NOVEL APPROACHES TO COMMON CHALLENGES IN MODELLING OF SURVIVAL OUTCOMES FOR COST-EFFECTIVENESS ANALYSES IN ONCOLOGY

ISPOR 2018 Barcelona: W8 Advanced Workshop
Discussion Leaders: Richard Birnie, Mario Ouwens, Bart Heeg, Matthew Dyer

Tues Nov 13, 2018

Today’s Workshop Agenda

1) Indirect Treatment Comparison in the presence of time varying relative treatment effects
   - Richard Birnie, PhD, Principal Statistician, BresMed Health Solutions Ltd, Sheffield, UK

2) Use of clinical expert opinion in the estimation of survival extrapolation distributions
   - Mario Ouwens, PhD, Statistical Science Director, AstraZeneca, Mölndal, Sweden

3) Subsequent treatment adjustment in oncology trials
   - Bart Heeg, PhD, Managing Partner, Ingress-Health, Rotterdam, Netherlands
Indirect Treatment Comparison in the presence of time varying relative treatment effects

Richard Birnie
ISPOR Europe
Barcelona 2018

Introduction

• To inform cost-effectiveness analyses and health technology assessments it is often necessary to make comparisons between treatments that have never been directly compared in clinical trials

• It is also common to extrapolate outcomes beyond the observed period of the clinical trial to estimate the effects of treatment over the whole lifetime of the patient

• Common to have access to individual patient data (IPD) for studies of a new intervention but only aggregate data for comparator studies.

• Commonly achieved as a two step process
  – Parametric survival modelling applied to IPD from the intervention study
  – Indirect treatment comparison method estimates relative effect of treatments
Estimating the relative effect of TKIs for the treatment of EGFR mutation positive NSCLC

- One study per treatment comparison
- All trials compare TKI (osimertinib, afatinib, dacomitinib) relative to standard care (gefitinib or erlotinib)
- Typical approach in this scenario would be network meta-analysis (NMA) pooling published hazard ratios from each study
  - Assumes that relative treatment effects remain constant over time

Time varying relative treatment effects

- Kaplan-Meier curves cross in ARCHER 1050 at ~12 months and ~36 months
  - Typically indicates violation of the proportional hazards assumption
  - Direction of treatment effect changes at different points in time

1. FLAURA, NCT02296125; 2. LUX-Lung7, NCT01466660; 3. ARCHER1050, NCT01774721
OS summary – FLAURA and LUX-Lung 7

Assessment of proportional hazards – ARCHER1050

- If proportional hazards holds the log cumulative hazard (LCH) curves are expected to be parallel
  - Crossing indicates a reversal of the relative treatment effect
- Schoenfeld plot shows variation in HR over time
NMA of relative effects on multiple parameters of the survival model 1

- Synthesis of relative treatment effects that influence multiple parameters of the parametric survival curve to reflect a time varying treatment effect
- Relative treatment effects are captured in a survival regression model by including terms for study and for treatment arm
  - Parametric survival curve and relative treatment effects estimated in a single analysis
  - Combined ITC and extrapolation in one step

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location (e.g. scale)</td>
<td>• Vary between treatments</td>
<td>• Vary between treatments</td>
<td>• Vary between treatments</td>
</tr>
<tr>
<td></td>
<td>• Vary between studies</td>
<td>• Vary between studies</td>
<td>• Vary between studies</td>
</tr>
<tr>
<td>Non-location (e.g. shape)</td>
<td>• Vary between treatments</td>
<td>• Vary between treatments</td>
<td>• Constant between treatments</td>
</tr>
<tr>
<td></td>
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<td>• Constant between studies</td>
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NMA of relative effects on multiple parameters of the survival model 2

\[ \ln(h_{jkt}) = \psi_{jk} + \theta_{jk} \ln(t) \]

- If we assume proportional hazards, only \( \psi_{jk} \) varies between treatments
- \( \theta_{jk} \) remains constant between treatments
  - Hazard functions have the same shape over time
  - Ratio of the hazards will be constant over time – proportional hazards
- Model can be extended by allowing both \( \psi_{jk} \) and \( \theta_{jk} \) to vary between treatments
  - Hazard functions will have the different shapes for each treatment over time over time
  - Ratio of the hazards will vary over time – non-proportional hazards – relative treatment effect varies over time
- Further extend the model by allowing both \( \psi_{jk} \) and \( \theta_{jk} \) to be influenced by other covariates
  - In these analyses, study acts as a proxy for IPD on other covariates
Model Comparison

