Original article

Scand J Work Environ Health 2012;38(1):70-77

doi:10.5271/sjweh.3194

Estimation of life expectancies and loss-of-life expectancies for workers with permanent occupational disabilities of the extremities – a 21-year follow-up study

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Refers to the following texts of the Journal: 1982;8(3):153-158 2006;32(2):91-99 2002;28(5):328-332

Key terms: amputee; disability; life expectancy; loss-of-life expectancy; lower extremity; occupation; occupational disability; permanent disability; prevention; worker

This article in PubMed: www.ncbi.nlm.nih.gov/pubmed/21912828

Scand J Work Environ Health 2012;38(1):70–77. doi:10.5271/sjweh.3194

Estimation of life expectancies and loss-of-life expectancies for workers with permanent occupational disabilities of the extremities – a 21-year follow-up study

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Lin S-H, Lee H-Y, Chang Y-Y, Jang Y, Wang J-D. Estimation of life expectancies and loss-of-life expectancies for workers with permanent occupational disabilities of the extremities – a 21-year follow-up study. *Scand J Work Environ Health*. 2012;38(1):70–77. doi:10.5271/sjweh.3194

Objectives This study aims to estimate the life expectancies and loss-of-life expectancies of workers with permanent occupational disabilities of the upper and lower limbs in Taiwan.

Methods We collected all cases of permanent occupational disability in the upper and lower limbs from the Bureau of Labor Insurance database of compensation claims between 1986–2006; these data were linked with the national mortality registry to obtain a survival function. Workers were divided into eight groups according to their injury types, three of which fulfilled the condition of constant excess hazard and the survival functions were extrapolated to 50 years using a semi-parametric method.

Results Of the subjects involved in the study, 1016 with toe amputations, 995 with foot or leg amputations, and 4339 with foot or leg non-amputations showed a life expectancy of 1.8 [95% confidence interval (95% CI) -1.3– -4.9], 4.9 (95% CI 2.2– -7.6), and 4.5 (95% CI 2.1– -6.9) years, respectively. The above method was validated by extrapolating partial cohorts based on the first 10 years of follow-up data to 21-year and comparing actual survival rates using the Kaplan Meier method. The relative bias of three groups was <8%.

Conclusions The semi-parametric extrapolation method is a feasible and accurate approach for projecting life expectancy and expected years of life lost for groups with occupational amputations of the lower extremities. The value of life lost among these groups should be considered when determining compensation for these workers and assessing the cost-effectiveness of preventive occupational health services.

Key terms amputee; disability; lower extremity; occupation; prevention.

Traumatic upper- and lower-extremity disability results in significantly reduced physical and psychological well-being and is a very common but severe health problem among workers. Many studies have reported short-term mortality associated with lower-limb amputation or other risk factors among these patients (1–3). Most of the subjects of these studies received surgical amputations, with diagnoses that included occlusive vessel disease, diabetes mellitus, osteosarcoma, and infection, which are often major determinants of the long-term mortality of these patients. To our knowledge, relatively few studies have investigated the long-term survival of patients with traumatic disabilities of the upper or lower extremities caused by accidental injury because such disabilities are usually not believed to reduce life expectancy.

Hwang et al (4) have developed a semi-parametric method to incorporate the life expectancy of a background general population into the estimation process for cohorts with life-threatening conditions such as

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HIV (5) or cancer (6, 7). That method was also applied in the estimation of life expectancy for workers with permanent occupational disabilities from 1986–2000 and demonstrated that the expected loss-of-life expectancy varied between 5–19 years, depending on the grade of major physiological dysfunction and injury type (8, 9). However, the above results cannot be directly applied to workers with less severe, more specific impairments such as amputation of the upper and lower extremities. The aforementioned cohort was followed up through 2006, providing an opportunity to evaluate the long-term survival of these physically challenged workers. The objective of this study was to estimate the life expectancy and loss-of-life expectancy of workers with permanent occupational disabilities of the lower and upper extremities, including amputees and non-amputees.

