
Median income, %					
First quartile	12.59	25.99	26.53	34.31	0.001
Second quartile	30.59	26.00	23.00	20.44	0.001
Third quartile	32.17	25.23	23.59	18.99	0.001
Fourth quartile	34.30	25.59	22.10	17.99	0.001
Insurance details, %					
Medicaid, Medicare	75.13	74.10	74.66	75.81	0.001
Private	18.69	18.51	17.30	17.36	0.001
Self-pay, other	5.93	7.27	7.85	6.71	0.001
Hospital region, %					
Northeast	20.61	19.56	18.77	15.81	0.001
Midwest	20.37	18.66	19.72	21.54	0.001
South	33.55	36.54	38.97	41.44	0.001
West	25.47	25.24	22.55	21.21	0.001
Hospital size, no. of beds, %					
Small, 1–99	9.29	9.38	9.38	15.27	0.001
Medium, 100–200	25.62	25.75	25.33	29.54	0.001
Large, >200	65.09	64.86	65.29	55.19	0.001
Urban hospital, %	88.75	90.66	91.67	94.29	0.001
Teaching hospital, %	40.90	42.62	48.98	69.89	0.001
Admission diagnosis, %					
Sepsis	12.20	16.65	21.43	24.55	0.001
AMI	13.98	10.20	9.84	10.99	0.001
Respiratory failure	6.05	10.06	9.42	8.12	0.001
Heart failure	6.46	5.86	4.67	4.81	0.001
Length of stay, d	8.22±0.13	8.68±0.12	8.60±0.08	8.51±0.05	0.061
VT/VF arrest, %	21.27	20.61	23.26	27.33	0.001
Intervention, %					
TTM	0.02	0.12	1.35	1.50	0.001

(*Continued*)

Table 1. Continued

Variable	5-year trends 1999–2003, n=354 013	2004–2008, n=412 553	2009–2013, n=491 336	2014–2018, n=537 460	Overall *P* trend value
Coronary angiography	5.33	6.17	7.93	11.60	0.001
PCI	3.09	3.80	5.16	7.66	0.001
ECMO	0.03	0.05	0.27	0.31	0.001
Disposition, % of all IHCA					
Home	7.46	6.95	7.62	8.60	0.001
SAR	3.99	3.08	3.31	3.83	0.111
SNF	7.00	8.93	11.61	13.97	0.001
HHC	2.53	3.06	3.80	4.74	0.001
Hospital cost, $, adjusted for inflation to 2018	70 150±1806	95 572±2183	125 877±2270	166 235±1425	0.001

AMI indicates acute myocardial infarction; ECMO, extracorporeal membrane oxygenation; HHC, home health care; IHCA, in-hospital cardiac arrest; PCI, percutaneous coronary intervention; SAR, subacute rehab; SNF, skilled nursing facility; TTM, targeted temperature management; and VT/VF, ventricular tachycardia/ventricular fibrillation.

*Other: Asian or Pacific Islander, Native American and other unclassified racial and ethnic groups.

Furthermore, the Zou method was used to directly estimate rate ratios instead of odds ratio by specifying a Poisson distribution and including a robust variance estimate.[11] Adjusted annual survival rates were calculated by multiplying each reference year with its respective adjusted rate ratio. All statistical analyses were conducted using Stata version 15.1 (StataCorp).

RESULTS

Over a 20-year study period from 1999 to 2018, a steady rise in IHCA as a proportion of all hospital admissions was observed (2.28–3.82 per 1000 hospitalization, *P* trend<0.001) (Figure [A]). This was predominantly composed of PEA-asystole cardiac arrests, which accounted for 76.81% of IHCAs. A substantial 118% and 52% increase in VT/VF (from 0.50 to 1.09 per 1000 hospitalizations) and PEA-asystole arrests (from 1.79 to 2.73 per 1000 hospitalizations), respectively, were observed during the study period.

Trends in the characteristics of patients suffering cardiac arrests were analyzed on a 5-year basis (Table 1). During this period, a significant decrease in mean age was observed (68.38 to 66.60 years, *P* trend<0.001), with a concomitant reduction in the proportion of White patients (68.7% to 62.1%, *P* trend<0.001). From a socioeconomic standpoint, a significant increase in patients in the lowest quartile of median income suffering IHCA was observed (12.6% to 34.3%, *P* trend<0.001), with relatively stable proportions of patients in different insurance groups over this period.