• AIC indicates that best fitting models were:
  – Weibull with treatment and study effects on the location parameter only (Scenario 3)
  – Generalised gamma with treatment and study effects on the location parameter only (Scenario 3)

• Generalised gamma model has three parameters; mean, sigma, Q
  – Generalised gamma includes Weibull as a special case when Q = 1
  – In this analysis Q = 0.98 (95%CI 0.70 to 1.25)
  – Effectively the same as the Weibull in this example

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<tbody>
<tr>
<td>Weibull</td>
<td>5648.1</td>
<td>5643.7</td>
<td>5639.9</td>
</tr>
<tr>
<td>Generalised Gamma - Mean + Sigma</td>
<td>5649.9</td>
<td>5645.6</td>
<td>5641.9</td>
</tr>
<tr>
<td>Log logistic</td>
<td>5653.0</td>
<td>5649.5</td>
<td>5649.8</td>
</tr>
<tr>
<td>Gompertz</td>
<td>5674.9</td>
<td>5669.7</td>
<td>5667.1</td>
</tr>
<tr>
<td>Log normal</td>
<td>5699.7</td>
<td>5698.7</td>
<td>5702.3</td>
</tr>
</tbody>
</table>

Weibull model: Treatment and study effects applied to scale parameter only

• Equivalent to assuming proportional hazards – unlikely to be plausible based on earlier work
• Poor fit to the gefitinib arm of the ARCHER 1050 study (pink) and to both arms of LUX-Lung 7
• Underestimates survival up 12 months in both studies
• Similar results observed with generalised gamma model
Exploring more complex models – Generalised F

- Generalised F distribution has four parameters: mean, sigma, Q, P
  - More parameters = greater flexibility
- Lowest AIC (best fit) was observed for models with
  - Treatment and study effects applied to both mean and Q (Scenario 1)
  - Treatment and study effects applied to mean only (Scenario 3)
- Slightly higher AIC for the generalized F with treatment and study effects on mean and Q
  - Increased penalty for model complexity
  - Minimal impact compared to the improvement in visual fit to the observed Kaplan-Meier curve

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<tr>
<td>Generalised F - Mean + Q</td>
<td>5641.8</td>
<td>5644.0</td>
<td>NA</td>
</tr>
<tr>
<td>Generalised F - Mean + P</td>
<td>5646.9</td>
<td>5643.9</td>
<td>NA</td>
</tr>
<tr>
<td>Generalised F - Mean + Sigma</td>
<td>5647.4</td>
<td>5643.3</td>
<td>5640.3</td>
</tr>
<tr>
<td>Weibull</td>
<td>5648.1</td>
<td>5643.7</td>
<td>5639.9</td>
</tr>
</tbody>
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Generalised F distribution - Treatment and study coefficients applied to both mean and Q

- Provides good visual fit to ARCHER1050
- Closest fit to the gefitinib arm of ARCHER1050 among the models tested
Generalised F distribution - Treatment and study coefficients applied to both mean and Q

- Provides reasonable visual fit to FLAURA and LUX-Lung 7

Extrapolation of overall survival

- Weibull and generalised gamma models give similar estimates of 10 year survival
  - Consistent with previous observations. These models are basically equivalent
- Generalised F models give much higher estimates of 10 year survival
- Models in scenario 3 rely on assumptions of constant relative treatment effect (Weibull, Gen Gamma, Gen F)
  - Unlikely to be plausible based on LCH and Schoenfeld plots presented earlier
  - Does not capture variation in relative effect over time