Methods

Study population

In Taiwan, the Bureau of Labor Insurance (BLI) has administered a compensation scheme for workers since 1950. A historical prospective study was carried out based on the computerized registry established by the BLI, which included all cases of permanent disability from 1986–2006 that resulted in compensation. According to statements released by the BLI in Taiwan, the term "approved compensation claim for permanent occupational disability" (ACCPOD) indicated that the disabilities of affected workers were caused by occupational injuries or diseases and that they were unable to recover within one year under medical care, regardless of whether they were able to return to work (www.bli.gov.tw/File.aspx?uid=NS%2B%2Fve99M9Q%3D). In total, the computerized registry consisted of 106 437 compensation claims for permanent occupational disability resulting from work-related injuries and included details of workers' gender, age on date of injury, type of disability and accident, body part affected, and monthly insured salary. Initially, 4745 cases were excluded due to incomplete information on gender, age on date of injury, or body part affected. Because the primary aim of this study was to determine whether people with single injuries of the extremities have reduced life expectancies, we only included subjects with a single disability in our analysis. Thus, we excluded 18 605 cases of individuals with more than one type of disability. Among these excluded cases, 12 237 were compensated in one single application, while the other 3049 subjects suffered from 6368 times of recurrent injuries. We also excluded 11 907 cases that involved injury locations other than the upper or lower extremities. As summarized in figure 1, a total of 71 001 cases remained for our analysis.

Among those individuals included in this study, 8017 suffered from injuries of the lower extremities and 62 984 suffered from injuries of the upper extremities. We further stratified these cases into four categories of injury: "toes only," "leg or foot," "fingers", and "hand or arm." Each of these four categories was further divided into amputee and non-amputee groups, which resulted in a total of eight groups analyzed in this study. According to the BLI, an amputation is defined as more than half of a segment cut off; patients with all other kinds of disability that did not result in amputation were classified as non-amputatees. The survival status of the individual in each case was tracked through the end of December 2006 and was verified with the National Mortality Registry (NMR) in Taiwan. The NMR, established in 1950, is maintained by the Department of Health of the Executive Yuan (or institute). It is the most reliable official database for certificates of death in Taiwan and has been computerized since 1981 (10). In this study, we linked the personal identification (ID) number of compensated individuals from the BLI registry to the NMR database. If a worker was found to have a record in the mortality registry under the same ID number, then the date and cause of death could be accurately confirmed. If this verification was not possible, the individual was considered to be either alive or to have had his or her record censored sometime prior to 31 December 2006. Because the annual emigration rate for Taiwan was generally below 0.1% from 1986–2000, and most emigrants still pay their premiums and keep their insurance under the National Health Insurance program due to its comprehensive coverage, the loss to follow-up among censored subjects was very low after comprehensive linkage with the data of NMR. Foreign workers were not included in this study because they have not been given ID numbers and hence their survival status could not be verified.

Method of extrapolating survival functions to lifetime

After the aforementioned procedure, we obtained the survival functions of eight different groups. As most of these workers survived past the 21-year follow-up period, we adopted a method of extrapolation to estimate the mean and 95% confidence interval (95% CI) of the lifetime survival for different types of disability. The general method of extrapolation used in this study was to assume that a disease can produce premature mortality (or excess hazard), which can be quantified based on the follow-up of the patient cohort for a shorter period of time (4, 11). If the excess mortality in the study population appears to be a constant hazard

