Quality of Life Loss Estimation Methods for the WISQARS Cost of Injury Module

Bruce A. Lawrence, Ph.D.
and Ted R. Miller, Ph.D.

Pacific Institute for Research and Evaluation

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11720 Beltsville Drive, Suite 900 | Calverton, MD 20705 | Tel: 301-755-2700 | Fax: 301-755-2799

Pacific Institute for Research and Evaluation www.pire.org

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The Pacific Institute for Research and Evaluation (PIRE) has produced estimates of quality-adjusted life year (QALY) losses resulting from nonfatal injuries treated in hospital emergency departments. These are intended to be used to compute quality-of-life losses to complement medical and work loss costs (Lawrence and Miller, 2014) in the Web-based Injury Statistics Query and Reporting System (WISQARS) Cost of Injury Reports. This report describes the methods behind these QALY estimates.

Definition. A QALY is a health status measure used to account for the impact of a health state on both quality and quantity of life. QALYs indicate how people value their health status. The concept of a QALY incorporates the quality-of-life impact from an injury or illness. It is derived from a comprehensive model of health that accounts for multiple dimensions of physical, psychological, and social well-being. A QALY is valued at 1.0 for perfect health and at 0.0 for death, typically with negative values (fates worse than death) allowed. Thus, loss of one year of QALY is equivalent to losing a year of life in perfect health due to premature mortality.

QALYs are routinely used worldwide in evaluating the outcomes of clinical trials of medical interventions, in deciding which pharmaceuticals to approve, and in studying the return on investment in preventive health and safety measures (Miller, 2000). The National Highway Traffic Safety Administration (NHTSA), for example, uses QALY estimates in its analyses that compare the cost and utility of regulatory alternatives (see, for example, Blincoe et al., 2002).

Background. In our work for NHTSA, PIRE has long estimated QALY losses based on the Injury Impairment Index (III). Its underlying impairment estimates were produced for NHTSA by a panel of medical experts (Hirsch et al., 1983), which predicted the outcomes of traumatic injuries of moderate or greater severity—i.e., those with an Abbreviated Injury Scale (AIS; States et al., 1980) rating of 2–5. We used the Hirsch impairment ratings, supplemented by data on work-related disability, to estimate lifetime QALY losses for nonfatal injuries—both those treated in an emergency department (ED) and released (called *ED-treated* hereafter) and those resulting in hospital admission. The Hirsch impairment estimates' focus on relatively severe traumatic injuries accords well with NHTSA's focus on motor vehicle traffic injuries but complicates their application to a broader range of injuries. The panel of medical experts did not rate the least severe injuries (AIS-1), nor did they consider non-traumatic injuries, such as poisoning, suffocation, and electric shock. Our addition of work-related disability to the model mitigates these deficiencies to a large extent by providing some measure of disability in minor injuries. The III estimates of impairment from road crash injuries have been validated through comparison with other such estimates and found to be of similar magnitude (Miller, Bergeron, and Lawrence, 2016). The utility weights used with the III were updated about a decade ago by means of a literature survey of the weights used in similar published models (Spicer, Miller, et al., 2011). We have also developed more detailed QALY estimates for hospital-admitted burns (Miller, Bhattacharya, et al., 2013) and for submersion and certain types of poisoning (Miller and Bhattacharya, 2013). For this project, we also developed new impairment estimates for electrical injuries, ED-treated burns, and methanol poisoning.

Overview. Briefly, we merged the III-based impairment estimates, along with our estimates for hospital-admitted burns, submersion, and certain types of poisoning, onto the same 2010 hospital and ED datasets that we used previously for estimating work loss costs for WISQARS. For diagnoses that did not have impairment ratings from these sources, we either borrowed impairment estimates from similar diagnoses or developed new estimates. Means of the III-based impairments, along with our estimates of work-related disability based on workers' compensation data, were then computed by NEISS injury diagnosis and body part and age group and merged onto NEISS-AIP data. Discounted life expectancy by age and sex was also merged onto the NEISS-AIP data, and expected QALY losses were computed for each case. These QALY losses were then monetized, resulting in an estimate of lost quality of life in dollars.

Computing QALY losses with the Injury Impairment Index. Hirsch et al. (1983) predicted the outcomes of most injuries listed in *The Abbreviated Injury Scale, 1980 Revision* (States et al., 1980; hereafter AIS-80). They rated injuries in six dimensions—mobility, cognitive, cosmetic, sensory, pain, and daily living. For each dimension, four levels of impairment were defined—slight, moderate, severe, and maximum/total. A doctor with relevant expertise (orthopedics, neurology, surgery, or plastic surgery) predicted the victim's recovery trajectory as the duration of time spent at each impairment level in the first year, along with continuing impairment levels for years 2–5 and years 6 and following. Impairment ratings were provided for four age groups (0–15, 16–45, 46–65, >65) but were not differentiated by sex. Hirsch et al. (1983) provided this detailed information in tabular form in the 48-page Appendix I. This is complemented by Appendix II, which lists all the AIS-80 diagnoses the panel rated.

Example. A 40-year-old woman with a scapula fracture is expected to experience the following impairments:

- Mobility: moderate (level 2) for six weeks.
- Cosmetic: moderate (level 2) for four weeks.
- Pain: severe (level 3) for two weeks, and moderate (level 2) for two weeks.
- Daily living: severe (level 3) for one week, moderate (level 2) for one week, and slight (level 1) for three weeks.

No impairments in the cognitive and sensory dimensions are expected, and no ongoing impairment is expected after the first year.

For a given injury, these impairment durations are combined into a single overall impairment rating for year 1, a rating for years 2–5, and a rating for years 6 and following (hereafter imp1, imp2, and imp6, or, collectively, impairment fractions) using utility weights collected from a survey of the QALY literature (see Table 1; Spicer and Miller, 2010). The six impairment dimensions are combined multiplicatively, rather than additively: Each dimension's loss is subtracted from 1 to compute the fraction of the year *not* lost to impairment. (For a dimension with no impairment, this is simply 1.) Then the six fractions are multiplied together to compute the total portion of the year not lost to impairment. Finally, this product is subtracted from 1 to compute the year's overall loss to impairment.

Example. Continuing the scapula fracture example, the first-year QALY loss is computed as

$$\begin{aligned} \text{imp1} = 1 - \{&[1 - (.2054 \times 42/365)] \\ &\times [1 - (.002 \times 28/365)] \\ &\times [1 - (.360 \times 14/365 + .150 \times 14/365)] \\ &\times [1 - (.365 \times 7/365 + .1705 \times 7/365 + .078 \times 21/365)]\} \end{aligned}$$

In the first term, for example, .2054 is the utility weight from Table 1 for level-2 mobility impairment, and 42/365 is the fraction of the first year spent by the victim with level-2 mobility impairment, as described previously. Thus, the total quality-of-life reduction due to reduced mobility is equivalent to the loss of.0236 years, or 8.63 days. Subtracting this from 1, the remaining utility from mobility that is not lost to impairment in the first year post-injury is .9764 years.