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Model</th>
<th>Estimated 5 year % survival (95% CI)</th>
<th>Estimated 10 year % survival (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Osimertinib</td>
<td>S3: Weibull</td>
<td>29.2 (18.8, 38.7)</td>
<td>3.0 (0.7, 7.6)</td>
</tr>
<tr>
<td></td>
<td>S3: Gen F</td>
<td>29.7 (22.5, 37.8)</td>
<td>10.3 (5.1, 18.3)</td>
</tr>
<tr>
<td></td>
<td>S1: Gen F - Mean + Q</td>
<td>29.4 (22.4, 36.9)</td>
<td>12.8 (7.1, 19.5)</td>
</tr>
<tr>
<td></td>
<td>S3: Gen Gamma</td>
<td>29.4 (19.5, 39.3)</td>
<td>3.3 (0.6, 9.3)</td>
</tr>
<tr>
<td>Afatinib</td>
<td>S3: Weibull</td>
<td>18.8 (8.8, 31.5)</td>
<td>0.9 (0.1, 3.9)</td>
</tr>
<tr>
<td></td>
<td>S3: Gen F</td>
<td>23.2 (14.8, 34.2)</td>
<td>7.9 (2.7, 16.5)</td>
</tr>
<tr>
<td></td>
<td>S1: Gen F - Mean + Q</td>
<td>23.8 (16.6, 36.8)</td>
<td>8.3 (3.8, 17.4)</td>
</tr>
<tr>
<td></td>
<td>S3: Gen Gamma</td>
<td>19.1 (8.8, 30.5)</td>
<td>1.0 (0.0, 4.8)</td>
</tr>
<tr>
<td>Dacomitinib</td>
<td>S3: Weibull</td>
<td>20.0 (9.4, 31.6)</td>
<td>1.0 (0.1, 4.2)</td>
</tr>
<tr>
<td></td>
<td>S3: Gen F</td>
<td>24.8 (16.0, 35.1)</td>
<td>8.5 (3.3, 16.6)</td>
</tr>
<tr>
<td></td>
<td>S1: Gen F - Mean + Q</td>
<td>27.5 (18.8, 42.5)</td>
<td>6.0 (3.5, 18.2)</td>
</tr>
<tr>
<td></td>
<td>S3: Gen Gamma</td>
<td>20.3 (10.0, 32.7)</td>
<td>1.2 (0.1, 5.5)</td>
</tr>
<tr>
<td>Standard care</td>
<td>S3: Weibull</td>
<td>13.9 (8.1, 21.4)</td>
<td>0.4 (0.1, 1.5)</td>
</tr>
<tr>
<td></td>
<td>S3: Gen F</td>
<td>19.0 (13.3, 26.6)</td>
<td>6.5 (2.3, 13.3)</td>
</tr>
<tr>
<td></td>
<td>S1: Gen F - Mean + Q</td>
<td>19.5 (15.3, 27.0)</td>
<td>7.0 (3.6, 12.7)</td>
</tr>
<tr>
<td></td>
<td>S3: Gen Gamma</td>
<td>14.2 (7.2, 22.2)</td>
<td>0.4 (0.0, 2.6)</td>
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Expected overall survival

- Inoue 2016 reported overall survival for a Japanese cohort receiving first line gefitinib, N = 929
- Reported OS at 5 years was ~20%, similar to generalised F model estimates for standard care

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<td></td>
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<td>0.4 (0.0, 2.6)</td>
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Conclusions

- Standard approach to NMA assumes that relative treatment effects are constant over time
- Kaplan-Meier curves from the ARCHER1050 study showed evidence of time varying relative treatment effects
  - Likely due to the combination of study design and treatment switching observed in this study
- Several models gave similar goodness of fit statistics
  - Three out of four best fitting models assumed constant relative treatment effects
    - Unlikely to be plausible
- Four parameter generalised F model with treatment and study effects on two parameters (mean and Q) gave a better fit to the observed Kaplan-Meier data
  - Slight penalty in goodness of fit statistics due to increased complexity
  - Increased flexibility leads to higher estimates of long term survival compared to alternative models
  - Estimated 5 year OS was comparable to external sources for the standard care arm

Inoue 2016 Japanese Journal of Clinical Oncology, 46(5) 462–467
Thank you

Questions?
ISPOR EU 2018 - Use of clinical opinion in the estimation of survival extrapolation distributions

Mario Ouwens
Statistical Science Director, Advanced Analytics Centre, AstraZeneca R&D

Disclaimer

The views and opinions expressed in the following PowerPoint slides are those of the individual presenter and should not be attributed to AstraZeneca.
Can extrapolation be more clinical information based?

- Immature survival data may need to be extrapolated for HTA purposes

- Current process: Clinicians expectations asked after extrapolation
  - But what if all curves cross/all estimated curves are not clinically plausible?

- Research question: Why not asking clinicians first and using clinical opinion in estimation thereafter?