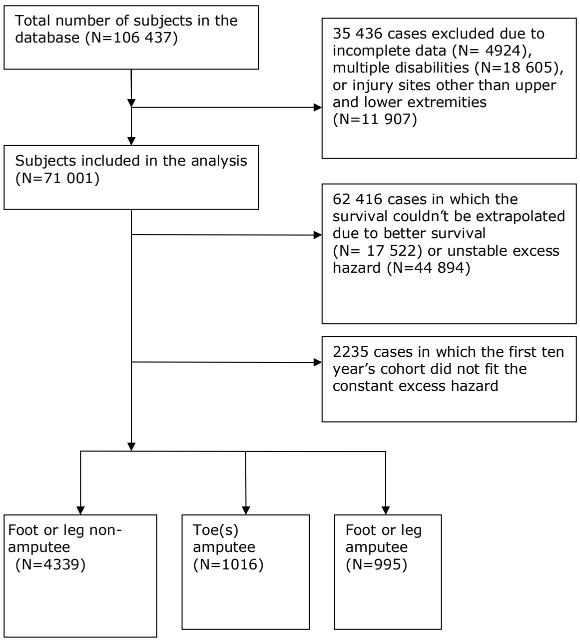

Figure 1. Flow chart of selection of subjects

compared with the age- and gender-matched reference population during the first several years of follow-up, we then use information from the reference population for further extrapolation. We applied the Monte Carlo method to generate the lifetime survival function for this matched reference population by incorporating data (or hazard functions) from national vital statistics. Finally, if the assumption of constant excess hazard holds, then the logit-transformed survival ratio, indicated by $W(t)$, between the study and reference population becomes linear during the later follow-up period, and the estimated regression line can be used to extrapolate lifelong survival beyond the follow-up period (5). We have simulated (11) and mathematically proven (5) that this is a valid method for predicting the life expectancy under a high censored rate, which is also corroborated by several real examples (5, 7, 9).

In order to verify whether the above method of extrapolation can be appropriately applied to workers with permanent occupational disabilities of the upper and lower extremities, we first checked the temporal trend of logit $W(t)$ during the first 21 years in each group. For each subject with a permanent disability, 100 age- and gender-matched referents were simulated from the life tables of vital statistics of Taiwan using the Monte Carlo method. If the hazard function for the population with permanent disabilities of the upper and lower extremities is proportional to that of the reference population at each time t, then the logit transformation of the ratio $W(t)$ will become linear after the follow-up period; the slope of that line can then be used to extrapolate long-term survival beyond the follow-up period. This sampling and estimation procedure was repeated 100 times to obtain 100 projected estimates of survival and 100 bootstrap standard errors.

Validation of the Monte Carlo extrapolation

The validation of the actual performance of the Monte Carlo extrapolation for workers with permanent occupational disabilities of the upper and lower extremities was performed on a sub-cohort of the study population that included workers with occupational injuries occurring between 1986–1995. Assuming that those patients were only followed until the end of 1995 (for the first ten years), we extrapolated their survival data through the end of 2006 using the Monte Carlo method. Because this sub-cohort was actually followed until the end of 2006, the actual observations at the end of the 21-year follow-up period calculated with the Kaplan-Meier method were considered the gold standard. In addition, we defined "relative bias", which is the indicator of the accuracy of our estimation, as the value of difference between the actual observations calculated using the Kaplan-Meier method and the Monte Carlo simulation results, divided by the Kaplan-Meier estimate.

We also defined "health gap" as the value of loss-of-life expectancy of the cohort of interest divided by the life expectancy of the age- and gender-matched general population.

Results

Characteristics of subjects

As summarized in table 1, the studied population groups were male-dominant; the proportions of male worker ranged from 74.0–87.6%. The mean age for each group ranged from 36.5–45.3 years old. The average of follow-up time among eight groups ranged from 6.9–12 years. The total follow-up person-years are summarized in table 1. The numbers of deceased individuals in the final three subgroups that were able to be extrapolated were 118, 391, and 175 for toe amputees, foot or leg non-amputees, and foot or leg amputees, respectively. The monthly insured salary for each group was between NTD $22 964–27 328 (equivalent to between USD $706.60–840.90). This salary was comparable to the average monthly salary of the employed population of Taiwan (NTD $27 404 or USD $ 843.20) (http://www.bli.gov.tw). Three groups, consisting of finger amputees, finger non-amputees, and hand or arm amputees, appeared to have lower adjusted average monthly