A substantial increase in the comorbidity burdens of patients suffering cardiac arrests was observed, as reflected by an increase in mean Charlson Comorbidity Index scores (2.08 to 3.25, *P* trend<0.001). Geographically, we observed an increase in the incidence of cardiac arrests in the South, whereas rates in the Northeast region declined significantly. In terms of types of hospitals, a steady rise in urban and teaching hospitals was noted, along with a significant increase in patients admitted to small and medium-sized hospitals, with a decline in those admitted to large hospitals. Sepsis was the most commonly encountered admitting diagnosis, with a significant increase (12.2% to 24.6%, *P* trend<0.001) during the study period, followed by respiratory failure. Interestingly, rates of heart failure as the admitting diagnosis saw a significant decline, from 6.5% to 4.8% (*P* trend<0.001) over the study period.

In terms of survival, unadjusted, age- and sex-adjusted as well as a risk-adjusted analysis was performed (Table 2 and Figure [B]). Between 1999 and 2018, a significant improvement in IHCA-related survival rates was noted overall, exceeding 10% after risk adjustment (21.3% to 32.7%, *P* trend<0.001). This was largely driven by improvements in PEA-asystole survival (from 18.9% to 30.2%, *P* trend<0.001) and to a lesser extent by VT/VF survival (from 29.8% to 39.7%, *P* trend<0.001) (Table 2). In more recent years (2014–2018), a relative plateauing of IHCA survival rates was observed, except for PEA-asystole–related survival (29.1% to 30.2%, *P* trend<0.001) (Table 2).

In accordance with the American Heart Association resuscitation guideline, use of target temperature management, coronary angiography, percutaneous coronary intervention, and extracorporeal membrane oxygenation has increased significantly in the setting of IHCA (Table 1). A significant increase in hospitalization costs was observed during the study period, even after adjustment for inflation ($70 150±$1806–$166 235±$1425, *P* trend<0.001). With regard to disposition following hospital discharge, a significant

Table 2. Annualized Trends in Survival Rates

	Annual rates										Adjusted rate ratio per year (95% CI)	Overall *P* trend value	*P* trend value since 2014
	1999–2000*	2001–2002	2003–2004	2005–2006	2007–2008	2009–2010	2011–2012	2013–2014	2015–2016	2017–2018			
Overall survival													
Unadjusted	21.28[†]	21.05	21.28	23.05	25.46	26.93	29.64	31.12	31.26	31.80	N/A	0.001	0.43
Age/sex adjusted	21.28	21.10	21.48	23.06	25.45	26.78	29.21	30.23	30.36	30.83	1.04 (1.04–1.05)	0.001	0.45
Risk adjusted	21.28	20.93	21.60	23.74	26.02	27.44	30.41	31.52	31.72	32.70	1.05 (1.05–1.06)	0.001	0.049[‡]
Ventricular tachycardia/fibrillation													
Unadjusted	29.79	29.86	29.94	30.67	34.41	34.46	37.69	38.61	37.43	37.57	N/A	0.001	0.12
Age/sex adjusted	29.79	29.50	29.73	29.77	33.78	33.56	36.53	37.23	36.14	36.12	1.01 (1.01–1.01)	0.001	0.07
Risk adjusted	29.79	29.17	30.01	30.59	34.66	34.55	38.49	39.34	38.71	39.73	1.03 (1.03–1.04)	0.001	0.9
PEA-asystole													
Unadjusted	18.89	18.65	19.07	21.10	23.11	24.76	27.12	28.64	28.96	29.53	N/A	0.001	0.21
Age/sex adjusted	18.89	18.91	19.46	21.43	23.37	24.96	26.95	27.93	28.17	28.70	1.02 (1.02–1.03)	0.001	0.001[‡]
Risk adjusted	18.89	18.78	19.54	22.07	23.87	25.58	28.02	29.09	29.23	30.16	1.03 (1.03–1.03)	0.001	0.001[‡]

N/A indicates not applicable; and PEA, pulseless electrical activity.
*Year 1999 to 2000 is used as reference year for risk adjustment.
[†]Each cell reflects the average value of 2 years.
[‡]*P*-value is less than 0.05.

increase in patients discharged home with health care and to skilled nursing facilities was observed. However, rates of discharge to subacute rehabilitation facilities have remained steady over the past 20 years.

