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How to do (or not to do) . . .

Calculating and presenting disability adjusted life years (DALYs) in cost-effectiveness analysis

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Disability adjusted life years (DALYs) are the sum of the present value of future years of lifetime lost through premature mortality, and the present value of years of future lifetime adjusted for the average severity (frequency and intensity) of any mental or physical disability caused by a disease or injury. They have been used as an outcome indicator in micro economic evaluations as well as sectoral prioritization exercises using league tables of cost-effectiveness. However, many of the current analyses are not comparable or transferable because either the assumptions used differ or are unclear, and because results are not presented in a way that allows researchers or policy-makers to re-calculate and re-interpret findings for use in an alternative context. However, at times there have also been miscalculations. This may happen either because evaluators disagree with the assumptions behind DALYs or because the methods of calculation have not been set out clearly. This paper shows how to calculate DALYs for cost-effectiveness analysis using a worked example. It also shows the impact of changing the age weighting and discount rates on estimates of cost-effectiveness, and suggests a set of minimum reporting criteria for using DALYs in cost-effectiveness analysis. Finally, readers are introduced briefly to a selected literature arguing for and against the use of DALYs.

Introduction

Disability adjusted life years (DALYs) are the sum of the present value of future years of lifetime lost through premature mortality, and the present value of years of future lifetime adjusted for the average severity (frequency and intensity) of any mental or physical disability caused by a disease or injury. DALYs are therefore a measure of something 'lost' rather than 'gained': DALYs are not desired themselves, but rather what is sought is their reduction. They were first introduced in the *World Development Report* (World Bank 1993) and the Disease Control Priorities Review (Jamison et al. 1993) as a method for estimating the global burden of disease and as an outcome measure for use in cost-effectiveness analysis. In 1996 a second version of DALYs was developed to replace the earlier construction and is used in the Global Burden of Disease series (Murray and Lopez 1996a–c).

Since 1993, DALYs have been used in cost-effectiveness analysis both at a micro level and in sectoral prioritization exercises. However, these evaluations have calculated DALYs in markedly different ways. For example, not only have analysts presented DALYs with different assumptions and different sources of disability weights, but at times DALYs have been miscalculated by using the wrong life expectancies (Fox-Rushby, forthcoming). We believe this occurs partly because evaluators disagree with some of the assumptions and modify the DALY calculations accordingly, but also because there are few examples showing how DALYs should be calculated in practice.[1]

Our second concern is that it is often not clear from papers or evaluation reports how researchers have calculated DALYs. For example, Fox-Rushby (forthcoming) showed that nine out of 16 papers published between 1993–2000 did not state which assumptions of the DALY were adopted. Given the variation in approaches that is observed when researchers *do* report their assumptions, it is highly likely that these studies are also producing DALY calculations that are not comparable. This leads to our final concern with the ways in which DALYs are presented.

To date few evaluators subject their cost/DALY averted estimates to any form of sensitivity analysis (Fox-Rushby, forthcoming) and few provide any disaggregation in their calculations of DALYs that allow readers to undertake this analysis. The result is that not only are readers of evaluations unable to assess the robustness of DALY estimates, but they are also unable to transfer results between settings with any degree of reliability. There has been some sensitivity analysis by the original developers of DALYs, but *only* with respect to the calculation of the global burden of disease (Murray et al. 1994). So, for example, the conclusion that age weights have little impact on the calculation of DALYs *cannot* be used to imply that this would also be the case in calculating the cost-effectiveness of specific health interventions.

This paper outlines how DALYs can be calculated for use in cost-effectiveness analysis, proposes how sensitivity analysis can be used to assess the impact of assumptions and suggests methods for presenting results that allow other researchers and policy-makers to consider how estimates used in cost-effectiveness analysis may be transferred between settings. Finally, for the interested reader, we provide a short bibliography that contains papers advocating and criticizing the use of DALYs in cost-effectiveness analysis.