All dimensions are multiplied together, and the result is subtracted from 1. The total QALY loss expected from this scapula fracture is .0570 years—roughly 21 days.

For a more severe injury that resulted in continuing impairment after the first year, imp2 and imp6 would also be computed. These are somewhat simpler to compute than imp1 because duration is not a factor. Each dimension is assigned a single impairment level for the whole period—i.e., years 2–5 for imp2, or year 6 until death for imp6.

The AIS-80 diagnoses not rated by Hirsch et al.—most notably minor (AIS-1) injuries and crushing injuries—were restored to create a more comprehensive mapping. We also augmented the mapping with some diagnoses added in the 1985 revision of AIS (Gennarelli et al., 1985), most notably spinal cord contusions of AIS-3 and AIS-4 severities. The added AIS-1 diagnoses were assigned impairment fractions of zero. The other added diagnoses were assigned impairment fractions based on those of similar diagnoses. For some, the impairment fractions were simply cloned from a similar diagnosis. For others, mean impairment fractions were computed for two or three diagnoses of the same AIS body region and severity. For a few, the most similar diagnosis had a higher severity rating, so we multiplied its impairment fractions by two-thirds before matching them to the new diagnosis. This conservative method reduces the likelihood the impairment fractions for these diagnoses will be overstated. Table 2 lists all the restored and added AIS diagnoses, along with the sources of their impairment fractions.

Mapping to ICD-9-CM. We mapped the six-dimensional imp1, imp2, and imp6 from the AIS-80 diagnosis system used by Hirsch et al. (1983) to ICD-9-CM. Since AIS-80 is often more detailed than ICD-9-CM, in many instances multiple AIS-80 diagnoses mapped to a single ICD-9-CM diagnosis. In these instances, means of the AIS-80 diagnoses were computed by ICD-9-CM diagnosis and age group. In the mapping process, we have typically computed such means without any weighting, but that could be problematic here. Because AIS-80 tends to contain more detailed diagnoses at higher severity levels, unweighted means would suffer from a disproportionate impact of high-severity injury diagnoses, resulting in an upward bias in the estimated impairment. To address this, we weighted this computation by the percentage of injuries at each AIS severity level. We differentiated these percentages by AIS body region and hospitalization status. We computed these percentages from two datasets of the Healthcare Cost and Utilization Project (HCUP), the 2010 Nationwide Inpatient Sample (NIS) and Nationwide Emergency Department Sample (NEDS), to which we had previously added AIS-90 severity scores produced by the ICDMAP-90 software (MacKenzie and Sacco, 1997). While it would have been more appropriate to use data coded with AIS-80 scores to match Hirsch et al. (1983), we know of no such data. These weights are shown in Table 3.

Example. A 40-year-old woman suffers a shoulder fracture and is admitted to the hospital for treatment. The NEISS injury diagnosis/body part code for this injury is 57/30. It is mapped from the ICD-9-CM diagnosis codes 810 (clavicle fracture), 811 (scapula fracture), and 818 (ill-defined fractures of upper limb). These, in turn, are mapped from five AIS-80 diagnoses rated by Hirsch et al. (1983). AIS-80 includes three kinds of shoulder fractures—acromion, clavicle, and scapula—all of which are associated with the Occupant Injury Code (OIC) S_FS2 (shoulder, fracture, skeletal system, AIS-2). These three AIS-80 diagnoses map to the ICD-9-CM diagnoses 810 and 811. Meanwhile, diagnosis 818 is mapped from three AIS-80 diagnoses—humerus fracture, open/displaced (A_FS3); radius/ulna fracture, open/displaced (R_FS3); and scapula fracture (S_FS2). (In OIC, A stands for upper arm and R stands for forearm. The first two are rated as AIS-3, the last as AIS-2.)

Just as we computed imp1 for scapula fracture above, we likewise compute the impairment fractions for all five AIS-80 diagnoses that map to shoulder fracture in NEISS:

- acromion fracture: imp1=0.03584, imp2=0, imp6=0
- clavicle fracture: imp1=0.03883, imp2=0, imp6=0
- scapula fracture: imp1=0.05701, imp2=0, imp6=0
- humerus fracture, open/displaced: imp1= 0.08435, imp2=0.078, imp6=0.078
- radius/ulna fracture, open/displaced: imp1=0.16012, imp2=0.07127, imp6=0.07127

ICD-9-CM diagnoses 810 and 811 are mapped from the first three AIS-80 diagnoses in a straightforward way:

- acromion fracture maps to 811.x1
- clavicle fracture maps to 810.xx
- scapula fracture maps to 811.xy for y=0,2,3,9

However, diagnosis 818 is more complicated. As an "ill-defined" diagnosis, it has no corresponding diagnosis in AIS-80. Therefore, it was mapped from three diagnoses chosen to be representative of upper limb fracture—the last three of the five listed AIS-80 diagnoses. (Scapula fracture maps to both 811 and 818.) Since scapula fracture is severity 2, while the other two diagnoses are severity 3, they must be weighted according to their treatment level (hospital-admitted), AIS body region (7=upper extremity) and AIS severity (2 or 3). (Table 3 provides these weights.) For hospital-admitted injuries of the upper extremity, 72.58% were AIS-2 and 11.9843% were AIS-3. These two weights sum to 0.845643. First, we compute the mean impairment fractions for the two AIS-3 diagnoses, which come to imp1=0.122240, imp2=0.074635, imp6=0.074635. Then we compute the weighted mean of the AIS-2 and AIS-3 impairment fractions:

$$\text{imp1} = (0.7258\times0.057006 + 0.119843\times0.122240) / 0.845643 = 0.066251$$
$$\text{imp2} = (0.7258\times0 + 0.119843\times0.074635) / 0.845643 = 0.010577$$
$$\text{imp6} = (0.7258\times0 + 0.119843\times0.074635) / 0.845643 = 0.010577$$

These computed impairment fractions are assigned to ICD-9-CM diagnosis 818 when the Hirsch-based impairment fractions are merged onto the injury subsets of the 2010 NIS.

