Using funnel plots and CUSUM techniques to monitor hospital-standardised mortality

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Overview

- Standardised Mortality Ratios
- Cross-sectional Comparisons: Funnel Plots
- Longitudinal Comparisons: CUSUMs

- Code examples on GitHub:
  - https://github.com/chrismainey/RSS_2019_FunnelPlot_CUSUMs

MORTALITY MEASUREMENT

Mortality Monitoring

- Mortality is an ‘outcome’ measure
- ‘Smoke alarms’ related to quality of care (Keogh,2013)
- Confused with being a quality metric
  - Not clearly linked with poor care (Lilford et al, 2004)
  - Low signal-to-noise ratio (Lilford & Pronovost, 2010)
  - Poor proxy of avoidable deaths (Girling et al, 2017)
- Susceptible to various biases (Mohammed et al ,2012)

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Standardisation

- Crude rates useful in a stable system
- “Case-mix” differs between hospitals and over time

- Two common ways to adjust for this:
  - **Direct Standardisation** (adjust all to common standard and compare)
  - **Indirect Standardisation** (adjust all to compare to average expected rate)

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Common Methods

- Hospital Standardised Mortality Ratio (HSMR) (Jarman et al, 1999)
  - Conditions accounting for ~80% in-hospital deaths
  - Extensive case-mix adjustment
- Summary Hospital-Level Mortality Index (SHMI) (Campbell et al, 2012)
  - All deaths in hospital or within 30 days of discharge
  - All admissions (excl. still birth)
  - Fewer case-mix factors than HSMR
- Both create stratified logistic regression models, per diagnostic group.
- Models used to predict probability of death per-patient

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Standardised Ratio

- 10 identical patients:
  - Risk factor of model
  - E.g. age, sex, primary diagnosis etc.
- If these patients had a probability of death of 0.3 (30%)
  - Expected deaths = 10 * 0.3 = 3
- If we then observed 4 deaths:

$$SMR = \frac{\sum Observed\ Deaths}{\sum Expected\ Deaths}$$

$$1.33 = \frac{4}{3}$$

- >1 = "higher than expected"
- <1 = "lower than expected"

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Visualising Uncertainty in SMRs

- Confidence intervals
- Process control theory:
  - Control limits
  - "Special-cause" variation
- Funnel plots (Speigelhalter, 2005a)
  - Plot measure of size (expected) on x-axis
  - SMR on the y-axis

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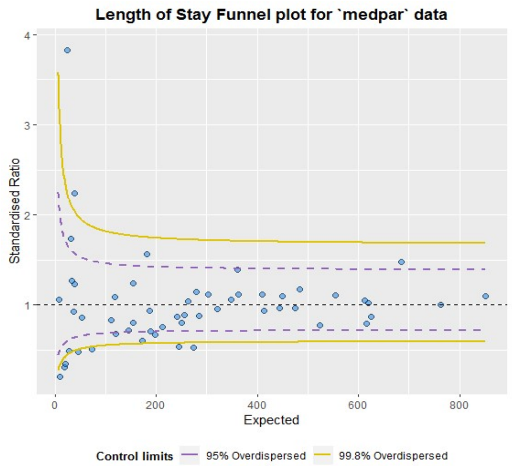
Issues with Funnel Plots

- Are we asking the right question?
- Implicit ranking
- Which limits do we use?
- Overdispersion
  - Assumed to be clustering
  - Adjustment proposed (Spiegelhalter, 2005b)
  - Alternative used by NHSD (plotted right)
- Strictly cross-sectional



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MONITORING MORTALITY OVER TIME

Monitoring Mortality over time

- Relative Risk snapshot not helpful
  – Denominator is not fixed
- Control chart approach attractive
  – Sensitive to variation over time
- Various other chart types suited to different questions:
  – P-charts, C-Chart, G-Chart etc.
- The challenge is the risk-adjusted element

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CUSUM

- Risk-adjusted, log-likelihood ratio, cumulative summary chart with triggers and resets.
- Accepted as ‘best’ option (Bottle & Aylin, 2011), given:
  – Ability to work with risk-adjusted data
  – Earliest alerting chart in comparison studies
- Two main applications:
  – Z-score-based aggregated CUSUM (Spieglehalter et al, 2012)
  – Patient level CUSUM (Steiner et al 2000)

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What are we plotting?

$$C_0 = 0$$
$$C_t = \max\{ C_{t-1} + w_t, 0\},$$

- Where C = is the cusum value, starting from 0,
- C_t the cusum value at observation/time-point t,
- w_t the cusum weight (log-likelihood ratio) for observation/time-point t.

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Z-score method

- Assume overdispersion, so model hierarchically
- We assume local trust mean (θ_k), with standard deviation (σ).
- Local means distributed around zero, with standard deviation (τ)

- CUSUM is a hypothesis test:
  - H_o: $\theta_k = \gamma_1\tau$ $\rightarrow$ Local mean within tolerance(γ_1), usually 0.5
  - H_1: $\theta_k = \gamma_1\tau + \gamma_2\sigma$ $\rightarrow$ Local mean (plus tolerance) + difference deemed 'out of control', usually 2.

