Comparative risk and impact assessment for occupational and environmental health

Jung-Der Wang, M.D., Sc. D.
College of Public Health,
National Taiwan University
National Taiwan University Hospital
Outlines

Concepts of quality-adjusted life expectancy with QALY as a common unit

Examples

- Underground water pollution
- Enforcement of helmet law
- Occupational lead exposure for women

Score-time via psychometry and lifetime cost of illness
Quantification of burdens of diseases

- Quality-adjusted life year (QALY)
- Disability-adjusted life year (DALY)
Quality adjusted life year (QALY) gained from an intervention

Calculation of QALY:
\[ QALY = S \times \text{Quality of life in state } i \]
\[ \text{model the probability of state change} \]
RISK (BS8800)

Likelihood of the event
(Incidence rate or probability after a period of time)

Consequence of the event
(loss of utility due to the event)

Impact of a health setting
Estimated survival function, mean QOL and quality adjusted survival curve; The area under the QAS curve is the expected quality adjusted survival time.

Quality-adjusted life expectancy (QALE)

\[ \int E[Q_{ol}(t|x_i)]S(t|x_i)dt \]

- By adjusting survival function with the mean of QOL at every time point
- Summing up throughout lifetime
- A common unit of QALY
Notation of a typical life table with added columns of QOL (quality of life) and QAST (quality adjusted survival time)

<table>
<thead>
<tr>
<th>Interval</th>
<th>Number Lost to Follow-up</th>
<th>Number Withdrawn Alive</th>
<th>Number Dying</th>
<th>Number Entering Interval</th>
<th>Number Exposed To Risk</th>
<th>Conditional Proportion Dying</th>
<th>Conditional Proportion Surviving</th>
<th>Cumulative Proportion Surviving</th>
<th>QOL(ti)</th>
<th>QAST</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_1 - t_2$</td>
<td>$l_1$</td>
<td>$W_1$</td>
<td>$d_1$</td>
<td>$n'_1$</td>
<td>$n_1$</td>
<td>$\hat{q}_1$</td>
<td>$\hat{p}_1$</td>
<td>$\hat{s}(t_1) = 1.00$</td>
<td>$qol(t_1)$</td>
<td>$QS_1$</td>
</tr>
<tr>
<td>$t_2 - t_3$</td>
<td>$l_2$</td>
<td>$W_2$</td>
<td>$d_2$</td>
<td>$n'_2$</td>
<td>$n_2$</td>
<td>$\hat{q}_2$</td>
<td>$\hat{p}_2$</td>
<td>$\hat{s}(t_2)$</td>
<td>$qol(t_2)$</td>
<td>$QS_2$</td>
</tr>
<tr>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
</tr>
<tr>
<td>$t_i - t_i + 1$</td>
<td>$l_i$</td>
<td>$W_i$</td>
<td>$d_i$</td>
<td>$n'_i$</td>
<td>$n_i$</td>
<td>$\hat{q}_i$</td>
<td>$\hat{p}_i$</td>
<td>$\hat{s}(t_i)$</td>
<td>$qol(t_i)$</td>
<td>$QS_i$</td>
</tr>
<tr>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
</tr>
<tr>
<td>$t_s - 1 - t_s$</td>
<td>$l_{s-1}$</td>
<td>$W_{s-1}$</td>
<td>$d_{s-1}$</td>
<td>$n'_{s-1}$</td>
<td>$n_{s-1}$</td>
<td>$\hat{q}_{s-1}$</td>
<td>$\hat{p}_{s-1}$</td>
<td>$\hat{s}(t_{s-1})$</td>
<td>$qol(t_{s-1})$</td>
<td>$QS_{s-1}$</td>
</tr>
<tr>
<td>$t_s - \infty$</td>
<td>$l_s$</td>
<td>$W_s$</td>
<td>$d_s$</td>
<td>$n'_{s}$</td>
<td>$n_s$</td>
<td>$\hat{q}_s$</td>
<td>$0$</td>
<td>$\hat{s}(t_s)$</td>
<td>$qol(t_s)$</td>
<td>$QS_s$</td>
</tr>
<tr>
<td>Group</td>
<td>No.</td>
<td>Age of diagnosis Mean (SD)</td>
<td>Median survival in mo (95% CI)</td>
<td>Survival rate (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------</td>
<td>------</td>
<td>---------------------------</td>
<td>-------------------------------</td>
<td>-------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Survival rate (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6 mo</td>
<td>1 yr</td>
<td>3 yr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supportive</td>
<td>1123</td>
<td>56.2 (14.9)</td>
<td>3</td>
<td>32.5</td>
<td>20.4</td>
<td>~8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surgical</td>
<td>846</td>
<td>57.3 (13.3)</td>
<td>48</td>
<td>90.1</td>
<td>78.4</td>
<td>~58</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medical*</td>
<td>630</td>
<td>61.3 (11.9)</td>
<td>16</td>
<td>72.8</td>
<td>58.5</td>
<td>~24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entire cohort</td>
<td>2599</td>
<td>57.8 (13.9)</td>
<td>11</td>
<td>60.7</td>
<td>48.2</td>
<td>~28</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Utility (SG) for Utility measures of HCC