The mean impairment fractions by ICD-9-CM diagnosis and age group were then merged onto the 2010 NIS and NEDS. (These are the same datasets that we used in developing the current generation of medical and work loss costs for WISQARS.) An initial test merge identified gaps in the mapping. Missing impairment fractions for traumatic injury diagnoses were filled by cloning the impairment fractions from a similar diagnosis or by averaging the impairment fractions from multiple similar diagnoses, a process similar to that described above for assigning impairment fractions to the AIS diagnoses we added or restored. This is necessary mostly for obscure diagnoses (whose descriptions often involve terms like *other*, *unspecified*, or *ill-defined*) that do not map between diagnosis systems in a straightforward way. In particular, we singled out diagnosis 959 (injury, other and unspecified) for special treatment. It lists diagnoses by body region, but not by nature of injury. Therefore, we computed impairment fractions for 959 by averaging across all traumatic injuries for each body region. For example, for diagnosis 959.2 (other and unspecified injury of shoulder and upper arm), we computed the mean impairment fractions for all traumatic injuries of the shoulder and upper arm.

Example. AIS-80 includes three crushing injuries of the shoulder region:

1. Shoulder (glenohumeral) joint crush (S_NW3-01)
2. Sternoclavicular joint crush (S_NW3-02)
3. Acromioclavicular joint crush (S_NW3-03)

Hirsch et al. (1983) provided impairment ratings for 1 and 2, but not 3. We computed the impairment fractions for 1 and 2 in the usual way. We then averaged the impairment fractions of 1 and 2 and assigned these averaged impairment fractions to 3. (This is listed in Table 2.)

The first and third AIS-80 diagnoses map nicely to the ICD-9-CM diagnosis 927.00, crushing injury of the shoulder region, but none maps to 927.01, crushing injury of the scapular region. Therefore, in a secondary phase of mapping, we filled in the missing impairment fractions for 927.01 with those of 3, acromioclavicular joint crush.

At this point, we substituted our own impairment estimates, developed for CPSC, for hospital-admitted burns (Miller, Bhattacharya, et al., 2013), plus submersion, carbon monoxide poisoning, and lead poisoning (Miller and Bhattacharya, 2013). We extended the burn estimates to hospital-admitted radiation and frostbite, and the submersion estimate to suffocation.

We also developed new impairment estimates to fill key gaps. For ED-treated minor burns, we relied on Finlay et al. (2009), a rare burn paper focused on recovery from non-severe burns, which reported average impairment of 1.63% after six months. Since burn recovery varies with age, we applied the age pattern from AIS-2 burns in the III, resulting in first-year impairment estimates of 0.957% for ages 0–15; 1.478% for ages 16–45; 1.714% for ages 46–65; and 2.888% for ages 66 and up. We also applied these estimates to ED-treated cases of frostbite, radiation, and electric shock.

Our notes from a poisoning panel sponsored by CPSC (July 19, 2009; contract CPSC-D-05-0006, Task 6) resulted in an estimated impairment of 4.8% for methanol poisoning. We applied this impairment to both hospital-admitted and ED-treated methanol poisonings for victims of all ages. The impairment persists for life—i.e., imp1, imp2, and imp6 are all the same.

Finally, we developed new impairment estimates for hospital-admitted electric shock. Appendix A presents these in detail.

Work-related disability. In addition to the six Hirsch impairment dimensions, the III adds a seventh dimension—work-related disability. While this dimension applies to all injuries, it is especially important for AIS-1 injuries, which otherwise would have an estimated QALY loss of zero. This dimension draws on the same disability probabilities we previously used in estimating work loss for WISQARS, based on workers' compensation claims (Lawrence and Miller, 2014). Since WISQARS already includes the value of lost income in work-loss costs, however, this seventh QALY dimension is given a relatively small weight, so as to represent only the utility the victim would have received from working, as opposed to lost earnings, which are covered by work loss. The derivation of this weight is shown in Appendix B.

Work-related disability is represented by the variables **perm** and **temp**, which are intermediate values in the work-loss computations. Their formulas are

perm = prob(total) + prob(partial)×avgloss
temp = [1−prob(total)] × dayslost/365

where

prob(total) = probability of being permanently totally disabled
prob(partial) = probability of being permanently partially disabled
avgloss = average loss of earning power if permanently partially disabled
dayslost = work days lost to temporary disability

Greater detail on the work-loss variables can be found in Lawrence and Miller (2014).

Example. The inputs for work-related disability are given by three-digit ICD-9-CM diagnosis. For our hospital-admitted shoulder fracture example, these inputs are

Diag	Prob(Total)	Prob(Partial)	AvgLoss	DaysLost
810	0.0125348	0.238162	0.135	312.446
811	0.0088785	0.115888	0.135	166.730
818	0.0090909	0.269920	0.180676	291.355

From these values we can calculate perm and temp, as per the formulas above. For diagnosis 810, these calculations are

perm = 0.0125348 + (0.238162×0.135) = 0.044687
temp = [1−0.0125348] × 312.446/365 = 0.845286

In the same manner, we compute perm and temp for the other diagnoses:

Diag	perm	temp
810	0.044687	0.845286
811	0.024523	0.452739
818	0.057859	0.790976

Mapping to NEISS. Once impairment ratings were assigned to every acute injury case in the NEDS and NIS, we used our existing diagnosis mapping from ICD-9-CM to NEISS to merge NEISS injury diagnosis and body part onto the NEDS and NIS. (This process is described in more detail in the appendix of Lawrence and Miller, 2014). We then computed means of imp1/imp2/imp6 and perm and temp by NEISS injury diagnosis and body part and age group. We filled in values for missing cells by extrapolating patterns of impairment fractions by age from similar diagnoses. For example, the data cell for amputation of the elbow (50 32) for children 0–15 was missing because there were no cases in the 2010 NEDS. We followed the pattern of the adjacent diagnosis, amputation of the lower arm (50 33). We computed the ratio of imp1 for ages 0–15 to imp1 for ages 16–45 for diagnosis 50 33. Then we multiplied this ratio times the value of imp1 for ages 16–45 for diagnosis 50 32 in order to compute the estimate for the missing cell. The same operation was performed for imp2, imp6, perm, and temp. When a diagnosis was entirely missing, we filled it by cloning the values from a similar diagnosis. For example, NEISS has a few cases coded as dislocation of the lower arm (55 33). Since this diagnosis is not valid, it does not map from ICD-9-CM, and no values were produced by the mapping process. Instead, we copied the values of imp1/imp2/imp6/perm/temp from the adjacent diagnosis, dislocation of the elbow (55 32) and used them as the basis for diagnosis 55 33. The result was four comprehensive sets of imp1/imp2/imp6/perm/temp by NEISS injury diagnosis and body part and age group. One set, computed from the NEDS, covered ED-treated injuries. The other three sets, computed from the NIS, covered hospital-admitted injuries, with separate files for motor vehicle traffic injuries and intentional injuries, just as we did previously for medical costs and work loss. These sets of QALY inputs are merged onto the NEISS-AIP data by admission status, injury class (for hospital-admitted injuries: traffic, intentional, other), NEISS injury diagnosis and body part, and age group.

One additional QALY input, discounted life expectancy, was merged onto NEISS-AIP by age and sex. Life expectancies are based on the life tables published by the National Center for Health Statistics (Arias, 2014). They are discounted at 3% (and 7% for sensitivity analysis).

