Quality-Adjusted Life-Years and Helmet Use Among Motorcyclists Sustaining Head Injuries

Hsin-Yi Lee, PhD, Yeh-Hsin Chen, MS, Wen-Ta Chiu, MD, PhD, Jing-Shiang Hwang, PhD, and Jung-Der Wang, MD, ScD

Objectives. We estimated loss of quality-adjusted life expectancy (QALE) among motorcyclists in Taiwan who sustained head injuries while wearing or not wearing a helmet.

Methods. Patients with head injuries (n=3328) were grouped into categories representing good and poor outcomes (moderate disability or death) at discharge. After linkage with the National Mortality Registry, survival functions were determined and extrapolated over a 50-year period on the basis of the survival ratio between patients and age- and gender-matched reference populations, as calculated from available Taiwan vital statistics. Survival functions were then multiplied by scores from quality-of-life measures.

Results. Percentages of good and poor outcomes were 87.2% and 12.8%, respectively, in the helmeted group and 66.4% and 33.6% in the nonhelmeted group. The mean QALE for helmeted motorcyclists, calculated by weighting percentages of good and poor outcomes, was 31.7 quality-adjusted life-years (QALYs), with an average loss of 5.8 QALYs. For nonhelmeted motorcyclists, the mean QALE was 25.9 QALYs, with a loss of 10.7 QALYs.

Conclusions. Helmet use could save approximately 5 QALYs among motorcyclists sustaining head injuries. Future cost-effectiveness analysis can calculate the incremental cost-effectiveness ratio for regulation of helmet use. (*Am J Public Health.* 2010;100:165–170. doi:10.2105/AJPH.2008.159004)

Motorcycles have become one of the most popular means of transportation in many developing countries, particularly in Asia, because of their convenience, affordability, and relatively high fuel efficiency.[1,2] However, relative to car drivers, motorcyclists are more easily injured, and are more often killed as a result of even minor collisions with other, larger vehicles.

According to traffic accident data from Taiwan's National Police Agency,[3] more than 1100 motorcyclists were killed on the country's roads in 2007, accounting for 59.7% of all traffic accident deaths. Furthermore, 57.1% of all motorcycle-related fatalities involved injuries to the head, thereby indicating a distinct correlation between motorcycle-related injury and head injury.

In a recent review of traffic accidents involving motorcyclists, Liu et al.[4] concluded that if motorcyclists are wearing a helmet at the time of the crash, their risk of death is reduced by 42%, and their risk of head injury is reduced by 69%. These findings have been corroborated in many other studies indicating that, after implementation and enforcement of laws requiring motorcyclists to wear helmets, there are clear reductions in motorcycle-related head injuries, the severity of such injuries, and the overall length of patient hospital stays.[5–7] Nevertheless, relatively few studies have set out to investigate the long-term effects of helmet protection among motorcyclists sustaining head injuries.

Many countries with national health insurance systems have been increasingly faced with a heavy financial burden, essentially as a result of an aging population and new forms of technology (e.g., gene therapy, positron emission tomography). Most of these countries have adopted economic analyses as a means of containing costs associated with medical care and increasing overall cost-effectiveness by improving the health outcomes achieved per dollar spent.[8] One of the most basic methods used to achieve such improvements is that of evaluating the cost per quality-adjusted life-year (QALY) gained from different health care services, an approach applied to ensure that preventive measures are competitive by saving more lives than would treatment after an illness occurs. The fundamental concept involves adjusting the survival function with the mean quality of life at each time point t and then summing this adjusted value over a lifetime. The resulting measure, "quality-adjusted life expectancy" (QALE), is expressed in the following equation[9–13]:

$$(1)\quad \text{QALE} = \int E[Qol(t|x)]\, S(t|x)\, dt,$$

where $S(t|x)$ denotes the survival function for condition x at time t and $Qol(t|x)$ denotes the quality-of-life function for condition x at time t. If an age- and gender-matched referent can be simulated from the vital statistics for every case of condition x, one should be able to calculate the QALE for a general referent (in the present case, if a head injury had not occurred).