DISCUSSION

Tremendous advances in resuscitative as well as post–cardiac arrest care have been made over the past 2 decades, which is reflected by this analysis. The current study of a nationally representative population reflects a gradual shift in IHCA toward a younger albeit sicker population. This increase has been most marked in patients in the lowest quartile of median income. A clear transition in proportions of IHCA cases from larger-sized, rural hospitals toward smaller and medium-sized urban teaching hospitals is noted. Furthermore, we also observed an increased burden of comorbidities among patients with IHCA, which is consistent with recent data from the Get With The Guidelines registry.[12] Interestingly, the proportion of IHCAs associated with noncardiac admissions, such as sepsis, have increased substantially, whereas cardiac disorders such as acute myocardial infarction and heart failure have gradually declined. This is perhaps a consequence of advances in medical management of acute myocardial infarction and heart failure over the past 2 decades.[4]

IHCA-related survival rates, especially in the setting of PEA-asystole, have increased significantly over the past 2 decades, in alignment with reports by Thompson et al [13] and recent data from a Swedish registry.[14] VT/VF-related survival has plateaued in recent years after rapid initial improvements in outcomes at the turn of the century. These survival rates correlate well with data from the Get With The Guidelines registry,[4,11–13] prior NIS-based studies,[3,7,8] and data from a Swedish registry,[14] but were lower compared with the UK National Cardiac Arrest Audit Database between 2011 and 2013 (reported survival after shockable rhythm of 49%).[2] The improved IHCA survival may have been a result of improvements in resuscitation techniques, the increasing use of guideline-directed intervention such as target temperature management, and early revascularization where indicated. Furthermore, the use of specialized code teams and a more protocolized approach to resuscitative care has likely contributed as well.[5]

We acknowledge that the ideal quality metric in IHCA is meaningful neurological recovery and long-term survival; however, survival to hospitalization is the first step toward this. In an updated analysis of the Get With The Guidelines-Resuscitation registry in 2017, among patients surviving to discharge, a majority had a favorable neurological profile (85% with cerebral performance category of 1 and 2).[4]

Limitations

The findings of this study should be interpreted in the context of certain limitations. First, the NIS database uses administrative codes and not patient-level data and is therefore subject to issues related to variability in reporting and coding errors. The *ICD-9-CM* codes for IHCA have been well validated in several prior studies. However, the *ICD-10-CM* codes for the same, though used widely in several recent articles, have not been formally validated. This could potentially lead to some coding-related inaccuracies. The transition of coding practices from *ICD-9-CM* to *ICD-10-CM* in 2015 might have impacted IHCA incidence and survival results as reflected by a slight decline in rates in 2015. Furthermore, no specifics of resuscitative care or measures of meaningful neurological recovery could be made. We are unable to determine how our analyses could be affected by the differences in admission code status and its impact on in-hospital survival. Although our study demonstrates increased risk-adjusted survival after IHCA and increased use of interventions such as target temperature management and percutaneous coronary intervention, our data do not permit a more granular analysis of resuscitation specifics and rates of adherence to the guidelines.

Another limitation involves rhythm identification using *ICD-9-CM* and *ICD-10-CM* diagnosis codes. Prior studies have validated the positive predictive value of *ICD-9-CM* and *ICD-10-CM* codes in VT/VF identification at between 77% and 100%.[15] However, the identification of nonshockable rhythms has been challenging, because specific codes and results pertaining to them must be interpreted with caution.

CONCLUSIONS

During the past 2 decades, significant improvements in IHCA survival have been witnessed, both with shockable and nonshockable rhythms. Future work is needed to identify trends in the characteristics of survivors that could better guide resource allocation and health policy.

ARTICLE INFORMATION

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None.

Disclosures

None.

Supplementary Material

Tables S1–S2

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SUPPLEMENTAL MATERIAL

Table S1. ICD-9 and ICD-10 Codes used for analysis.