Decision problem: 3 year idelalisib trial in chronic lymphocytic leukaemia

  - Idelalisib compared to placebo
  - Relapsed or refractory chronic lymphocytic leukaemia

→ Clinical opinion: 10%-15% 10 year survival for placebo arm

Elicitation: In line with elicitation work from Kate Ren at PSI

https://www.psiweb.org/docs/default-source/default-document-library/kate-ren-slides.pdf?sfvrsn=12c85f0b_0
Large difference in estimated 10yr benefit, while having equivalent fit to KM

<table>
<thead>
<tr>
<th>Distribution</th>
<th>AIC</th>
<th>BIC</th>
<th>(\Delta)RMST benefit KM end</th>
<th>(\Delta)RMST benefit 10 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weibull</td>
<td>1032</td>
<td>1045</td>
<td>0.22</td>
<td>1.97</td>
</tr>
<tr>
<td>Log logistic</td>
<td>1031</td>
<td>1045</td>
<td>0.21</td>
<td>1.68</td>
</tr>
<tr>
<td>Lognormal</td>
<td><strong>1031</strong></td>
<td>1045</td>
<td>0.20</td>
<td><strong>1.74</strong></td>
</tr>
<tr>
<td>Exponential</td>
<td>1032</td>
<td>1039</td>
<td>0.20</td>
<td>1.19</td>
</tr>
</tbody>
</table>

Difference in 10yr restricted mean survival benefit idelalisib versus placebo purely due to post-trial period:
- Benefit lognormal: 1.74
- Benefit exponential 1.19
- Benefit lognormal 46% larger

So, what do we do about it?

**Current approach**

\(\exp(-\lambda t)\)

Estimate \(\exp(-\lambda t)\)

Go to clinician

**New proposal**

Go to clinician first

\(\exp(-\lambda t)\)

Estimate \(\exp(-\lambda t)\)

Using clinical opinion

Additional option: when clinician rejects distribution, ask him to provide reasonable percentage range and re-estimate
How does it work? Bayesian estimation

Construction of a priori distribution for exponential distribution:

Clinician: “At 10 years, placebo survival percentage is between 10 and 15%”

Statistician: \( \exp(-\lambda t) \)

“I can do my magic with the exponential”

\[ S = \exp(-\lambda t) \]

10% = \( \exp(-10 \lambda_{\text{upper bound}}) \)

15% = \( \exp(-10 \lambda_{\text{lower bound}}) \)

\( \lambda_{\text{lower bound}} = 0.19, \lambda_{\text{upper bound}} = 0.23 \)

To be very specific: Our analyses used lognormal \( \lambda \) with log of bounds of confidence intervals

How does it work? Bayesian estimation; Challenge: What to do with multiple parameters

But what to do with distributions with more than 1 parameter? \( \exp??? \)

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<tr>
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<th>Functional form</th>
<th>Rewritten for S=10% at t = 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exponential</td>
<td>( S = \text{Exp}(-\lambda t) )</td>
<td>( \lambda = -\ln(10%) / 10 )</td>
</tr>
<tr>
<td>Weibull</td>
<td>( S = \text{Exp}(-\lambda t \varphi) )</td>
<td>( \lambda = -\ln(10%) / 10 \varphi )</td>
</tr>
<tr>
<td>Lognormal</td>
<td>( S = 1 - \Phi \left( \frac{\log(t) - \mu}{\sigma} \right) )</td>
<td>( \mu = \log(10) - \sigma \Phi^{-1}(1 - 10%) )</td>
</tr>
<tr>
<td>Loglogistic</td>
<td>( S = \frac{1}{1 + \exp\left(\frac{\beta}{\phi}\right)} )</td>
<td>( \beta = 10 - (\log((1-10%)/10%))^{1/\phi} )</td>
</tr>
<tr>
<td>Gompertz</td>
<td>( \exp(-\varphi (\exp(\beta t) - 1)) )</td>
<td>( \varphi = -\log(10%)/(\exp(10\beta) - 1) )</td>
</tr>
</tbody>
</table>
How does it work? Bayesian estimation; Challenge: What to do with multiple parameters

Solution: Sample $\varphi$ first and compute $\lambda_{\text{upper bound}}$ and $\lambda_{\text{lower bound}}$ using $S$ and $\varphi$

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<td>$\lambda = -\ln(10%) / 10$</td>
</tr>
<tr>
<td>Weibull</td>
<td>$S = \exp(-\lambda t \varphi)$</td>
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<td>$S = 1 - \Phi \left( \frac{\log(t) - \mu}{\sigma} \right)$</td>
<td>$\mu = \log(10) - \sigma \Phi^{-1}(1 - 10%)$</td>
</tr>
<tr>
<td>Logistic</td>
<td>$S = \frac{1}{1 + \exp(\frac{t}{\beta})^\varphi}$</td>
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</tbody>
</table>

Did it help for comparator arm?