The difference between the QALE for head injury cases and referents just noted would be the expected loss of QALE for an average head injury case. In this study, we sought to quantify QALE and expected loss of QALE among motorcyclists in Taiwan who sustained head injuries while wearing or not wearing a helmet and to determine life-years saved as a result of helmet use in such cases.

METHODS

Our primary data source was the Head Injury Registry,[14] a system designed to monitor the epidemiology of traumatic head injuries in Taiwan. The registry includes in the definition of head injuries: brain concussions, contusions, skull bone fractures, brain damage with clear neurological deficits, clinically observable cognitive deficits, posttraumatic amnesia, neurological sequelae, and any evidence of intracranial hemorrhage. Head-injured motorcyclists are defined as motorcycle riders or passengers who, after having sustained direct or indirect trauma to the head, exhibit one or more of the aforementioned diagnoses.

Data on head injuries were recorded by experienced neurosurgeons from each of the hospitals included in the study and extracted by a research assistant from the Injury Prevention Center at Taipei Medical University to ensure consistent data quality. The procedure for ascertaining each case involved a careful review of inpatient medical records, examination of surviving motorcyclists with head injuries admitted to the hospital, review of death certificate data to determine the number of patients who died during the course of their treatment, and review of the deaths that occurred outside the hospital (e.g., at the scene of the accident) through the National Mortality Registry. Registry certificates were issued once a forensic examination indicated that brain injury was the primary cause of death.

Data on 3328 patients hospitalized as a result of motorcycle-related head injuries were collected from 22 major hospitals in Taipei City and 4 hospitals in Hualien County between 2001 and 2007. The Glasgow Outcome Scale[15] was used to categorize head injury outcome at the time of hospital discharge as follows: death, persistent vegetative state, severe disability (conscious but dependent), moderate disability (disabled but independent), or good recovery.

Although our primary aim was to investigate the difference between helmeted and nonhelmeted motorcyclists in terms of loss of QALYs, the outcome of the patient at discharge was considered to be the most important prognostic factor. Thus, in accordance with the Glasgow Outcome Scale, we divided our head injury cohort into 2 categories: those with good outcomes (good recovery) and those with poor outcomes (ranging from moderate disability to death). We used these categories to subsequently estimate and extrapolate survival functions and quality-of-life functions.

Extrapolation of Long-Term Survival

After verifying the survival status of patients by cross linking them with the updated database of the National Mortality Registry at the end of the follow-up period (December 31, 2007), we used the Kaplan–Meier method to estimate survival functions based on 2001 to 2007 follow-up data. Because a high percentage of these patients were still alive at the end of follow-up (survival rates were 92.6% and 85.5% for the helmeted and nonhelmeted groups, respectively), we estimated the lifetime survival function by incorporating life expectancy data from the general population of Taiwan.[11–13,16]

We assumed that head injuries might produce excess mortality, which could be quantified from following-up the cohort for a short period of time (5 years). If this excess mortality appeared to be a constant hazard in the chronic stage (1 or 2 years after the head injury), the long-term survival of our cohort could be projected from a survival function for an age- and gender-matched reference population.[11,12] The survival function of this reference population can be generated, via the Monte Carlo method, from national vital statistics life tables.[12]

Also, we were able to obtain expected and mean quality-of-life values at each study time point by conducting a cross-sectional survey among the patients; these data served to adjust the survival curve.[13] In previous studies involving simulation[11] and mathematical[16] methods, we have shown that this is a valid means of predicting life expectancy, even when the censored rate is above 50%; it has also been corroborated by several real-world examples.[16–19]

Quality-of-Life Values

We used the EuroQol 5-dimensional (EQ-5D) questionnaire, a preference-based, generic, self-reported instrument,[20,21] to estimate quality-of-life values for helmeted and nonhelmeted motorcyclists who sustained head injuries. This instrument has been extensively used as an outcome measure[22–24]; the Chinese version was developed in Taiwan, along with the value categorization used in this study.[25]