	ICD 9	ICD 10
In-Hospital Cardiac Arrest	9960, 9963	5A12012
Out Hospital Cardiac Arrest	4275	I46
Ventricular Tachycardia/Ventricular Fibrillation	4274.xx	I472, I490
Sepsis	0031 0202 0223 0362 0380 0381 03810 03811 03812 03819 0382 0383 03840 03841 03842 03843 03844 03849 0388 0389 0545 449 77181 7907 99591 99592 481 482 483 484 485 486 5950	A021 A207 A227 A267 A327 A392 A393 A394 A400 A401 A403 A408 A409 A4101 A4102 A411 A412 A413 A414 A4150 A4151 A4152 A4153 A4159 A4181 A4189 A419 A427 A5486 B007 B377I76 J13 J14 J15 J16 J17 J18 N390 R7881
Acute Myocardial Infarction	4100 41000 41001 41002 4101 41010 41011 41012 4102 41020 41021 41022 4103 41030 41031 41032 4104 41040 41041 41042 4105 41050 41051 41052 4106 41060 41061 41062 4107 41070 41071 41072 4108 41080 41081 41082 4109 41090 41091 41092	I21.x
Respiratory failure	5173 5185 51851 51852 51853 51881 51882 51883 51884 7991 V461 V4611 V4612 V4613 V4614 V462	J80 J95821 J95822 J9600 J9601 J9602 J9610 J9611 J9612 J9620 J9621J9622 J9690 J9691 J9692 R092
Heart failure	39891 4280 4281 42820 42821 42822 42823 42830 42831 42832 42833 42840 42841 42842 42843 4289	I0981 I110 I130 I132 I501 I5020 I5021 I5022 I5023 I5030 I5031 I5032 I5033 I5040 I5041 I5042 I5043 I50810 I50811 I50812 I50813 I50814 I5082 I5083 I5084 I5089 I509 I97130 I97131
Target temperature management	9981	6A4Z0ZZ
Coronary Angiography	3722	4A023N7 4A023N8
Percutaneous coronary intervention	3601 3602 3605 3606 3607 3609 0066	02703 02704 02713 02714 02723 02724 02733 02734
Extracorporeal membrane oxygenation	3965	5A1522F 5A1522G 5A1522H

Table S2. Charlson Comorbidity Index code.

Comorbidities	ICD-9-CM	ICD-10
Myocardial infarction	410.x, 412.x	I21.x, I22.x, I25.2
Congestive heart failure	428.x	I09.9, I11.0, I13.0, I13.2, I25.5, I42.0, I42.5-I42.9, I43.x, I50.x, P29.0
Peripheral vascular disease	443.9, 441.x, 785.4, V43.4 38.48	I70.x, I71.x, I73.1, I73.8, I73.9, I77.1, I79.0, I79.2, K55.1, K55.8, K55.9, Z95.8, Z95.9
Cerebrovascular disease	430.x-438.x	G45.x, G46.x, H34.0, I60.x-I69.x
Dementia	290.x	F00.x-F03.x, F05.1, G30.x, G31.1
Chronic pulmonary disease	490.x-505.x, 506.4	I27.8, I27.9, J40.x-J47.x, J60.x-J67.x, J68.4, J70.1, J70.3
Connective tissue disorder	710.0, 710.1, 710.4, 714.0-714.2, 714.81, 725.x	M05.x, M06.x, M31.5, M32.x-M34.x, M35.1, M35.3, M36.0
Peptic ulcer disease	531.x-534.x	K25.x-K28.x
liver disease	571.2, 571.4-571.6	B18.x, K70.0-K70.3, K70.9, K71.3-K71.5, K71.7, K73.x, K74.x K76.0, K76.2-K76.4, K76.8, K76.9, Z94.4
Diabetes without chronic complication	250.0-250.3, 250.7	E10.0, E10.l, E10.6, E10.8, E10.9, E11.0, E11.1, E11.6, E11.8, E11.9, E12.0, E12.1, E12.6, E12.8, E12.9, E13.0, E13.1, E13.6, E13.8, E13.9, E14.0, E14.1, E14.6, E14.8, E14.9
Diabetes with chronic complication	250.4-250.6	E10.2-E10.5, E10.7, E11.2-E11.5, E11.7, E12.2-E12.5, E12.7, E13.2-E13.5, E13.7, E14.2-E14.5, E14.7
Hemiplegia or paraplegia	344.1, 342.x	G04.1, G11.4, G80.1, G80.2, G81.x, G82.x, G83.0-G83.4, G83.9
Renal disease	582.x, 583-583.7, 585.x, 586.x, 588.x	I12.0, I13.1, N03.2-N03.7, N05.2-N05.7, N18.x, N19.x, N25.0, Z49.0-Z49.2, Z94.0, Z99.2
Any malignancy	140.x-172.x, 174.x-195.8, 200.x-208.x	C00.x-C26.x, C30.x-C34.x, C37.x-C41.x, C43.x, C45.x-C58.x, C60.x-C76.x, C81.x-C85.x, C88.x, C90.x-C97.x
Metastatic cancer	196.x-199.1	C77.x-C80.x
Moderate or severe liver disease	456.0-456.21, 572.2-572.8	I85.0, I85.9, I86.4, I98.2, K70.4 K71.1, K72.1, K72.9, K76.5, K76.6, K76.7
AIDS/HIV	042.x-044.x	B20.x-B22.x, B24.x

AIDS = acquired immunodeficiency syndrome, HIV- human immunodeficiency virus