Example. Using all NIS cases with a primary injury diagnosis of 810, 811, or 818 that do not involve motor vehicle traffic or violence, we compute mean values of imp1, imp2, imp6, perm, and temp (derived in the last two example boxes) by age group. (Cases involving 818 do not receive their full weight because, being an ill-defined diagnosis, it gets divided across several body parts in the mapping from ICD-9-CM to NEISS.)

AgeGp	imp1	imp2	imp6	temp	perm
Missing	0.043468	0.000023984	0.000023984	0.86186	0.045527
0–15	0.031525	0.000005538	0.000005538	0.65770	0.044429
16–45	0.040836	0.000020427	0.000020427	0.69613	0.044669
46–65	0.044812	0.000025160	0.000025160	0.87418	0.044456
66+	0.045450	0.000027337	0.000027337	0.96482	0.046766

The values for missing age are computed as the mean across all ages. Similar values are computed from the NIS for motor vehicle traffic injuries and intentional injuries, as well as for ED-treated injuries from the NEDS. These are then applied to cases of shoulder fracture in NEISS-AIP.

Computing QALYs. Having merged all the necessary QALY inputs onto NEISS-AIP, we can proceed to compute the lifetime expected QALY loss for each case. These QALYs are then monetized by multiplying them times a cost per QALY based on the recommended value of statistical life (VSL) to compute lost quality of life. CDC follows current HHS guidance (HHS, 2016), which recommends a VSL of $9.7 million, in 2014 dollars. It is easiest to show these computations by laying out the SAS code:

```
temp1=temp;
temp2=0;
IF temp>1 THEN DO;
   temp1=1;
   temp2=temp-1;
   END;
perm1=perm*(1-temp1);
perm2=perm;
IF temp2>0 THEN perm2=perm*((4-temp2)/4);

D1=1-(.170*(perm1+temp1));
D2=1-(.170*(perm2+temp2));
D6=1-(.170*perm);

Q1=1-((1-imp1)*D1);
Q2=1-((1-imp2)*D2);
Q6=1-((1-imp6)*D6);
```

```
QALY3m = MIN(0.98533,LifeExpt3)*Q1
       + MAX(0,MIN(LifeExpt3-0.98533,3.66257))*Q2
       + MAX(0,(LifeExpt3-4.64790))*Q6;

QoL2010d3=QALY3m*333285;
```

The first nine lines allow for the rare possibility that temp is greater than 1 year and reallocate anything in excess of 1 year to years 2–5 so that it gets discounted properly. The next three lines (D1, D2, D6) use these adjusted values of perm and temp to compute the work-related disability components for years 1, 2–5, and 6+, respectively. (Appendix B shows the derivation of the work disability factor, 0.170.) The next three lines (Q1, Q2, Q6) combine the Hirsch-based six-dimensional impairment fractions with work disability to create the III's seven-dimensional impairment fractions. These are then used in the QALY formula to compute the QALY loss with midyear discounting at 3%. The various MIN and MAX functions allow for very short remaining life expectancies.

The three numeric values in the QALY formula embody the 3% midyear discounting. The first is for year 1, the second is for years 2–5, and the last is the sum of the first two, which is to be subtracted from the remaining life expectancy.

$$0.98533 = (1/1.03)^{½}$$
$$3.66257 = (1/1.03)^{1½} + (1/1.03)^{2½} + (1/1.03)^{3½} + (1/1.03)^{4½}$$
$$4.64790 = 0.9853 + 3.6626$$

Note that mid-year discounting entails an extra half-year's discounting of each year's QALY loss—thus the fractional exponents. This makes for slightly lower cost estimates than year-end discounting. For 7% discounting, 1.03 would be replaced with 1.07 in each formula.

Finally, the last line monetizes the QALY loss to produce the dollar estimate of lost quality of life. The value $333,285 is the cost per QALY (in 2010 dollars, the current WISQARS standard) for a VSL of $9.7 million (in 2014 dollars) and a discount rate of 3%. The cost per QALY is calculated as (VSL – discounted lifetime earnings) / discounted life expectancy. The lifetime earnings and life expectancy used in this calculation are the averages across all deaths from road crash or occupational injury. We used those two risks because the VSL studies are dominated by values of reducing the risks of road crash or occupational injury.

Limitations. Although III-based QALY losses have long been used in regulatory analysis, they are based on expert judgment. They have been validated through comparisons of aggregate QALY loss with QALY loss estimates from other sources (Spicer, Miller, et al., 2011). However, they have not been validated more robustly by comparing the ratings to mean losses by a cohort of patients tracked over time. The estimates for minor (AIS-1) injury, such as contusions and abrasions, are underestimates, in that they consider only impairments that affect ability to work.

Like many algorithms that compute QALY losses, the III algorithm assumes that people are in perfect health before applying the functional loss due to the injury. This assumption ignores chronic and acute conditions that may have been in place prior to the injury. In reality, most people are not in perfect health when injured, and the older the person the lower the health state. Therefore, QALY loss estimates using the III algorithm may be overestimated, especially for older injury victims (Spicer, Miller, et al., 2011).

Only one diagnosis per injury episode was taken into account in estimating QALY losses. Hirsch et al. (1983) assigned impairment levels and durations for single AIS-80 diagnoses, and we mapped the resulting estimates to a single NEISS diagnosis on each case. But severe injury episodes might involve multiple injury conditions, which could be expected to result in greater long-term impairment than those with a single injury condition. Therefore, the III is likely to underestimate QALY losses when applied to NEISS-AIP data—especially hospital-admitted injuries. With the revised NEISS system allowing for a second diagnosis beginning in 2019, perhaps the next iteration of QALY loss estimates for WISQARS could find a way to incorporate the second diagnosis. Depending on how often NEISS coders use this second diagnosis field and how severe the secondary diagnoses are relative to the primary, taking secondary diagnoses into account could raise future QALY estimates a little or a lot.

Estimates. Tables 4 and 5 show estimated QALY losses that result from applying our estimates to the 2013–2014 NEISS–AIP data. Table 4 shows mean QALY losses by admission status and NEISS injury diagnosis, and Table 5 by admission status and NEISS body part. Overall, the mean estimated QALY loss for an ED-treated injury is 0.323, or about four months, and that for a hospital-admitted injury is 0.971, nearly a year. The largest QALY losses result from hospital-admitted submersion (22.49) and anoxia (8.37), which often have serious permanent consequences. Injuries with above-average QALY losses whether ED-treated or hospital-admitted include crushing, internal organ injury, amputation, nerve damage, and concussion. The diagnoses with the smallest losses are poisoning, aspiration of foreign object, contusion/abrasion, and hematoma. The body part associated with the greatest losses is the head.