- Transform to z-scores:
- *Detecting doubling of log-likelihood ratio, with 0.5 tolerance*

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Person-level method

- Based on method by (Steiner et al, 2000)
- Calculate a weight for each patient:

$$W_t = \begin{cases} \ln\left(\dfrac{1}{1-p+2p}\right) & y=0 \\ \ln\left(\dfrac{2}{1-p+2p}\right) & y=1 \end{cases}$$

- Plot consecutive patients, based on discharge date

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Triggers and Resets

- Threshold set for “trigger” to investigate
  - Normal approximation for z-score cusum (Grigg & Spiegelhalter, 2008)
  - Approximation within site/group (Bottle & Aylin, 2011)
- After trigger we reset at avoid continual triggers
  - Usually to zero
  - Imperial college method is to half, based on (Lucas and Crosier, 1982)

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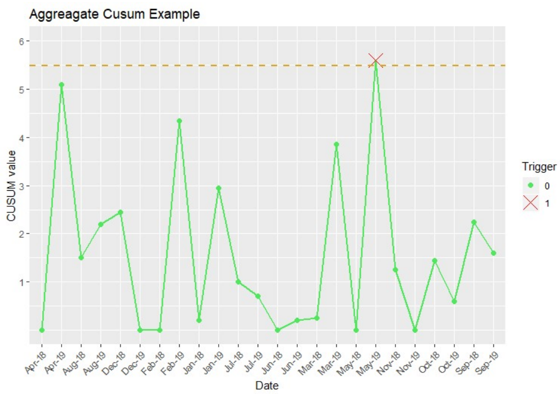
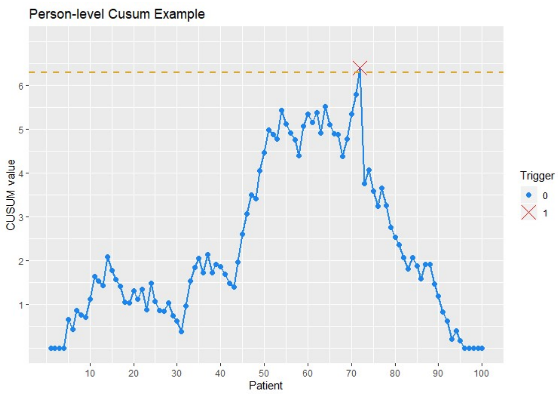
Example plots





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How are they used?

- Interactive modules and online tools
- Monthly email alerts
- CUSUMs built for diagnostic groups with both methods
- Use published approximation for person-level triggers

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Quick R plug…

- FunnelPlotR
  – is now available on CRAN:

- https://chrismainey.github.io/FunnelPlotR/
- https://github.com/chrismainey/FunnelPlotR

- Contributions and bug reports welcome!

FunnelPlotR

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Questions?

THANK YOU FOR YOUR TIME!

References

- BOTTLE, A. & AYLIN, P. 2011. Predicting the false alarm rate in multi-institution mortality monitoring. *The Journal of the Operational Research Society,* 62**,** 1711-1718.
- CAMPBELL, M.J., JACQUES, R.M., FOTHERINGHAM, J., MAHESWARAN, R. and NICHOLL, J., 2012. Developing a summary hospital mortality index: retrospective analysis in English hospitals over five years. *BMJ,* **344**, pp. e1001
- GRIGG, A.O., SPEGELHALTER, D.J., 2008 An Empirical Approximation to the Null Unbounded Steady-State Distribution of the Cumulative Sum Statistic. *Technometrics.* **50**(4), pp501 – 511
- JARMAN, B., GAULT, S., ALVES, B., HIDER, A., DOLAN, S., COOK, A., HURWITZ, B. and IEZZONI, L.I., 1999. Explaining differences in English hospital death rates using routinely collected data. *BMJ,* **318**(7197), pp. 1515-1520.
- KEOGH, B. 2013. *Keogh review on hospital deaths published - NHSUK* [Online]. Department of Health. Available: https://www.nhs.uk/NHSEngland/bruce-keogh-review/Documents/outcomes/keogh-review-final-report.pdf [Accessed 13/11/2017 2017].
- LILFORD, R. and PRONOVOST, P., 2010. Using hospital mortality rates to judge hospital performance: a bad idea that just won't go away. *BMJ,* **340**, pp. c2016.
- LILFORD, R., MOHAMMED, M.A., SPIEGELHALTER, D. and THOMSON, R., 2004. Use and misuse of process and outcome data in managing performance of acute medical care: avoiding institutional stigma. *The Lancet,* **363**(9415), pp. 1147-1154.
- MOHAMMED, M.A., DEEKS, J.J., GIRLING, A., RUDGE, G., CARMALT, M., STEVENS, A.J. and LILFORD, R.J., 2009. Evidence of methodological bias in hospital standardised mortality ratios: retrospective database study of English hospitals. *BMJ,* **338**, pp. b780.
- PITCHES, D., MOHAMMED, M. and LILFORD, R., 2007. What is the empirical evidence that hospitals with higher-risk adjusted mortality rates provide poorer quality care? A systematic review of the literature. BMC Health Serv Res, 7(1), pp. 91.
- SPIEGELHALTER, D., GRIGG, O., KIINSMAN, R., FAREWELL, V., T., TREASURE, T., Risk-adjusted sequential probability ratio tests: applications to Bristol, Shipman, and adult cardiac surgery. I*Int J Qual Health Care;* **15**, pp 7-13
- SPIEGELHALTER, D.J., 2005a. Funnel plots for comparing institutional performance. *Stat Med,* **24**(8), pp. 1185-1202.
- SPIEGELHALTER, D.J., 2005b. Handling over-dispersion of performance indicators. *Qual Saf Health Care,* **14**(5), pp. 347-351

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