The 5 dimensions encompassed in the questionnaire are mobility, self-care, usual activities, pain–discomfort, and anxiety–depression, with 3 levels of severity (no problems, some or moderate problems, and severe or extreme problems). The resulting utility value is coded from 0 to 1 (on the basis of the 5-dimensional classification), where 1 indicates optimal health.[21]

Using computer-generated random numbers, we selected a cross-sectional sample of 600 surviving patients from the Head Injury Registry. Telephone contact numbers were obtained from the members of this sample when they were admitted to the hospital; survivors were subsequently contacted by telephone after their discharge to determine their willingness to participate in our study. In cases in which patients were unable to answer the questionnaire, their family members were invited to provide the necessary information.

Between January and March 2008, 190 patients were successfully interviewed (response rate: 31.7%). Excluding the 20 patients who refused to be interviewed, most of the others who did not respond had changed their telephone number or could not be reached after 3 calls. To examine the representativeness of the interviewed sample, we conducted a supplementary analysis in which we compared selected characteristics (e.g., age, gender, severity of injury) of those who were interviewed, those who could not be reached, and those who refused to be interviewed.

Also, we asked patients who had sustained their injury in 2007 to recall their health condition at the time of their discharge from the hospital, given that their injuries had occurred within a short period before their interview (less than 1.2 years) and recall bias would thus be minimal. As a result, these patients could contribute 2 or more data points of quality of life to our study. We used smoothing methodology to estimate differences in duration of time after occurrence of head injury, and we assumed that the utility value for all hypothetical referents was 1 throughout the survival of the sample patient.

Calculation of Quality-Adjusted Life Expectancy

After calculating lifetime survival functions for the groups with good and poor outcomes, we adjusted these values according to the corresponding quality-of-life function and the period of time after the occurrence of the head injury to calculate QALE on the basis of an 80-month follow-up period and 50 years of extrapolation.[13] Given that the mean age of our cohort was approximately 37 years and the average life expectancy of the Taiwanese population in 2007 was 78.4 years, we believed that a 50-year extrapolation could approximate lifelong utility loss among patients sustaining a head injury.

To facilitate our analyses, we used the software program MC-QAS (http://www.stat.sinica.edu.tw/jshwang), built on the R statistical package. The validity of this program in extrapolating long-term survival data has been established in previous studies, including those focusing on permanent disability from occupational injuries,[17] HIV infection,[16] and cancer.[19] We calculated average QALE values for helmeted and nonhelmeted motorcyclists by weighting the respective percentages of good and poor outcomes and then summing these percentages.

RESULTS

The basic characteristics of the 3328 members of our cohort are summarized in Table 1. There were no significant age or gender differences between helmeted and nonhelmeted motorcyclists. However, the rate of helmet use was much higher in urban Taipei City (71.3%) than in rural Hualien County (28.7%).

Nonhelmeted motorcyclists had longer average intensive care unit stays and worse outcomes at discharge than helmeted motorcyclists. No significant demographic or helmet use differences were observed among patients who were interviewed, those who could not be reached, and those who refused to be interviewed (Table 2), although the proportion of good outcomes at discharge appeared to be slightly lower among respondents than among nonrespondents. Finally, Taipei City residents made up a higher percentage of the interviewed group (70.5%) than they did of the other groups (approximately 50%).

An independent-sample *t* test showed that the mean utility score for poor outcomes was 0.7 (SD=0.3; $P<.01$), significantly lower than the mean utility score for good outcomes (0.9; SD=0.2). Patients with good outcomes were also found to have a longer QALE than those with poor outcomes, as illustrated in Figure 1.

Life expectancies and QALE values, by discharge outcome and helmet use, are summarized in Table 3. After the proportions of the 2 outcome categories were weighted among helmeted and nonhelmeted motorcyclists (Table 1), the QALE of the typical helmeted motorcyclist after 50 years of extrapolation was 31.7 QALYs, representing a loss of 5.8 QALYs relative to a hypothetical age- and gender-matched reference group. Among nonhelmeted motorcyclists, the estimated QALE after 50 years of extrapolation was 25.9 QALYs, with a greater loss (10.7 QALYs) relative to the reference group.