Quality adjusted survival

Time in Months

0.0 0.2 0.4 0.6 0.8 1.0

0 10 20 30 40 50 60

0 1 2 3 4 5 6
Shaded area = 233.6 QALM loss due to liver cancer
Example 1: underground water pollution

Pit dug for washing underground soil and water
Cancer risks based on reasonable maximal exposure and cancer slopes

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Likelihood of liver ca.</th>
<th>Loss of QALM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vinyl chloride</td>
<td>$8.4 \times 10^{-6}$</td>
<td>2</td>
</tr>
<tr>
<td>Tetrachloroethylene</td>
<td>$1.9 \times 10^{-4}$</td>
<td>44</td>
</tr>
<tr>
<td>Trichloroethylene</td>
<td>$1.4 \times 10^{-4}$</td>
<td>32</td>
</tr>
</tbody>
</table>

Estimated population at risk in the exposed community: 1000 people
Example 2:
helmet law for motor cycle riders
Helmet law

12% of motor cycle riders wear helmet before 1996

The proportion increased to 95% in 1997 (helmet law enforcement)

- Prevent 1300 cases of head injury in Taipei city annually
  - Each case of head injury may lose 4.8 QALY
  - Total impact of enforcement of helmet law
  - $1300 \times 4.8 = 6240$ QALY per year.
The survival function of the head injury cases and the reference population in the 80 months after onset.
The health-related quality of life of the head injury cases and the reference population in the 80 months after onset.
The quality-adjusted survival time of the head injury cases and the reference population in the 80 months after onset.
Health risk assessment in lead exposure

- **Exposure assessment**
  - 649 female lead workers
  - blood lead

- **Hazard identification**
  - lead can impair IQ of offspring of lead workers

- **Dose response**
  - < 30 ug/dl reversible
  - > 30 ug/dl irreversible

- **Risk characterization**
  - estimation of QALY loss due to different policy
Index of health-related quality of life (IHQL) for children delivered by lead-exposed women. The IHQL was adapted from reference

<table>
<thead>
<tr>
<th>Mother’s blood lead levels</th>
<th>Disability</th>
<th>Offspring</th>
<th>IHQL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Discomfort (physical)</td>
<td>Distress (emotional)</td>
</tr>
<tr>
<td>≥30 ug/dL</td>
<td>Slight social disability</td>
<td>No pain</td>
<td>Moderate distress</td>
</tr>
<tr>
<td>10 to 29 ug/dL</td>
<td>Slight social disability</td>
<td>No pain</td>
<td>Slight distress</td>
</tr>
<tr>
<td>&lt;10 ug/dL</td>
<td>No physical disability</td>
<td>No pain</td>
<td>No distress</td>
</tr>
</tbody>
</table>
## Estimated utility loss in QALY from 2 policies

<table>
<thead>
<tr>
<th>Distribution of blood lead in 1991</th>
<th>No. of worker with blood lead &gt;10 ug/dl</th>
<th>No. of offspring with blood lead &gt;10 ug/dl</th>
<th>Potential utility loss (QALY)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-29 (ug/dl)</td>
<td>282</td>
<td>17.3</td>
<td>51.6</td>
</tr>
<tr>
<td>30-59 (ug/dl)</td>
<td>331</td>
<td>19.0</td>
<td>164.4</td>
</tr>
</tbody>
</table>

### Policy 1: Improve industrial hygiene
- reduce 5 ug/dl in blood lead: 567, 33.1, 169.5
- reduce 10 ug/dl in blood lead: 511, 29.6, 126.8
- reduce 15 ug/dl in blood lead: 425, 24.1, 92.3

### Policy 2: Raise employment age
- up 5 years: 613, 29.8, 174.6
- up 10 years: 613, 18.2, 107.4

### Sensitivity analysis (different ASFRs):
- 1991: 613, 36.3, 216.0
- 5-year average: 613, 36.9, 219.6
Extension to health profile (psychometric score)

- Consequence of the event can be replaced by QOL measured by psychometrics
Cost of illness approach

\[ \int E[W_A(t|x_i)]S(t|x_i)dt \]

- Human capital left over for determinant \( x_i \)
- \( W_A(t|x_i) \): work ability function

\[ \int E[Cost(t|x_i)]S(t|x_i)dt \]

- Direct medical cost of determinant \( x_i \)
- \( Cost(t|x_i) \): medical cost function
Saving following costs through proactive prevention:

- Loss of life expectancy & QOL (or quality-adjusted life expectancy) in QALY
- Loss of wages because of loss of work ability
- Lifetime financial burden to the National Health Insurance
Thank you for your attention!