Table 1a. Frequency distribution of subjects stratified by demographic factors and amputee injury types. [NTD=New Taiwan Dollar]

	Finger amputees [a] (N=15 855)			Hand or arm amputees [b] (N=1404)			Toe amputees [c] (N=1016)			Foot or leg amputees [d] (N=995)		
	Mean	SD	%	Mean	SD	%	Mean	SD	%	Mean	SD	%
Proportion deceased			7.4			8.7			11.6			17.6
Male gender			76.0			81.5			85.8			87.6
Age at injury (years)	36.6	12.1		36.9	12.3		40.1	12.8		42.4	12.5	
Calendar year of injury												
1986–1990			26.8			28.7			19.8			23.7
1991–1995			28.9			30.7			27.3			27.6
1996–2000			22.4			21.2			25.1			23.5
2001–2006			22.0			19.4			27.9			25.1
Insured salary at injury												
<20 000 NTD [e]			53.0			52.0			40.1			40.5
20 000–30 000 NTD [e]			29.6			29.7			32.5			31.6
30 000–40 000 NTD [e]			9.3			10.7			14.9			16.0
40 000–50 000 NTD [e]			7.2			7.5			12.1			11.9
>50 000 NTD [e]			0.9			0.2			0.5			0.1
Insured salary (NTD) [e]	22 964	8765		23 165	8588		25 370	9716		25 220	9512	
Injury type												
Fallen to lower level			0.1			0.7			1.1			2.4
Slipped, tripped, or stumbled			0.1			0.3			0.6			2.0
Struck by sliding object or knocked down			1.2			1.7			16.8			18.0
Trapped or caught in machinery			76.7			70.8			47.4			20.1
Cuts, lacerations, or punctures			20.0			15.8			15.9			9.5
Transportation incidents			0.5			2.6			11.2			35.4
Other			1.4			8.1			6.9			12.7

[a] Total follow-up person-years=190 260.
[b] Total follow-up person-years=14 809.
[c] Total follow-up person-years=10 668.
[d] Total follow-up person-years=10 547.
[e] USD 1.00=NTD 32.5 in 2006.

insurance salaries. Up to 70% or more of all disabilities of the upper extremities were caused by individuals becoming trapped or caught in machinery, except among the hand or arm non-amputee subgroup (table 1). In contrast, more than one-third of injuries in the foot or leg amputee and non-amputee subgroups were the result of transportation incidents.

Life expectancy and loss-of-life expectancy for three subgroups

Data analysis revealed a violation of constant excess hazard for the following five subgroups: (i) toe non-amputee; (ii) finger amputee; (iii) finger non-amputee; (iv) hand or arm amputee; and (v) hand or arm non-amputee. We therefore performed Monte-Carlo extrapolations only on the following three subgroups: toe amputee; foot or leg amputee; and foot or leg non-amputee. The estimates of loss-of-life expectancy compared with the general population among all groups varied between 1.8–4.9 years, while the health gaps ranged from 5.6–17.7%, as shown in table 2 and figure 2.

Validation of extrapolation

In order to examine the validity of the Monte-Carlo method in the above three groups, we extrapolated the cohorts established between 1986–1995 (10 years) for an additional 11 years and then compared the results with actual survival derived from Kaplan-Meyer estimation of the 21 years of follow-up from 1986–2006 (table 2). The relative bias in the survival estimation for both the toe amputee and foot or leg amputee groups was <2%, while that of the foot or leg non-amputee group was about 8%.