Calculating DALYs for cost-effectiveness analysis: general issues

DALYs are the sum of years of life lost (YLLs) and years of life lived with disability (YLDs). The impact of interventions on DALYs (i.e. the DALYs averted by an intervention) is measured by calculating DALYs in two scenarios: with and without the intervention. The relevant formulas were outlined by Murray (1996, p. 65–6) and are shown below. These calculations incorporate weights for life expectancy, age, future time and disability. The general equation shown below is for YLLs. The calculation YLLs $[r, K, \beta]$ is used to signify key assumptions. To reflect the base case recommended and used by Murray and Lopez (1996a,b) this would mean that $r = 0.03$, $K = 1$ and $\beta = 0.04$. This representation is also a quick way for evaluators to highlight any key changes in the assumptions of the DALYs they calculate.

$$\text{YLLs}[r,K,\beta] = \frac{KCe^{ra}}{(r+\beta)^2}\{e^{-(r+\beta)(L+a)}[-(r+\beta)(L+a)-1] - e^{-(r+\beta)a}[-(r+\beta)a-1]\} + \frac{1-K}{r}(1-e^{-rL})$$

Where: K = age weighting modulation factor; C = constant; r = discount rate; a = age of death; β = parameter from the age weighting function; L = standard expectation of life at age a.

The formula for YLDs$[r, K, \beta]$ differs only in the addition of D (the disability weight), and is shown below:

$$\text{YLDs}[r,K,\beta] = D\{\frac{KCe^{ra}}{(r+\beta)^2}\{e^{-(r+\beta)(L+a)}[-(r+\beta)(L+a)-1] - e^{-(r+\beta)a}[-(r+\beta)a-1]\} + \frac{1-K}{r}(1-e^{-rL})\}$$

Where: K = age weighting modulation factor; C = constant; r = discount rate; a = age of onset of disability; β = parameter from the age weighting function; L = duration of disability; D = disability weight.

With the discount rate set to zero[2] and uniform age weighting, the length of life lost at a particular age is L (i.e. the life expectancy at age a) and the years of life lived with disability is the product of the disability weight and duration of disability at age a, i.e. DL. It is also important to note that, in contrast to measuring the general burden of disease, the appropriate life expectancy for cost-effectiveness analysis is *not* 'standard expected years of life lost' (SEYLL) where females are expected to live for 82.5 years, and males 80 years, from birth. What is needed is the difference between life years lived with and without the intervention, and SEYLL measures neither. For calculating DALYs averted in cost-effectiveness analysis, local life expectancy is recommended as a good approximation of life expectancy, provided that mortality is stable (Murray 1996, p. 20, citing Preston 1993). If underlying mortality is changing over time each new birth cohort will experience a different life expectancy and the local life expectancy becomes a less accurate representation of future life for interventions that impact on particular age groups. Therefore, a cohort life expectancy is recommended as the basis for estimating change with and without an intervention (Murray 1996, p. 20). However, the situation quickly becomes more complex if the evaluation considers an intervention run over several years that changes age-specific mortality rates. Not only is a great deal more information required (age specific mortality rates and the impact of the interventions on mortality at each age), but it also requires moving to a population model to capture the dynamic nature of the impact of the intervention.

Calculating DALYs for cost-effectiveness analysis: worked examples

Any cost-effectiveness analysis requires that at least two alternatives are compared as well as both costs and effects of the two options. The worked example below shows how DALYs can be calculated to compare the expected gains for an individual for treatment versus no treatment.