TABLE 1—Frequency Distributions in the Helmeted (n=2879) and Nonhelmeted (n=449) Patient Groups and Between-Group Comparisons: Taiwan, 2001–2007

Characteristic	Helmeted, % or Mean (SD)	Nonhelmeted, % or Mean (SD)	Between-Group Comparison *P*
Age, y	36.6 (16.9)	38.4 (19.6)	.06[a]
No. of days in intensive care unit	1.8 (4.8)	2.9 (5.7)	<.01[b]
No. of days in general hospital ward	8.6 (12.5)	9.7 (13.9)	.31[b]
Male	60.9	65.0	.09[c]
Location of accident			<.001[c]
Taipei City	71.3	45.7	
Hualien County	28.7	54.3	
Outcome at discharge			<.001[d]
Good recovery	87.2	66.4	
Moderate disability	4.6	9.6	
Severe disability	2.6	9.3	
Vegetative state	1.0	3.8	
Death	4.6	10.9	

[a]By the *t* test.
[b]By the Mann-Whitney test.
[c]By the χ^2 test.
[d]By the Cochran-Armitage trend test.

DISCUSSION

Although previous studies have documented the protective effects of helmets in reducing mortality and improving short-term outcomes among motorcyclists,[4–7,26] relatively few of these studies have focused on the long-term health benefits of wearing a helmet. One of the major challenges faced in such research is that most patients who have sustained head injuries survive for long periods. If a head injury cohort is not followed for a sufficiently long period, the result is often a high censored rate (above 50%), and the research team would not be able to obtain the lifetime survival function for estimation of QALE required by the conventional method.[27] To the best of our knowledge, ours is the first study of its kind to estimate the lifelong utility losses of helmeted and nonhelmeted motorcyclists sustaining head injuries. To determine the validity of our basic assumption, a constant excess mortality rate associated with head injuries, we initially estimated the QALE of patients with head injuries according to outcome at discharge. This strategy helped ensure the homogeneity of our subcohorts, with a stable survival ratio relative to the reference population after the first several years of follow-up.

The percentage of good outcomes was higher among helmeted motorcyclists (87.2%) than among nonhelmeted motorcyclists (66.4%), and thus the weighted average QALE loss in the helmeted group was below that of the nonhelmeted group (5.8 versus 10.7). In other words, use of a helmet can save an average of approximately 5 QALYs among individuals sustaining head injuries as a result of motorcycle accidents.

In an earlier study, Tsauo et al.[28] found that the average QALE loss for a single head injury case was 4.8 QALYs, lower than the values we found (Table 3). The difference in these findings may be attributable to a pair of factors. First, there was a 12-year gap in the data periods used in the 2 studies. The QALE loss in our study relative to the reference population might have been slightly increased because there was a 2-year increase in the average life expectancy of the general population[29] at the time of our study as compared with the average at the time of the Tsauo et al. study.

TABLE 2—Comparison of Characteristics Among Patients With Head Injuries Who Were Interviewed (n = 190), Who Could Not Be Contacted (n = 390), and Who Refused to Be Interviewed (n = 20): Taiwan, 2001–2007