Discussion

There have been several studies investigating the survival of subjects with lower-limb amputations. However, most of the subjects' limbs were amputated due to chronic diseases such as diabetes mellitus, peripheral arterial occlusive disease, and osteosarcoma (1–3,

Table 1b. Frequency distribution of subjects stratified by demographic factors and non-amputee injury types. [NTD=New Taiwan Dollar]

	Finger non-amputees [a] (N=43 690)			Hand or arm non-amputees [b] (N=2235)			Toe non-amputees [c] (N=1667)			Foot or leg non-amputees [d] (N=4339)		
	Mean	SD	%	Mean	SD	%	Mean	SD	%	Mean	SD	%
Proportion deceased			6.6			8.2			7.7			9.0
Male gender			76.4			74.0			86.2			78.1
Age at injury (years)	36.5	12.1		45	10.9		39.1	11.9		45.3	10.9	
Calendar year of injury												
1986–1990			28.0			16.0			21.8			14.5
1991–1995			26.5			7.5			25.1			5.8
1996–2000			21.8			13.9			23.8			16.4
2001–2006			23.6			62.6			29.3			63.3
Insured salary at injury												
<20 000 NTD [e]			51.9			26.4			34.7			26.4
20 000–30 000 NTD [e]			29.1			38.4			36.5			38.3
30 000–40 000 NTD [e]			10.3			20.9			14.8			19.6
40 000–50 000 NTD [e]			8.0			14.3			12.4			15.7
>50 000 NTD [e]			0.8			0.0			1.7			0.1
Insured salary (NTD) [e]	23 301	8996		27 244	9361		26 155	9997		27 328	9582	
Injury type												
Fallen to lower level			0.2			14.1			1.7			15.2
Slipped, tripped, or stumbled			0.3			13.6			0.9			11.4
Struck by sliding object or knocked down			1.5			13.9			20.0			18.7
Trapped or caught in machinery			74.4			15.0			47.8			7.7
Cuts, lacerations, or punctures			21.5			4.5			13.9			3.1
Transportation incidents			0.7			32.5			10.1			38.3
Other			1.4			6.3			5.6			5.7

[a] Total follow-up person-years=519 911
[b] Total follow-up person-years=16 092
[c] Total follow-up person-years=18 004
[d] Total follow-up person-years=29939
[e] USD 1.00=NTD 32.5 in 2006

Table 2. Frequency distributions and estimates of life expectancies and loss-of-life expectancies for three cohorts in which the long-term survival could be extrapolated by Monte-Carlo simulation: from 21–50 years. [95% CI=95% confidence interval.]

	Foot or leg amputees				Toe amputees				Foot or leg non-amputees			
	N	Mean	%	95% CI	N	Mean	%	95% CI	N	Mean	%	95% CI
Cases	995				1016				4339			
Proportion deceased			17.6				11.6				9.0	
Mean extrapolation by Monte Carlo method from 10–21 (years)		17.6		16.8–18.4		18.6		16.1–21.1		16.7		11.6–21.8
Mean survival up to 21 years based on actual observations calculated by Kaplan-Meier method (years)		17.9		17.5–18.3		18.9		18.5–19.3		18.1		17.7–18.5
Relative bias [a]			-1.7				–1.6				–7.7	
Mean lifetime survival based on Monte Carlo method (years) [b]		27.7		24.6–30.8		32.4		29.3–35.5		27.0		24.6–29.4
Mean loss of life expectancy based on Monte Carlo method (years) [b]		4.9		2.2–7.6		1.8		–1.3–4.9		4.5		2.1–6.9
Health gap			17.7				5.6				16.7	

[a] Relative bias=(difference between Kaplan-Meier observations and Monte Carlo simulation) / Kaplan-Meier observations
[b] Based on age- and gender-matched general population