The hospital-admitted QALY loss is greater than ED-treated loss for every injury diagnosis except dislocation. Dislocation of the knee results in much greater QALY loss than other dislocations, and knees account for a larger proportion of ED-treated dislocations than of hospital-admitted dislocations. The only body part for which the ED-treated loss is greater is unknown/not stated. Injuries of unknown body part are mostly associated with the diagnoses contusion/abrasion and other. ED-treated has a higher proportion of other, while hospital-admitted has a higher proportion of contusion/abrasion. Other has a higher QALY loss than contusion/abrasion.

Table 6 shows quality-of-life losses in 2010 dollars by age and sex. Losses are highest for older injury victims. Males have greater losses at younger ages, while females have greater losses at older ages. On average, injuries in NEISS-AIP entail about $131,000 in lost quality of life. The aggregate quality-of-life loss due to injury is estimated to be about $4 trillion per year.

Diagram 1. Mapping Shoulder Fracture from AIS-80 to ICD-9-CM to NEISS

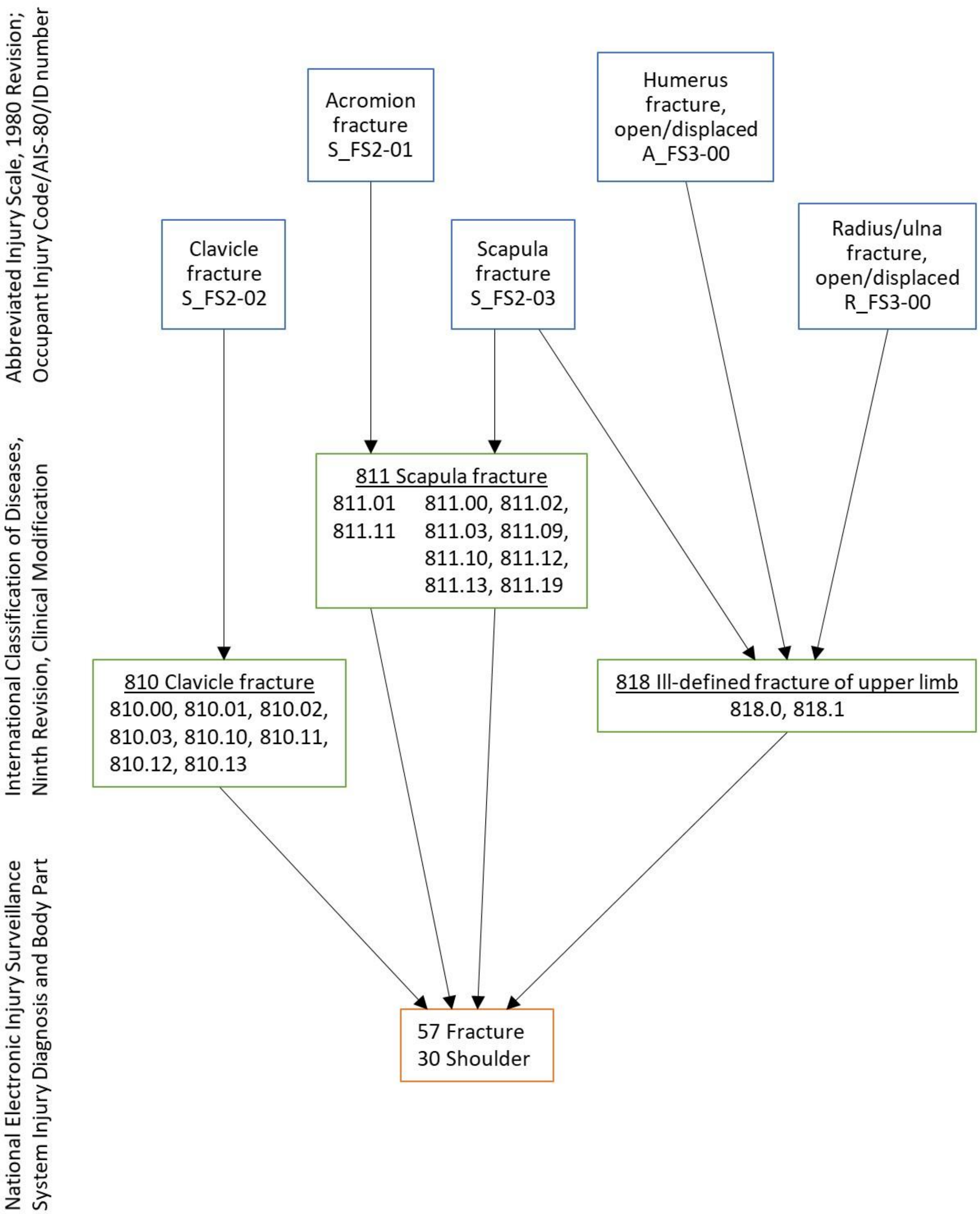

Table 1. Median Utility Weights by Impairment Dimension and Level

Dimension	Level	Weight	Inverse
Mobility	1	0.93	0.07
	2	0.7946	0.2054
	3	0.49675	0.50325
	4	0.40	0.60
Cognitive	1	0.935	0.065
	2	0.75	0.25
	3	0.164	0.836
	4	−0.004	1.004
Cosmetic	1	1	0
	2	0.998	0.002
	3	0.9675	0.0325
	4	0.86	0.14
Sensory	1	0.89	0.11
	2	0.84	0.16
	3	0.7125	0.2875
	4	0.61	0.39
Pain	1	0.97	0.03
	2	0.85	0.15
	3	0.64	0.36
	4	0.40	0.60
Daily Living	1	0.922	0.078
	2	0.8295	0.1705
	3	0.635	0.365
	4	0.365	0.635

Source: Spicer & Miller (2010), Table 5

Table 2. AIS Injuries Restored or Added to Impairment Ratings of Hirsch et al. (1983)