Imagine a woman in Chile becomes sick with bipolar depression at age 35, that she has it for 10 years and dies as a result. How many DALYs [0.03,1,0.04] have been lost as a result? How many DALYs [0.03,1,0.04] would be averted if she had treatment? To calculate this we need to estimate the numbers of DALYs lost due to YLDs and then YLLs. The expected time horizon for this woman is shown below, by age, with and without treatment:

Time horizon without treatment:

Depression Death

Age 35 45

Time horizon with treatment:

Depression treated Death

Age 35 79.13

The calculation of YLDs focuses on the period during which she is alive from 35–45 years. By substituting the following values into the general equation, the YLD based DALYs can be calculated:

K = 1
C = 0.1658
r = 0.03
a = 35
β = 0.04
L = 10
e = 2.72 (approx)
D = 0.6 (from Murray 1996, p. 415)

$$\text{YLDs }[0.03,1,0.04] = 0.6\left\{\frac{1 \times 0.1658 \times 2.72^{(0.03 \times 35)}}{(0.03 + 0.04)^2}\left[2.72^{-(0.03+0.04)(10+35)}[-(0.03+0.04)(10+35) - 1] - 2.72^{-(0.03+0.04)35}[-(0.03+0.04)35 - 1]\right] + \frac{1-1}{0.03}\left(1 - 2.72^{-(0.03 \times 10)}\right)\right\}$$

The number of DALYs [0.03,1,0.04] lost due to disability is therefore 6.95.[3]

The calculation of the YLLs focuses on the time from death to the age at which the woman would have expected to live without the disease, and requires two steps in this example. First, the years of life lost from age 45 onwards is calculated; and secondly, this value is converted to the expectation of life lost from age 35 so all DALYs can be added up from age 35 onwards using a common metric. The first step requires a straightforward substitution of values into the general YLL equation using the following values:

K = 1
C = 0.1658
r = 0.03
a = 45
β = 0.04
e = 2.72 (approx)
L = 34.73 (life expectancy at age 45)[4]

$$\text{YLLs }[0.03,1,0.04] = \frac{1 \times 0.1658 \times 2.72^{(0.03 \times 45)}}{(0.03 + 0.04)^2}\left[2.72^{-(0.03+0.04)(34.73+45)}[-(0.03+0.04)(34.73+45) - 1] - 2.72^{-(0.03+0.04)45}[-(0.03+0.04)45 - 1]\right] + \frac{1-1}{0.03}\left(1 - 2.72^{-(0.03 \times 34.73)}\right)$$

The total DALYs [0.03,1,0.04] lost from the age of 45 onwards, due to lost years of life is therefore 19.97.[5] The conversion of this to DALYs calculated at age 35 uses the following formula:

DALY at age x = DALY(y) e^{-rs},

Where: s = number of years we have to discount and y is the age at death.

Substituting in the appropriate values, where $s = (y - x)$:

$$\text{DALYs at age 45} = 19.97 \times (2.72)^{(-0.03 \times (45-35))} = 14.80$$

Therefore, from the time of onset of disease at age 35, the total number of YLLs [0.03,1,0.04] lost due to premature death equals 14.80. Adding this to the years of life lost with disability (YLDs [0.03,1,0.04] = 6.95) gives the total number of DALYs [0.03,1,0.04] lost of 21.75.

Now imagine if this woman received treatment for her depression at age 35, and that she does not die at age 45 but lives for her expected life span at age 35 (in the treated state). How many DALYs would be averted by the intervention? A DALY weight for the treated form of the disease is given in Murray and Lopez (1996a, p. 415) as 0.302[6] (a fall of 0.298 from the untreated DALY weight). Using the YLD formula with the following figures (K = 1; C = 0.1568; r = 0.03; a = 35; β = 0.04; L = 44.13; D = 0.302) the DALYs [0.03,1,0.04] now associated with her condition equal 7.94.[7] This means the total number of DALYs [0.03,1,0.04] averted following treatment of the woman is 21.75 − 7.94 = 13.81. If we exclude age and/or discount weights, the results would vary as follows: DALYs averted [0.03,0,0] = 13.76; DALYs [0,1,0.04] = 25.07 and; DALYs [0,0,0] = 27.4.[8]

To move from this calculation to the total number of DALYs averted in a population due to treatment of bipolar depression would require calculating the DALYs lost to each individual with bipolar depression with and without treatment, using the approach shown above, and then adding them all up together. With full knowledge, this would give the most detailed figures. However, in reality the calculations tend to work from a population level down with gross assumptions, for example about proportions of the population treated. Finally, if the calculation of effectiveness was intended for use in a country- or region-specific cost-effectiveness analysis, the country- or region-specific life tables should be used.

