Control, compare and communicate: designing control charts to summarise efficiently data from multiple quality indicators

B Guthrie, T Love, T Fahey, A Morris, F Sullivan

Summarising the complex data generated by multiple cross sectional quality indicators in a way that patients, clinicians, managers and policymakers find useful is challenging. A common approach is aggregation to create summary measures such as star ratings and balanced score cards, but these may conceal the detail needed to focus quality improvement. We propose an alternative way of summarising and presenting multiple quality indicators, suitable for use for quality improvement and governance. This paper discusses (1) control charts for repeated measurements of single processes as used in industrial statistical process control (SPC); (2) control charts for cross sectional comparison of many institutions for a single quality indicator (rarely used in industry but commonly proposed for health care); and (3) small multiple graphics which combine control chart signal extraction with efficient graphical presentations for multiple indicators.

In the UK and internationally, comparison of the quality of care in different healthcare institutions is increasingly common, but there is uncertainty about the most effective way to present the data to clinicians, managers, or patients. The way that data are presented is known to affect interpretation of treatment effectiveness and risk, and there is some evidence that the form of graphic chosen influences interpretation of quality data by the public and professionals.

This paper focuses on comparative analysis of primary care performance data from a quality improvement perspective, where measures are treated as indicators that prompt further investigation rather than being used to make definitive judgements that a practice is “good” or “bad”.

A number of general considerations are applicable, irrespective of the form of graphical analysis used. Firstly, the quality measures themselves have to be valid and reliable.

Secondly, careful consideration should be given to what the appropriate comparator is—which may be locality, regional and national means, or comparisons against practices serving similar populations in terms of deprivation, urban/rural, or age distribution (as a way of incorporating some case-mix adjustment). Finally, where statistical techniques are used to identify outliers, an explicit choice needs to be made about where to set confidence or control limits.

This paper focuses particularly on the use of control chart techniques when applied to data from multiple quality indicators. As examples it uses Scottish immunisation data, data extracted from a comprehensive, population based, externally validated diabetes register in the Tayside region of Scotland, and data from one practice collected as part of the requirements of the new UK general practice contract.

LEAGUE TABLES
League tables are ubiquitous in health care and other sectors for interpreting cross sectional quality data comparing different institutions. Figure 1 shows a league table for the proportion of patients with type 2 diabetes whose glycated haemoglobin is ≤7.4% in the 12 months before 31 December 2003 in all general practices in the Tayside region of Scotland. Practices are plotted in ascending order of measured performance and the horizontal line shows the regional mean (55.6%) for comparison.

Such a league table has the advantages of familiarity and ease of interpretation, but the disadvantage of implying considerable variation between practices and overemphasising the ranking and the ends of the distribution (the “best” and “worst”). However, ranks are statistically highly unreliable, and most of the variation implied cannot be distinguished from chance. More sophisticated versions follow biostatistical convention by including 95% confidence intervals around each practice point to allow a test of whether the practice is different from the mean, but are less commonly used (fig 2). Although they more appropriately account for chance variation, they require some prior knowledge or instruction to interpret.

CONTROL CHARTS FOR LONGITUDINAL DATA
Control charts are a tool developed for industrial statistical process control (SPC) where they are used to examine the performance of a single process over time. All processes are considered subject to common cause variation, which is the sum of all random events influencing the process being measured. Such variation is predictable within a range defined by statistical theory and requires no intervention. Special or assignable causes are specific non-random disturbances
which control charts are designed to identify to allow intervention to remove them.13

Figure 3 shows a longitudinal control chart11 for the percentage of Scottish children with completed primary tetanus immunisation at the age of 1 year.10 The central horizontal line shows the mean for June 1996 to December 2000 (95.2%). Following US industrial convention, control and warning limits set at three and two standard deviations from this mean are shown by the two outer and inner lines.14 There are a number of potential signals of special cause variation, several of which are present here (box 1).

Firstly, immunisation rates were lower than expected in the four quarters from March 2001. Secondly, more recent performance has improved (10 successive points plot above the historical mean). Thirdly, there is a seasonal pattern in the early part of the time series. Investigating the reasons why special cause variation is present may identify remediable problems or identify examples of good practice that can be generalised. For example, lower rates in 2001 were probably caused by a vaccine shortage15 (the data for 2 year olds shows no dip, consistent with some delayed immunisation). Equally, if recent improvement is predominately in a few Health Boards, then there may be generalisable lessons for other areas.

The attraction of SPC methods for longitudinal data is that they are statistically informed and rigorous, but pragmatic with a long history of use in other settings. Users are not required to understand the underlying statistics because the chart summarises complex data by signalling likely special cause variation to prompt appropriate further investigation or action.

Figure 3 Control chart for percentage of 1 year old children in Scotland with three tetanus vaccinations (p chart for proportional data with varying denominator).