Characteristic	Interviewed, % or Mean (SD)	Not Contacted, % or Mean (SD)	Refused, % or Mean (SD)	Between-Group Comparison *P*
Age, y	36.7 (17.9)	39.4 (19.5)	42.7 (20.1)	.19[a]
No. of days in intensive care unit	3.5 (7.2)	3.3 (7.7)	3.5 (5.7)	.94[a]
No. of days in general hospital ward	8.6 (12.9)	8.4 (19.1)	10.9 (23.5)	.81[a]
Male	59.5	62.3	55.0	.68[b]
Location of accident				<.001[b]
Taipei City	70.5	51.3	50.0	
Hualien County	29.5	48.7	50.0	
Outcome at discharge				.22[b]
Good recovery	76.8	80.8	70.0	
Moderate disability	9.5	5.6	5.0	
Severe disability	5.8	5.6	5.0	
Vegetative state	2.6	2.3	0.0	
Missing	5.3	5.6	20.0	
Helmet use	85.5	79.6	89.5	.2[b]
Year admitted				.2[b]
2001–2002	5.8	3.8	5.0	
2003	21.6	23.8	15.0	
2004	15.3	16.9	30.0	
2005	20.0	16.2	15.0	
2006	26.8	30.3	10.0	
2007	10.5	9.0	25.0	

[a]By analysis of variance.
[b]By the χ^2 test.

Second, Tsauo et al.[28] included only cases occurring within Taipei City, where the rate of good outcomes at discharge (88.2%) tends to be higher than that of our cohort from Taipei and Hualien. Although they did not report the percentage of helmet use in their study population, the rate of good outcomes in their study is comparable to the rate among helmeted motorcyclists in our study (87.2%) and much higher than that among nonhelmeted motorcyclists (66.4%), whose life expectancy would presumably be shorter.

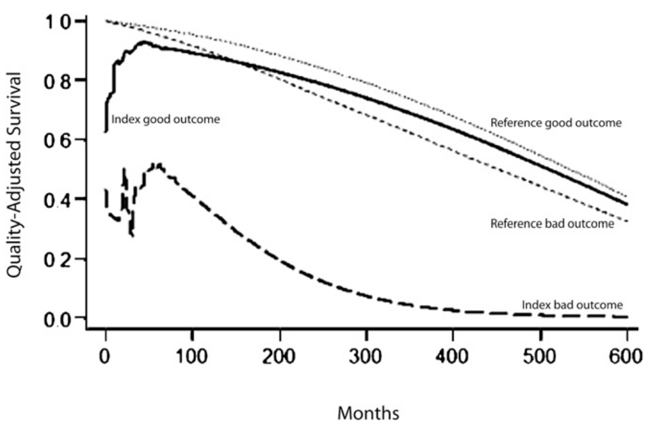

FIGURE 1—Quality-adjusted life expectancy among patients with head injuries and the reference population after 50 years of extrapolation, by outcome at discharge: Taiwan, 2001–2007.

Study Limitations and Strengths

One of the major limitations of our study was the low response rate (31.7%). As mentioned, to examine the representativeness of the sample, we compared the characteristics of respondents and nonrespondents. Although nonrespondents were more common in Hualien County, there were no significant between-group differences in terms of age, gender, number of days spent in intensive care units or general wards, helmet use rates, and distribution of years of admittance (Table 2). Most important, there were no differences with respect to the major determinant of both survival and quality of life: outcome at time of discharge. Thus, our sample appears to be relatively representative.

Another possible limitation is the validity of the quality-of-life measure among patients with severe head injuries, given that such patients suffer from cognitive impairment.[30,31] During the interviews, only 5 patients were unable to answer the questionnaire because they had been in a vegetative state since their accident. In these instances, we invited patients' family members (caregivers) to answer the questionnaire if they agreed, and they usually assigned the lowest score in all 5 EQ-5D dimensions.

Under such conditions, it was difficult to accurately validate the quality of life perceived by patients themselves and compare the results with those reported by caregivers. Nonetheless, differences may have been relatively small given that the EQ-5D included only 3 levels of severity (no problems, some or moderate problems, severe or extreme problems). Moreover, considering that these patients accounted for only 2.6% of the patients interviewed, we believe that the potential overall bias is small.

It should be kept in mind that speed limits in Taipei City and Hualien County were 50 km/h and 60 to 70 km/h, respectively, and motorcycles were prohibited on freeways. Therefore, percentages of poor outcomes in our study areas may have been lower than those in areas with higher speed limits. Higher speeds can produce more severe injuries[32] as well as greater loss of health-related utility.