Presenting DALYs

It can be seen that the calculation above required many assumptions associated with the calculation of DALYs (e.g. choice to discount and at what rate, choice to age weight and at what rate, disability weight with and without treatment) and estimates (e.g. the age at onset, expected age of death with and without treatment). All these decisions affect the difference in expected DALYs with and without treatment, and should therefore be tested in a sensitivity analysis to allow judgement of the impact these assumptions have on the final results. The sensitivity analysis we used in the above example was a simple one-way sensitivity analysis that included testing the impact of assuming the age weights and discount rates were zero (singly and together), and it was shown that dropping both discounting and age weighting would result in a doubling of DALYs averted. Incorporating such testing in cost-effectiveness analysis would show the effect that altering the assumptions about effectiveness (as measured by DALYs averted) could have on whether or not interventions are considered cost-effective. For example, using a threshold analysis could identify the rate (threshold) of age-weighting that leads to a switch in the relative cost-effectiveness of two treatment alternatives.

Our example was also able to show the relative contribution of YLLs and YLDs to total DALYs. Presentation of the full calculation also allows others to insert alternative values to re-estimate DALYs. This would be particularly helpful if, for

Table 1. Method for presenting the results of calculations of DALYs averted for use in CEA: the worked example

	Alternative 1 (no treatment)	Alternative 2 (treatment)
Base case assumptions		
• Age of death	45 years	79.13 years
• Life expectancy at age of death	34.73	n.a.
• Discount rate	0.03	0.03
• Age weight	0.04	0.04
• Disability weight	0.6	0.302[b]
• Age of onset	35 years	35 years
• Duration of disability	10 years	44.13 years
• Type of DALY used	Murray 1996a[a]	Murray 1996a
DALYs [0.03,1,0.04]		
• Contribution of YLLs	14.80	0
• Contribution YLDs	6.95	7.94
Total DALYs averted	Gains from treatment	
• DALYs [0.03, 1, 0.04]	13.81	
• DALYs [0.03, 0, 0]	13.76	
• DALYs [0, 1, 0.04]	25.07	
• DALYs [0, 0, 0]	17.40	

[a] This distinguishes the DALY formula presented in Murray (1994) – what Fox-Rushby (in press) calls the Mark 1 version.
[b] We recommend the source of data for disability weight is given. In this case we used Murray and Lopez (1996a, p. 415).

example, others wished to generalize the results to another setting where life expectancy differed, or where disability resulting from the condition was considered to be better or worse, or where more or less favourable treatment outcomes were achieved from the intervention.[9]

Using our example, we would suggest the following minimum reporting format for presenting the results[10] from the DALY averted calculations in cost-effectiveness analysis (see Table 1).

DALYs discussed . . .

The principal papers in which DALYs are presented are Murray (1994, 1996), Murray and Lopez (1997, 2000) and Murray and Acharya (1997). However, there is increasing debate about the value of DALYs in decision-making. Part of the debate has centred on the weights incorporated in DALYs (see, for example, Anand and Hanson 1997; Arnesen and Nord 1997; Paalman et al. 1998; Elbasha 2000; Musgrove 2000), and part has focused on whose values are, and should be, represented in DALYs (see, for example, Hanson 1999; Nygaard 2000; Rock 2000) with others questioning the equity implications of DALYs (see, for example, Anand and Hanson 1998; Gilson 1998). There has also been particularly strong criticism of the use of DALYs in the burden of disease approach to decision-making (see, for example, Williams 1999, 2000; Mooney and Wiseman 2000). Critics have called for an end to the use of burden of disease exercises as a resource allocation tool, and advocate the use of economic evaluations of available technologies, with Mooney and Wiseman (2000) also calling for a more socially inclusive view of outcomes than allowed for by DALYs.