DxID	OIC	ID	AIS injury description	Source of impairment fractions
3	A_FS3	02	Humerus fracture involving radial nerve	A_FS3-00
10	BICC3	00	Lumbar cord contusion (1985)	BSLN3 (imp1) & NPCC3 (imp2+)
11	BICC4	00	Lumbar cord contusion, incomplete cord syndrome (1985)	NP_C4
20	BITS1	00	Lumbar spine, acute strain	zero
25	BSCC3	00	Thoracic cord contusion (1985)	BSLN3 (imp1) & NPCC3 (imp2+)
26	BSCC4	00	Thoracic cord contusion, incomplete cord syndrome (1985)	NP_C4
35	BSTS1	00	Thoracic spine, acute strain	zero
38	BSZV2	00	Thoracic spine dislocation/fracture, spinous or transverse process or unspec.	⅔×BSZV3-02
44	C_CS1	00	Rib cage fracture	zero
45	C_FS1	00	Rib cage fracture, open/displaced/>2 ribs	zero
46	C_FS2	00	Rib cage fracture, hemothorax	⅔×C_FS3
47	C_FS3	01	Rib cage fracture, pneumothorax	⅔×C_FS4-01
48	C_FS3	02	Rib cage fracture, hemothorax, open/displ/>2	⅔×C_FS4-02
51	C_FS4	03	Rib cage fracture, pneumothorax, open/displ/>2	C_FS4-01
52	C_FS4	04	Rib cage fracture, hemomediastinum	C_FS4-02
53	C_FS4	05	Rib cage fracture, pneumomediastinum	⅔×C_FS5-02
54	C_FS4	06	Bronchus rupture	⅔×C_FS5-04
73	CCCR2	00	Bronchus contusion (1985)	NACR2-01
74	CCCS1	00	Sternum contusion (1985)	zero
76	CCLA4	00	Thoracic artery/vein laceration, major bleeding (excl. aorta) (1985)	N_LA4-02
81	CCLR3	00	Bronchus laceration (1985)	⅔×NALR4-02
82	CCLR4	00	Bronchus laceration, full thickness (1985)	NALR4-02
90	CCRR5	00	Rib cage contusion	NARR5-02
95	E_CJ1	00	Elbow contusion	zero
100	E_NW3	00	Elbow sprain	(E_DJ3+E_LJ3)/2
101	E_SJ1	00	Elbow crush	zero
102	F_AO1	01	Conjunctiva laceration	zero
103	F_AO1	02	Iris laceration	zero
104	F_AO1	03	Lid laceration	zero
106	F_FS1	00	Retina laceration	zero
111	F_FS2	05	Tear duct laceration	⅔×F_FS2-03
118	F_LO1	01	Vitreous laceration	zero
119	F_LO1	02	Choroid rupture	zero
120	F_LO1	03	Uvea injury	zero
121	F_LO1	04	Nose fracture	zero
122	F_LO1	05	Teeth fracture/avulsion/dislocation	zero
123	F_LO1	06	Tongue laceration, superficial or unspecified	zero
127	F_RO1	00	Gum laceration/contusion	zero

DxID	OIC	ID	AIS injury description	Source of impairment fractions
129	F_UO1	00	Lip laceration/contusion	Zero
133	FCFS1	00	Cornea abrasion/contusion	zero
137	FIFD1	00	Conjunctiva abrasion/contusion	zero
141	FILD1	01	Lid abrasion/contusion	zero
142	FILD1	02	Mandible fracture, ramus or unspec	zero
144	FILI1	00	Mandible fracture, ramus, open/displ/comminuted	zero
160	H_UE1	00	Awake, no prior unconsciousness	zero
167	HWKB1	00	Ear canal injury	zero
204	K_CM1	00	Knee contusion	zero
212	K_NW3	00	Knee crush	Q_NW3-00
217	L_CS1	00	Fibula contusion	zero
226	L_FS3	03	Fibula fracture, open/displaced/comminuted	L_FS2-03
227	L_FS3	04	Fibula fracture involving tibial nerve (1985)	⅔×Y_LN2
228	L_FS3	05	Average of L_FS3 (replaces L_FS3-00)	
230	L_NW3	00	Thigh-leg crush below knee	Q_NW3-00
233	M_LA4	01	Iliac artery/vein laceration, major bleeding (1985)	N_LA4-04
234	M_LA4	02	Inferior vena cava laceration, major bleeding (1985)	N_LA4-04
235	M_LA4	03	Other vessel laceration, major bleeding (1985)	N_LA4-04
239	M_LI1	00	Duodenum perforation, superficial	zero
243	M_PI1	00	Biliary tract perforation, superficial	zero
258	MICG1	01	Abdominal wall laceration, superficial	zero
259	MICG1	02	Abdominal wall perforation, superficial	zero
260	MICG1	03	Penis contusion	zero
264	MICI1	01	Vagina contusion	zero
265	MICI1	02	Vulva contusion	zero
275	MILG1	01	Perineum contusion	zero
276	MILG1	02	Scrotum contusion	zero
288	MILI1	01	Vagina laceration, superficial	zero
289	MILI1	02	Vulva laceration, superficial	zero
299	MIPG1	01	Scrotum laceration, superficial	zero
300	MIPG1	02	Perineum laceration, superficial	zero
301	MIPG1	03	Scrotum perforation, superficial	zero
306	MIPG3	04	Vagina perforation, superficial	MILG3-04
309	MIPI1	00	Vulva perforation, superficial	zero
323	MIRI1	00	Bladder perforation, superficial	zero
335	MIVG4	05	Perineum perforation, superficial	MILG4-02
347	MRVL5	00	Scrotum rupture	MRRL5
363	MSPD4	03	Bladder avulsion	MSLD4-03
364	MSPD4	04	Liver avulsion	MSLD4-04
381	N_LA4	05	Jugular vein, internal, major laceration (1985)	N_LA4-01
382	N_LA4	06	Vertebral artery, major laceration (1985)	N_LA4-01
384	NACI1	00	Throat contusion	zero
385	NACR1	01	Pharynx contusion	zero
386	NACR1	02	Trachea contusion	zero

DxID	OIC	ID	AIS injury description	Source of impairment fractions
392	NALI1	00	Throat laceration	zero
393	NALR1	00	Pharynx laceration	zero
400	NAPR1	00	Pharynx puncture	zero
402	NARR1	00	Pharynx rupture	zero
412	NPEC6	00	Total cord transection, C-3 or above	NPEC5
415	NPLC6	00	Cord laceration, C-3 or above	NPLC5
418	NPNW6	00	Cord crush, C-3 or above	NPNW5
421	NPTM1	00	Neck, acute strain	zero
434	P_SJ1	00	Pelvis crush	zero
440	PWNW4	00	Hip sprain	P_FS3-02
441	Q_CI1	00	Ankle contusion	zero
442	Q_DJ1	00	Toe dislocation	zero
446	Q_FS1	00	Toe fracture	zero
452	Q_FS3	02	Fibula (lateral) malleolus fracture, open	(Q_FS2-04+Q_FS3-00)/2
458	Q_NW2	00	Toe crush	(Q_DS2+Q_FS2-02+Q_MW2)/3
460	Q_NW3	02	Ankle crush	Q_NW3-00
461	Q_NW3	03	Foot crush	Q_NW3-00
463	Q_SJ1	01	Ankle sprain	zero
464	Q_SJ1	02	Foot sprain	zero
465	Q_SJ1	03	Toe sprain	zero
472	R_FS3	03	Radius fracture involving radial nerve	R_FS3-01
473	R_FS3	04	Ulna fracture involving radial nerve	R_FS3-02
474	R_FS3	05	Radius/ulna fracture involving radial nerve	(R_FS3-01+R_FS3-02)/2
475	S_CJ1	01	Contusion of acromioclavicular joint or shoulder	zero
476	S_CJ1	02	Contusion of sternoclavicular joint	zero
489	S_NW3	03	Acromioclavicular joint crush	(S_NW3-01+S_NW3-02)/2
490	S_SJ1	01	Sprain of acromioclavicular joint	zero
491	S_SJ1	02	Sprain of shoulder	zero
492	S_SJ1	03	Sprain of sternoclavicular joint	zero
499	T_NW4	00	Thigh-leg crush above knee	Q_NW3-00
500	U_AI1	00	Abrasion, superficial	zero
502	U_BI1	00	Burn, 1st degree or <6% TBS	zero
507	U_CI1	00	Contusion, superficial	zero
509	U_LI1	00	Laceration, superficial	zero
512	W_CI1	00	Wrist contusion	zero
513	W_DJ1	00	Finger dislocation	zero
517	W_FS1	00	Finger fracture	zero
523	W_NW2	00	Finger crush	(W_LJ2-03+W_MW2)/2
524	W_NW3	01	Hand crush	(W_DJ3+W_MW3)/2
525	W_NW3	02	Wrist crush	(W_DJ3+W_MW3)/2
526	W_SJ1	01	Finger sprain	zero
527	W_SJ1	02	Wrist sprain	zero
534	X_NW3	00	Arm-forearm crush	(W_DJ3+W_MW3)/2