Photos are adopted from www.taiwan.net.tw & retire.cts.com.tw
Monthly cost (NT$) for patients with end stage renal disease under chronic hemodialysis
EXTENSION TO HEALTH PROFILE (PSYCHOMETRIC SCORE)

• Consequence of the event can be replaced by QOL measured by psychometrics

• Hwang JS, Wang JD. Quality of Life Research 2004; 13:1-10
Survival-weighted Health Profile in Long-term Survivors of Acute Myelogenous Leukemia (AML)

Chiun Hsu¹, Jung-Der Wang¹, Jing-Shiang Hwang², and Jih-Luh Tang¹

National Taiwan University Hospital¹
Academia Sinica²
Taipei, Taiwan

(Quality of Life Research 2003; 12:503-517)
Comparison of life time psychometric Scores for BMT and chemotherapy (WHOQOL generic instrument)
Comparison of life time psychometric scores for BMT and chemotherapy (WHOQOL generic measurement)

Domain 3 (social)

Domain 4 (environmental)
Conclusion: for comparative risk assessment in health and medicine

• The QALY or life year gained or loss plus the psychometric score time can be estimated in national health resources allocation and clinical decision makings

• Challenges for proactive prevention

• Needs for establishing different patient cohorts to estimate QALY loss per case
Clinical decision making
Maximize individual patient’s utility under resource constraint
based on: psychometric theory
WHOQOL health profile (multi-dimensions)
  + survival function

National resource allocation
Maximize utility of all people (No. of QALY) under the constraint of National Insurance System (NIS)
based on: expected utility theory
EQ-5D (or other utility measurement)
  + survival function

Survive weighted psychometric scores for each facets
\[
E[PAS] = \int_0^{t_{max}} S(t) \cdot Q(t) \, dt + \delta \int_0^{t_{max}} (1 - S(t)) \, dt
\]

QAS (QALY) = \int E(Qol(t \mid x)) \cdot S(t \mid x) \, dt

Cost / QALY (or DALY)

Each patient participates in clinical decision to maximize no. of QALY per given cost

How much is the patient willing to pay?

How much will NIS pay per QALY under the constraint of distributive justice?

Summarize to only one dimension
• **Life-time utility (Economist)**

経済學家：終生預期效用

\[
\int E[U(t|xi)]S(t|xi)dt
\]

- survival function 人命(存活函數)
- utility function 工作能力、薪資、醫療費用
- --HRQL(健康相關生活品質)
- --working ability, wages, medical costs

• **Quality-adjusted life expectancy or healthy life expectancy (生活品質調整後預期壽命)**

\[
\int E[Qol(t|xi)]S(t|xi)dt
\]
Tsauo JY, et al. (Utility of enforcement of helmet law) Accident Anal Prev 1999;31:253-63
Ho WL, et al. (survival and cost of thalassemia) Bone Marrow Transplant 2006; 37(6):569-574.
Health Care Decision: Diagnosis, Treatment, Prognosis, etc.

- Does every patient with head injury need a CT imaging?
- Does every patient with epidural hematoma require surgery?
- What is the decision basis for a patient to be transferred into ICU?
- Who gets the priority to use the limited health service resources, e.g. respirator, ICU (intensive care unit) ward, donated kidney?
Psychometric mean score

- The sum of scores of those who are still alive plus those who die
- The following simple equation establishes the relationship between population mean QoL score function and survival function,

\[ Q(t) = S(t) \times Q_s(t) + [1 - S(t)] \times \delta \]

where \( Q_s(t) \) is the average QOL of surviving subjects at time \( t \)
Estimations

• The estimate of expected psychometric score-adjusted survival (PAS) for an index population,

\[
E[PAS] = \int_0^{T_{\text{max}}} S(t) \cdot Q_s(t) \, dt + \delta \int_0^{T_{\text{max}}} (1 - S(t)) \, dt
\]

is obtained by firstly estimating and \(Q_s(t)\) at chosen time points \(t_k\)’s.