TABLE 3—Life Expectancy and Quality-Adjusted Life Expectancy (QALE) in Years, by Outcome at Discharge and Helmet Use: Taiwan, 2001–2007

	Life Expectancy		QALE	
	80-Month Follow-Up, Mean or Mean (SE)	50-Year Extrapolation, Mean or Mean (SE)	80-Month Follow-Up, Mean or Mean (SE)	50-Year Extrapolation, Mean or Mean (SE)
Good outcome at discharge				
Head injury patients	6.4** (0.03)	36.7* (6.2)	5.9** (0.5)	35.3** (5.8)
Reference population		38.0* (0.02)		38.0** (0.02)
Difference		1.3		2.8
Poor outcome at discharge				
Head injury patients	4.1** (0.2)	9.6* (5.6)	2.9** (0.2)	7.6** (4.6)
Reference population		34.0* (0.03)		33.9** (0.7)
Difference		24.4		26.3
Helmeted motorcyclists with head injury				
87.2% good outcome + 12.8% bad outcome	6.1	33.2	5.5	31.7
Expected life loss relative to reference population		4.3		5.8
Nonhelmeted motorcyclists with head injury				
66.4% good outcome + 33.6% bad outcome	5.7	27.6	4.9	25.9
Expected life loss relative to reference population		9.1		10.7

*$P < .01$; **$P < .001$, for between-group comparison of good versus poor outcome at discharge. Between-group differences were assessed via the log-rank test (80-month follow-up) and the z statistic (50-year extrapolation).

Conclusions

Use of a helmet can save an average of approximately 5 QALYs among individuals sustaining head injuries as a result of motorcycle accidents. Economic evaluations (e.g., cost-effectiveness and cost-utility analyses) generally involve a comparative analysis of alternative courses of action in terms of their costs and consequences.[8] By quantifying consequences, we successfully estimated the expected utility, in terms of QALYs, that would have accrued to motorcyclists wearing a helmet during an accident in which they sustained a head injury. Such results can be applied in future assessments of the value of mandatory helmet legislation for motorcycle riders.

The next step involves identifying the difference in costs (e.g., to the health care sector, to patients and families) associated with mandatory legislation and lack of regulation. Future cost-utility or cost-effectiveness analyses can calculate the incremental cost-effectiveness ratio for regulation of helmet use (i.e., the cost per QALY gained by wearing a helmet). If the human capital or productivity saved by prevention can be converted to monetary values, cost-benefit analyses can also be performed by summing direct medical costs and indirect productivity losses.[33] ■

About the Authors

Hsin-Yi Lee, Yeh-Hsin Chen, and Jung-Der Wang are with Institute of Occupational Medicine and Industrial Hygiene, College of Public Health, National Taiwan University, Taiwan, Republic of China. Wen-Ta Chiu is with the Institute of Injury Prevention and Control, Taipei Medical University, Taiwan. Jing-Shiang Hwang is with the Institute of Statistical Science, Academia Sinica, Taiwan. Jung-Der Wang is also with the Department of Internal Medicine and the Department of Environmental and Occupational Medicine, National Taiwan University Hospital.

Correspondence should be sent to Jung-Der Wang, MD, ScD, Institute of Occupational Medicine and Industrial Hygiene, College of Public Health, National Taiwan University, Room 719, No. 17, Xu-Zhou Road, Taipei 10055, Taiwan (e-mail: jdwang@ntu.edu.tw). Reprints can be ordered at http://www.ajph.org by clicking the "Reprints/Eprints" link.

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Contributors

H.-Y. Lee conducted the data analyses and contributed to the writing of the article. Y.-H. Chen assisted in the quality-of-life assessment and conducted the initial statistical analyses. W.-T. Chiu contributed to the collection of quality-of-life data. J.-S. Hwang supervised the statistical analyses. J.-D. Wang originated the study, supervised the analyses, and led the writing.

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Human Participant Protection

This study was approved by the National Taiwan University institutional review board. Participants provided verbal informed consent before their interviews.

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