Original fit

Fit using clinical opinion

Yes, it helped
Active arm; No 10 years experience

- **Active more difficult**
  - Less experience
  - Less convincing to HTA authorities

What could we at least do:

- Assume $\exp(-\lambda t)$
  - proportional hazards (PH) or
  - constant accelerated failure time (AFT)

- Clinicians know that the 10 years survival percentage is between 0 and 100%
  - Thus: Use more uncertainty or larger ranges of survival percentages

Run scenarios

Did it help?

**Placebo**

**Idelalisib**

Aligned with clinical expectations and good fit to KM
Subsequent treatment adjustment in Oncology trials

Bart Heeg, Managing Partner INGRESS Health

Background

• Cross-over/treatment switching might bias clinically reliability of reported (relative) survival

• Several methods exist that can adjust for treatment switching, e.g.
  • Rank preserving structural failure time models (RPSFTM)
  • Inverse probability of censoring weighing (IPCW)
  • Two stage method

• Traditionally these methods are used to generate counterfactual survival times/weights for patients in the placebo arm to reflect the situation that no one switched to the “novel treatment or to not reimbursed therapies in clinical practice”.
Decision problem

• Novel oncology agents are usually developed first for relapsed refractory patients and subsequently for front-line patients.

• In a front line clinical trial the novel agent can be prescribed as relapsed/refractory treatment (mostly in the placebo arm).

• Potential local decision problems/questions:
  - In clinical practice the percentage of patients in the placebo arm being switched to the novel agent differs for the trial.
    • This impacts costs in the cost-effectiveness model but how does it impact expected relative survival?
    • Isn’t it “more cost-effective” to initiate novel treatment in a later line?

Methods

1. Use “RPSFTM / two stage method” to estimate counterfactual survival times from time of switch OR progression for situation that
   1. 0% of the patients switched to novel second line treatment
      • Survival times of patients switching from switch are multiplied with the acceleration factor (RPSFTM)
   2. 100% of the patients switched to novel second line treatment
      • Survival times of patients not switching are from progression multiplied with \(1/\text{acceleration factor (RPSFTM)}\)

2. Estimate the weighted mean survival for each decision problem for the placebo arm
   1. Decision problem 1: 70% of patients are assumed to switch and 30% are assumed not to switch in the placebo arm, whereas in the trial 50% switched
      \[ S(t)_{\text{70\% switch}} = 30\% \cdot S(t)_{\text{no switch}} + 70\% \cdot S(t)_{\text{100\% switch}} \]
   2. Decision problem 2: 100% of the patients is assumed to switch in the placebo arm

3. Per decision problem compare the new weighted mean survival in placebo arm with that of the active arm.
RPSFT (adjust post switch times)

Control -> % intervention

Intervention

Survival time

Control

Intervention

Survival time

Control -> 100% intervention

Intervention

Survival time

Kaplan Meier curve

50% of patients in placebo arm switches to the active treatment

- Kaplan-Meier OS unadjusted population placebo arm
- Kaplan-Meier adjusted population active arm OS

13/11/2018
Kaplan Meier curve: Impact of switching in placebo arm on survival

In the orange curve 0% of patients in placebo arm switches to the active treatment.

Kaplan-Meier OS unadjusted population placebo arm
Counterfactual Nobody switches
Weibull nobody switched

In the grey curve 100% of patients in placebo arm switches to the active treatment.

Kaplan-Meier OS unadjusted population placebo arm
Counterfactual Everybody switches
Weibull everybody switched
Kaplan Meier curve: Impact of switching in placebo arm on survival

- Kaplan-Meier OS unadjusted population placebo arm
- Counterfactual Nobody switches
- Counterfactual Everybody switches
- Weibull nobody switched
- Weibull everybody switched

70% of patients in placebo arm switches to the active treatment as seen in clinical practice (green line)

\[ S(t)_{\text{green}} = 30\% S(t)_{\text{red}} + 70\% S(t)_{\text{grey}} \]
Discussion

- The approach can be used to adjust the survival of the trial to reflect local clinical practice decision problems.
- This can easily be implemented in partition survival model (PSM) framework for health economic modelling purposes.
- Alternatives like treatment sequencing models have limitations:
  - How to derive efficacy after treatment switch, as in trial often many different treatment sequences are found?
  - If post treatment switch survival is time dependent transitions a more complex PSM model is required.
- All limitations of the cross-over methods apply here.
- More difficult situations like switching in active arm can be accounted for.