With respect to economic evaluations, it is important to note that the DALY has not yet been operationalized as a tool for collecting data alongside experimental or quasi-experimental trials of health interventions. Thus, none of the estimates of disability provided in the current Global Burden of Disease series relate to any specific intervention. This creates a problem for using DALYs in cost-effectiveness analysis if researchers base their estimates on those provided in the Murray and Lopez (1996a-c) books, because there is no way of distinguishing alternative interventions using the existing disability weights.

Conclusions

The calculation and presentation of DALYs for use in cost-effectiveness analysis should:

- depending on the circumstances, use relevant cohort life expectancies, local life tables or a population model, *not* the standard expected years of life lost (SEYLL) method;
- state *all* the assumptions used to calculate DALYs;
- present a range of DALY estimates (at least DALYs [0,0,0] and DALYs [0.03,1,0.04]);
- test the sensitivity of cost-effectiveness ratios to changes in the assumptions used to calculate DALYs.

Following this minimal set of common procedures will help researchers and policy-makers to understand the robustness of the results for the setting in which interventions are being evaluated, and will allow results to be transferred more reliably across settings.

Endnotes

1 One helpful example showing how to calculate an early version of DALYs is given in Homedes (1995).

2 See Murray (1996, p. 65–6) for a simplified equation where the discount rate is set to zero.

3 The formula in Excel for base case YLDs is =0.6*(1*0.1658*EXP(0.03*35)/(0.03+0.04)^2)*(EXP(−1*(0.03+0.04)*(10+35))*(−(0.03+0.04)*(10+35)−1)−EXP(−1*(0.03+0.04)*35)*(−(0.03+0.04)* 35−1))+((1−1)/0.03)*(1−EXP(−1*0.03*10)).

4 Source: United Nations Model Life Tables for Females using Chilean Pattern with a life expectancy of 75 at birth (United Nations 1982, p. 76–117).

5 The formula in Excel for base case YLLs is =(1*0.1658*EXP(0.03*45)/(0.03+0.04)^2)*(EXP(−1*(0.03+0.04)*(34.73+45))*(−(0.03+0.04)*(34.73+45)−1)−EXP(−1*(0.03+0.04)*45)*(−(0.03+0.04)*45−1))+((1−1)/0.03)*(1−EXP(−1*0.03*34.73)).

6 Note, whilst we are given this value, we do not know what the treatment is. Also, the value is meant to represent the ‘average’ response of people to treatment of bipolar depression. In an average, some people will be better, and may have a 100% recovery with no need for further treatment and no remission. Others may not recover at all following treatment.

7 Using the formula: =0.302*(1*0.1658*EXP(0.03*35)/(0.03+0.04)^2)*(EXP(−1*(0.03+0.04)*(44.13+35))*(−(0.03+0.04)*(44.13+35)−1)−EXP(−1*(0.03+0.04)*35)*(−(0.03+0.04)*35−1))+((1−1)/0.03)*(1−EXP(−1*0.03*44.13)).

8 A slightly modified formula is used to calculate DALYs when the discount rate is set to zero. The Excel formula for YLLs in the

case of r=0 is: = (K*C*EXP(b*a)/b^2)*(EXP(−b*L)*(−b(L+a)−1) − (−b*a−1))+((1−K)*L). For YLDs, the formula when r = 0 is: =D*((K*C)*(EXP(−b*a)/b^2)*(EXP(−b*L)*(−b*(L+a)−1)−(−b*a−1))+(1−K)*L). In an excel spreadsheet, the IF command can be used to create a cell formula that allows the discount rate to be toggled between 0 and a positive number.

[9] For further reading on how to conduct sensitivity analysis in cost-effectiveness analysis readers are directed to Manning et al. (1996), Briggs (2000), and Walker and Fox-Rushby (forthcoming).

[10] The methods section in reports should detail all relevant sources of data.

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