Table 3. Weights for Mapping Impairment Fractions from AIS-80 to ICD-9-CM

AIS Body Region	AIS Severity	Inpatient Weight	ED Weight
1 Head	1	0.042890	0.642604
	2	0.163304	0.309673
	3	0.174977	0.026398
	4	0.593718	0.021049
	5	0.025110	0.000275
2 Face	1	0.548403	0.966970
	2	0.315653	0.030008
	3	0.089979	0.002646
	4	0.044294	0.000370
	5	0.001671	0.000006
3 Neck	1	0.366918	0.819676
	2	0.238664	0.156967
	3	0.257670	0.014119
	4	0.096770	0.001960
	5	0.039979	0.007278
4 Thorax	1	0.136441	0.959427
	2	0.078471	0.022908
	3	0.565401	0.014677
	4	0.212855	0.002488
	5	0.006832	0.000500
5 Abdomen	1	0.274464	0.937619
	2	0.443621	0.057870
	3	0.139776	0.003192
	4	0.102724	0.000640
	5	0.039414	0.000680
6 Spine	1	0.052569	0.935766
	2	0.786852	0.062036
	3	0.086953	0.001830
	4	0.063430	0.000326
	5	0.010196	0.000041
7 Upper extremity	1	0.143577	0.726051
	2	0.725800	0.269315
	3	0.119843	0.004582
	4	0.010487	0.000047
	5	0.000293	0.000004
8 Lower extremity	1	0.048926	0.682456
	2	0.324727	0.302393
	3	0.621642	0.015003
	4	0.004497	0.000144
	5	0.000208	0.000002
9 Unspecified	1	0.615992	0.869567
	2	0.280692	0.112875
	3	0.079795	0.015143
	4	0.022159	0.002270
	5	0.001362	0.000145

Table 4. Mean QALY Losses by Admission Status and NEISS Injury Diagnosis, 2013–2014 NEISS–AIP

NEISS Injury Diagnosis	ED-Treated	Hospital-Admitted
41 Ingestion	0.00731	0.15388
42 Aspiration	0.00415	0.08513
46 Burn, Electric	0.02690	1.43269
47 Burn, Not Spec	0.02692	1.39884
48 Burn, Scald	0.02588	1.80357
49 Burn, Chemical	0.02456	1.55461
50 Amputation	1.55883	4.30252
51 Burn, Thermal	0.02594	1.65160
52 Concussion	1.06022	2.43774
53 Contusn/Abrasn	0.00643	0.10761
54 Crushing	6.92203	7.03349
55 Dislocation	1.19288	0.96189
56 Foreign Body	0.00681	0.27811
57 Fracture	0.10062	0.51599
58 Hematoma	0.00676	0.10734
59 Laceration	0.01840	0.25026
60 Dental Injury	0.06859	0.29850
61 Nerve Damage	1.52390	3.01924
62 Internal Injury	3.00156	4.31220
63 Puncture	0.01561	0.53313
64 Strain/Sprain	0.08524	0.38336
65 Anoxia	0.76260	8.37424
66 Hemorrhage	0.09777	0.30052
67 Electric Shock	0.01689	3.49995
68 Poisoning	0.00306	0.01727
69 Submersion	0.00159	22.49292
71 Other	0.10833	0.71270
72 Avulsion	0.01281	0.19166
73 Radiation	0.02858	2.20935
74 Dermat/Conjunc	0.00198	0.06986
All Diagnoses	0.32284	0.97090

Table 5. Mean QALY Losses by Admission Status and NEISS Body Part, 2013–2014 NEISS–AIP

NEISS Body Part	ED-Treated	Hospital-Admitted
00 Internal	0.00610	0.12730
30 Shoulder	0.07115	0.30277
31 Upper Trunk	0.03869	0.84573
32 Elbow	0.04158	0.34572
33 Lower Arm	0.05248	0.38500
34 Wrist	0.07734	0.29614
35 Knee	0.36255	0.58875
36 Lower Leg	0.06329	0.43248
37 Ankle	0.04443	0.32332
38 Pubic Region	0.07722	1.43571
75 Head	1.85677	3.80800
76 Face	0.02798	0.46328
77 Eyeball	0.00598	0.58690
79 Lower Trunk	0.20932	0.45157
80 Upper Arm	0.07346	0.37428
81 Upper Leg	0.15570	0.86547
82 Hand	0.12100	0.57204
83 Foot	0.12072	0.56689
84 25-50% of Body	0.07707	2.15849
85 All Parts Body	0.02152	0.19468
87 UNK/Not Stated	0.49243	0.39169
88 Mouth	0.04263	0.28945
89 Neck	0.21056	0.51935
92 Finger	0.18854	1.59767
93 Toe	0.02157	0.30868
94 Ear	0.03400	0.31261
All Body Parts	0.32284	0.97090

Table 6. Mean and Aggregate Annual Quality of Life Losses 2013–2014 NEISS–AIP
2010 Dollars

Sex	Age	2013–2014 Incidence	Mean QoL Loss	Aggregate Annual Loss (*Billions*)
Female	00-15	5,536,284	$105,190	$291.2
	16-45	12,082,307	$105,244	$635.8
	46-65	6,227,599	$153,673	$478.5
	>65	4,889,755	$226,674	$554.2
Male	00-15	7,403,866	$112,254	$415.6
	16-45	15,496,198	$106,822	$827.7
	46-65	7,054,359	$145,586	$513.5
	>65	3,023,957	$222,289	$336.1
Total/Mean		61,714,323	$131,331	$4,052.5

Appendix A. New Impairment Estimates for Hospital-Admitted Electrical Injuries

We developed new estimates of impairment for hospital-admitted electrical injuries, based on Shih et al. (2017), which surveys numerous studies of electrical burn admissions.