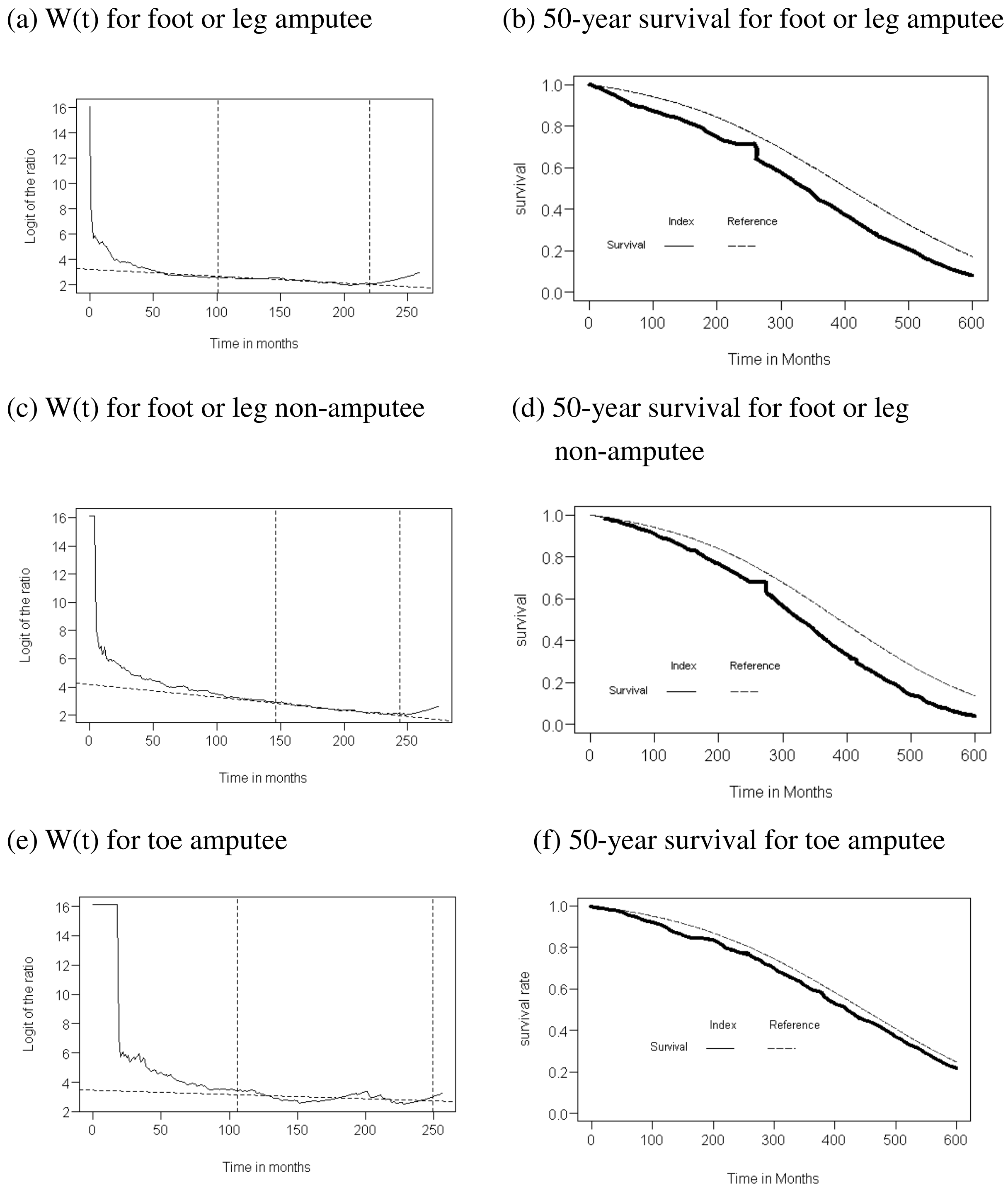

Figure 2. a, c, and e depict the logit transformation of the survival ratio *W(t)* between the survival functions of three groups and those of the age- and gender-matched reference population generated by the Monte Carlo method. The three groups consist of foot or leg non-amputees, foot or leg amputees, and toe amputees, of which the long-term survival is appropriate to extrapolate by Monte-Carlo simulation; b, d, and f depict the predicted 50-year survival curve for these three groups.