CROSS SECTIONAL CONTROL CHARTS FOR SINGLE MEASURES

Unlike industrial uses where the focus is on longitudinal measurement of single settings,13–14 healthcare quality data analysis is usually of cross sectional data from many settings. Control charts for cross sectional data have been proposed,31 16 and fig 4 uses a funnel plot design to analyse the same diabetes data as in fig 1.17 The horizontal line shows the regional mean, with exact 95% warning limits and 99% control limits plotted around it. Practices plotting outside the control limits are considered to show special cause variation requiring further investigation or action. However, because each practice only contributes one plotted point, the only extractable signal that depends on patterns of two or more points is that the chart may give a visual indication of systematic differences in quality between smaller and larger practices.17

Although their interpretation is less intuitive than the league table, most professionals can use them appropriately with minimal instruction.7 Control charts avoid the problems of ranking in league tables, and clearly indicate that most of the variation between practices is what would be expected by chance or common cause variation. They have been used where a single quality indicator is assumed adequately to capture the overall quality of care for an episode, particularly in the analysis of surgical mortality.10–20

Box 1 Commonly used signals of special cause variation in longitudinal control charts13

<table>
<thead>
<tr>
<th>Signals based on plotting a single new point</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Any single point outside a control limit</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Signals based on patterns of two or more plotted points</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Two out of three consecutive points between a warning limit and a control limit</td>
</tr>
<tr>
<td>• Eight or more consecutive points on one side of the mean</td>
</tr>
<tr>
<td>• Eight or more consecutive points in a continually ascending or descending run</td>
</tr>
<tr>
<td>• Any unusual or non-random pattern</td>
</tr>
</tbody>
</table>

Figure 1 Simple league table and regional mean for glycaated haemoglobin control in type 2 diabetes in Tayside practices.
In the context of healthcare quality indicators, each cross sectional control chart can be reduced to a set of varying strength signals of evidence of special cause variation. Figure 5 shows an example intended to facilitate comparison of neighbouring practices for a locality based quality improver. A colour version can be found in the online supplement available at www.qshc.com/supplemental. It displays comparative data for 13 indicators of the quality of type 2 diabetes care in 14 practices in one locality. Each dot encodes the control chart signal for one indicator in one practice, where the comparator is the overall Tayside mean and control and warning limits are defined with exact 99% and 99.9% probability. Examining the columns can identify practices outlying on multiple indicators where there are likely to be systematic factors affecting quality for better or worse (for example, practices 4 and 10). Single signals may still be deserving of attention but are less likely to be meaningful given the multiple comparisons being made (for example, practices 12 and 3). Examining the rows can identify indicators where there may be a more global problem across the locality compared with the area mean (for example, the pattern seen for foot examination may relate to access to podiatry within this locality).

Figure 6 takes a similar form but is designed to facilitate comparison of indicators within one practice. It compares related indicators across disease areas. Examining the columns allows comparisons of diseases across common indicators (for example, quality of care for diabetes in this practice appears generally better than that for other conditions). Examining the rows compares indicators shared across disease areas (for example, the chart suggests a potential quality problem across the diagnostic indicators). In principle, for a single practice all 65 of the continuous indicators in the new GMS contract could be summarised on a single sheet.

The key advantage over multiple graphs for single measures is that it is easier to detect patterns in the data to help users interpret complex sets of indicators that are related to each other. Although we have used control chart techniques to signal that a practice is different from average, the same kind of graphic could be constructed using signals from league tables with varying width of confidence interval.

CONCLUSIONS

Single measure control charts are more statistically robust than simple league tables, but neither is ideal where quality
Finally, graphical tools should be designed to suit the needs of their intended audience. This paper focuses on use by professionals and managers, but other graphical analyses are likely to better suit patient and public use for choice or accountability.\(^3\) Although there are grounds for believing that well designed graphical analyses can promote quality improvement, the actual usefulness of any particular design can only be judged after implementation. We plan to pilot the implementation of these designs within the single Scottish Diabetes IT system (SCI-DC) to examine this further.

Immunisation data were supplied by the Information and Statistics Division of NHS Scotland, the GP contract data by the Ferguson Medical Practice, and the diabetes data by the DARTS/MEMO. For the latter, the authors thank Philip Thomson and Douglas Boyle for assistance in data extraction, GPs and other clinicians in Tayside, and the members of the DARTS Steering Group (D Boyle, B Brennan, K Boyle, J Broomhall, F Cargill, P Clark, A Connacher, S Cunningham, E Dow, D Dunbar, A Dutton, S Greene, K Hunter, R Jung, M Kenicer, B Kilgallon, G Leese, R Locke, T MacDonald, R McAlpine, S McKendrick, R Newton, P Slane, F Sullivan, R Walker, S Young). DARTS is supported by the Scottish Executive, Tayside University Hospitals NHS Trust and Tayside Primary Care NHS Trust.

### Figure 6

Selected new GMS contract indicators for one practice compared against arbitrary standard.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>QID</th>
<th>Stroke</th>
<th>Diabetes</th>
<th>Hy.</th>
<th>Asthma</th>
<th>COPD</th>
<th>All patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Had influenza vaccination</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>✓</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Smoking recorded</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Smoking advice given</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>BP measured</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>BP controlled ≤150/90</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Cholesterol measured</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td></td>
<td></td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Cholesterol controlled ≤5</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td></td>
<td></td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Appropriate diagnosis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>On antplatelet or warfarin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

- ○ Much better than comparator (outside upper control limit)
- ○ Better than comparator (between upper warning and control limits)
- ○ Achieving comparator
- ○ Worse than comparator (between lower warning and lower control limits)
- ○ Much worse than comparator (outside lower control limit)

**Colour versions of figures 5 and 6 are shown in the online supplement available at the QSHC website www.qshc.com/supplemental.**

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This study was funded by the Health Foundation and the Chief Scientist’s Office of the Scottish Executive Health Department.

Competing interests: none.

BG had the idea for the paper, designed the first version of the small multiples, and wrote the first draft. All authors discussed the results, contributed to development of the design, and wrote the paper.

Ethical approval for the study was granted by Tayside local research ethics committee.

**REFERENCES**