Hospital-admitted electrical injuries can have serious long-term consequences in addition to the short-term effects. Low-voltage injuries (LVI) tend to have less serious long-term effects than high-voltage (HVI). Results of HVI can include long-term neurological conditions similar to traumatic brain injury (TBI) and spinal cord injury (SCI), renal dysfunction, amputation, and PTSD. Short-term effects in addition to burns (averaging 10.6% TBSA for LVI and 17.6% TBSA for HVI) can include cardiac arrest, ventricular fibrillation, loss of consciousness, and traumatic injuries that result from falls caused by the shock, such as fractures and TBI.

Shih et al. (2017) provide percentages of LVI and HVI admissions with various diagnoses. We identified AIS-80 diagnoses for which Hirsch et al. (1983) provided impairment information that corresponded to the electrical burn conditions listed by Shih et al. (2017). We compiled the Hirsch impairment fractions for these conditions, weighted them by the Shih probabilities, and combined them. We performed these computations separately for LVI and HVI, and then computed the weighted mean of LVI and HVI.

The LVI calculation used these Hirsch diagnoses and Shih percentages:

Amputation	X_MW3	7.3%
Burn, AIS-2	U_BI2	100%

Neither Shih nor other articles we examined specified what body parts were amputated, but there was some indication that upper limbs were the most frequently injured body part, so we used forearm amputation. (We assume that the long-term effects of surgical amputation are similar to those for traumatic amputation.) The resulting LVI impairment fractions for ages 16–45 were

imp1=0.0919
imp2=0.0469
imp6=0.0469

The HVI calculation used these Hirsch diagnoses and Shih percentages:

Amputation	X_MW3	30.2%
Burn, AIS-3	U_BI3	100%
Renal dysfunction	M_CK3	13.9%
Loss of consciousness	HWKB2-01	36.8%
Traumatic brain injury	HWKB2-07	5.1%
Neuropathy	X_LN2	28.0%
Fracture	S_FS2-02	11.8%

For TBI we used AIS-2 concussion, the least severe option in Hirsch. Using cerebral contusion (AIS-3) instead would raise imp1 by only about 0.02 because of the small percentage of cases affected by TBI. For fracture, we assumed it was the of the shoulder, following Gehlen and Hoofwijk (2010), who found that most skeletal injuries resulting from electric shock "are in the upper extremities, especially the shoulders." For renal dysfunction we used kidney contusion. There were other HVI conditions that could have been included, but they had low probabilities (e.g., cataracts, 1.0%). We also did not include psychological conditions (e.g., PTSD) because the III has never included them. The resulting HVI impairment fractions were for ages 16–45 were

imp1=0.55389
imp2=0.31539
imp6=0.24566

Of the injuries Shih et al. (2017) were able to classify, 32% were LVI and 68% were HVI. Using these shares to compute a weighted mean of LVI and HVI, computed multiplicatively:

Ages	imp1	imp2	imp6
0–15	0.38578	0.17119	0.07967
16–45	0.40605	0.17900	0.07967
46–65	0.46904	0.24415	0.11736
66+	0.56578	0.47028	0.34445

These impairment fractions will be applied to hospital-admitted electric shock injuries (NEISS injury diagnosis 67).

We did not find any studies involving non-admitted electrical injuries. However, Czuczman and Zane (2009), in a review aimed at ED doctors, summarize the types and effects of electrical injuries and make treatment recommendations. Their clinical pathway diagram appears to say that all HVI should be treated at burn centers. If doctors follow this practice, then only LVI would ever be treated in the ED and released—and even these would be admitted if they suffered loss of consciousness or any heart condition. We assume surgical amputation of the forearm would require hospital admission, as well. Therefore, the main impact of an ED-treated electric shock is probably just a burn of AIS-2 or less. Therefore, we apply the III's burn impairment fractions to ED-treated electric shocks.

Appendix B. Derivation of the Utility Weight on Work-Related Disability

In recent versions of our injury costing algorithms, we have used different values for the utility weight on the seventh dimension of the Injury Impairment Index, work-related disability, and none of them was adequately documented. As it took some effort to reconstruct the derivation of the weight, we want to take this opportunity to record it in complete detail.

Because this utility weight depends on the value of statistical life (VSL), and PIRE's various clients, including CDC, CPSC, and NHTSA, have used different VSLs at various times, the value of this weight can vary from one project to another. But the different values all come from the same formula:

$$\text{weight7} = [\text{VSL}\times 0.3266 - (\text{lifetime earnings} + \text{lifetime household production})] / \text{VSL}$$

The factor 0.3266 is derived from the Health Utilities Index (HUI), found in Drummond, Stoddart, and Torrance (1987), pp. 119–124. It comes from level 3 of the second dimension of the four-dimensional HUI. This dimension is described as *role function: self-care and role activity*, and the description of level 3 is "Being able to eat, dress, bathe and go to the toilet WITHOUT HELP; AND NOT being able to play, go to school or work." Therefore, this type of impairment (R3) which disallows work but does not hinder other aspects of daily life, appeared to best represent work disability, of the available options. (Higher severity levels in this dimension require help with daily activities, while lower levels permit some work.) The utility weight on impairment R3 is 0.77. Because of the way the HUI works, this must be fed into the formula, $U=1.42\times(m1\times m2\times m3\times m4)-0.42$, where m1–m4 are the utility weights from the HUI's four dimensions. If the victim suffers no disability in the other three dimensions, then this works out to $U=1.42\times(1\times 0.77\times 1\times 1)-0.42=0.6734$. This number represents the share of quality of life that is retained. Thus, its inverse, 0.3266, is the utility loss associated with inability to work.

The tangible benefits of working—income and household production—are included in this figure. Since our cost estimates account for these separately under work loss, they must be subtracted out. CDC assumes a VSL of $9.6 million (in 2014 dollars). Furthermore, CDC assumes a 1.4% rate of annual earnings/productivity growth. Therefore, the computation (in 2014 dollars) is

$$\text{weight7} = (\$9.6 \text{ million} \times 0.3266 - \$1{,}501{,}846) / \$9.6 \text{ million} = 0.170$$

where $1,501,846 is the expected combined lifetime loss of earnings and household production, discounted at 3%. This weight is substantially greater than the weights we have previously used on this dimension—0.0685 for NHTSA and 0.021 for CPSC. This is due entirely to the much higher VSLs that are now in use.

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