12). To our knowledge, this study is the first to estimate the long-term survival of people with traumatic disabilities of the upper and lower extremities by using the semi-parametric extrapolation method. Our results showed that the life expectancies of workers with toe amputations, foot or leg amputations, and foot or leg amputees were 32.4, 27.7, and 27.0 years, respectively, while their average loss-of-life expectancy were 1.8, 4.9, and 4.5 years, respectively (table 2). These results were carefully validated by calculating the relative biases, which were relatively small except for the estimate of the foot or leg non-amputee subgroup. However, because the 95% CI for the loss-of-life expectancy of the toe amputee subgroup included 0 years, we should not make any strong inferences based on those results.

The major reason why the people in these three groups died prematurely was demonstrated in one of our previous studies (13). This showed that workers with permanent occupational disabilities of lower extremities tend to die from diabetes mellitus, cerebrovascular disease, liver cirrhosis, and chronic renal failure, with increased standard mortality ratios (SMR) of 7.66, 2.40, 2.07, and 5.09, respectively. In addition, this study also found that the survival function of workers with disabilities of the upper extremities could not be extrapolated using this method because of the violation of the assumption of constant excess hazard. In fact, these workers still suffered from increased mortalities from suicide, transportation fatalities, and other injuries, but their causes of deaths did not constitute a constant mortality rate for their survival curve.

This study has at least two major implications. First, it quantified the amount of loss-of-life expectancy due to occupational injury, which can be used in future cost-effectiveness analyses aimed at helping prevent such injuries. Although this study did not show the lifetime medical cost for such injuries, we have demonstrated that the prevention of a case of foot or leg amputation can save about 4.9 life-years, while preventing a foot or leg injury that does not result in amputation can save about 4.5 life-years. Second, while most countries' current system of worker's compensation provides some form of income supplementation for injured workers, none have incorporated compensation for the reduction in workers' life expectancy. Based on the theory of justice to preserve one's own capabilities and possibly to compensate others for the loss-of-life expectancy (14, 15), we recommend that future improvements to compensations systems take reduction in life expectancy into account.

Study limitations

Although we have used the most comprehensive national data currently available in Taiwan, this study has some limitations. First, life expectancy is also a function of comorbidity. Besides age, gender, and the occurrence of occupational disability of the upper or lower extremities, there are many other risk factors, including underlying chronic diseases, lifestyle, and socioeconomic status, that determine people's life expectancy. As subjects included in this study were young or middle-aged workers with an average age ranging between 36.5–45.3 years (table 1), the extent to which comorbidity of chronic diseases confounds our results might not be very large.

Second, all subjects were actively employed; they were healthy workers who would have had better baseline health conditions and reduced mortality compared to the general population had the work-related injuries not occurred (16, 17). Thus, our study mildly underestimated the reduction in life expectancy associated with disability. Moreover, the lifetime extrapolation is based on the life tables established by current and previous vital statistics. Because health technology continues to improve, such a method could easily underestimate the actual survival of workers in the future, including those with permanent occupational disabilities of the lower extremities. Thus, our estimations of life expectancy and loss-of-life expectancy for these workers are conservative and must be constantly adjusted to reflect the most current data.

Concluding remarks

Workers who sustained occupational injuries and possessed permanent disabilities of the foot or leg were found to have a loss-of-life expectancy of 4.9 years when their injuries resulted in amputation and 4.5 years when they did not. We have also demonstrated that the semi-parametric extrapolation method is feasible and accurate for predicting life expectancy and expected years-of-life-lost for cohorts with permanent occupational disabilities. In the interest of fairness, we recommend that such losses be taken into consideration in workers' compensation systems. In addition, these results can be used to assess the cost-effectiveness of preventive occupational health services.

Acknowledgements

This study is supported partially by a grant from the Institute of Occupational Safety and Health (IOSH) of the Council of Labor Affairs, Executive Yuan of Taiwan (No. IOSH97-M101) and another grant from the National Science Council (NSC 96-2628-B-002-071-MY3).

We are indebted to the Bureau of Labor Insurance of Taiwan for kindly providing the database of worker's compensation during 1986–2006.

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Received for publication: 24 September 2010