The role of quantitative feedback in coronary angiography radiation reduction

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Abstract

Objective. To evaluate the benefits of radiation education with and without feedback reporting in altering clinician radiation use behaviour in performing coronary angiography (CA).

Design. A retrospective review of radiation use (fluoroscopy time) in coronary angiograms performed between July 1996 and December 2005 by 10 cardiologists to assess the impact of various interventions aimed at minimizing radiation risk. The impact of interventions such as education and audit/feedback was correlated against radiation use using cumulative sum and cumulative expected minus observed charts.

Setting. Private Hospital in Brisbane, Australia.

Participants. Ten cardiologists.

Intervention. Education and audit/feedback.

Results. Baseline radiation use subject to standard guidelines was stable. Group performance charts show a modest transient improvement in radiation use associated with an education intervention alone. However, regular detailed personalized feedback comparing an individual’s radiation use to group and external benchmarks was successful in achieving sustained reduction in overall radiation use. For individual participants, significant improvement was noted in 7 of 10 cardiologists.

Conclusion. Although an improved theoretical understanding of effective radiation hygiene strategies might contribute to reduced radiation use, this study suggests that regular detailed quantitative feedback supporting education is an effective tool in altering radiation use in CA. Understanding triggers that stimulate change in clinician behaviour is critical to the design of systems to optimize clinical performance. Confidentially reported benchmarking systems may be a useful tool to alter clinician behaviour.

Keywords: feedback, audit, behaviour, radiation, coronary angiography

Introduction

Quantitative performance monitoring has been accepted in many industries, particularly manufacturing, as an essential step in the quality improvement cycle. Although a number of approaches for quality improvement have been applied within the health-care industry, including provider education, audit and feedback [1], the effects of these approaches have been inconclusive [2]. In addition, interventions intended to change clinical practice are rarely designed using a theory-based approach [3]. Radiation risk management in clinical practice is an illustration of this approach with most professional guidelines [4–6], typically only emphasizing the role of education as the prime intervention. In regard to audit processes, there has also been considerable debate within the health-care industry about the relative merits of confidential-peer review reporting systems when compared with public performance reporting [7]. Education and guidelines are often proposed as effective strategies to influence clinician behaviour. However, previous work by others [2] suggests that an appropriately managed audit and feedback programme may more successfully achieve greater long-term sustained improvement.

The recent increased use of radiation-based imaging modalities in cardiology has heightened awareness of total individual radiation exposure. During the diagnosis and treatment of chronic illnesses, such as coronary artery disease, patients often undergo a series of imaging procedures most of which involve the use of ionizing radiation [8]. Increased sensitivity of cardiologists to the issue could be fuelled by
reports suggesting that man-made radiation has equalled natural radiation as a source of human exposure (with exposure from medical sources being the major contributor) [9]. The detrimental effects of radiation have long been understood with published evidence of severe X-ray induced injuries appearing as early as 1 month after X-rays were discovered [10]. Precise risks associated with medical radiation are, however, unknown but some perspective can be gained from one recent estimate [11] suggesting that up to 2% of all new cancer cases in the USA might be due to computerized tomography (CT) use alone.

To address this issue, professional bodies responsible for establishing and maintaining standards of clinical practice [4–6] and regulators charged with controlling the use of ionizing radiation [12, 13] have implemented strategies aimed at ensuring that the benefits derived from the various radiation-based procedures significantly outweigh the risks involved. A common and often dominant requirement for most radiation risk minimization programmes is regular user education [4–6, 14, 15]. In spite of these efforts, however, studies continue to demonstrate poor awareness amongst physicians and radiologists of the radiation doses associated with the procedures they commonly request or perform [16–18].

Behaviour modification theorists [3], however, suggest that reliance on a single intervention strategy, such as education, is flawed. The ‘Theory of Planned Behaviour’ [19], for example, builds on the concept that for change to take place three factors need to be considered and addressed; an individual’s perceptions concerning the advantages and disadvantages of performing a particular behaviour, the perceived importance of the change to ‘significant others’ (and how much the individual values the opinions of these others regarding the alternative behaviour), and whether or not the objective behaviour is possible. Programmes built around education alone may address the first factor but not second or third factors. It is possible that addition of a programme of audit and feedback of both groups and individual performance can not only reinforce the belief that outcomes are important to others but also demonstrate that change is possible by providing comparison to realistic benchmarks of excellence.

In this study, we evaluate the effectiveness of annual personalized confidential quantitative feedback as an adjunct to radiation protection education intervention in stimulating change in radiation use by a group of experienced cardiologists performing coronary angiography (CA) in a single centre. Through this analysis, we seek to better understand the combination of interventions that may be a useful in modifying clinician behaviour.

**Methods**

**Radiation safety interventions**

The entire cardiology group involved in this study undertook a 4-h long compulsory radiation safety training course in October 2001 comprising both theory and practical elements. The requirement for cardiologists to undertake this course arose out of the introduction of the Queensland Radiation Safety Act 1999 [13]. Under this, legislation cardiologists intending to use irradiating apparatus must be licensed to administer radiation to patients. Subsequent to this course, the Radiation Safety Officer at St Andrew’s War Memorial Hospital (SAWMH) introduced a number of radiation feedback mechanisms to provide all of the cardiologists with confidential quantitative information concerning comparative individual and group radiation use. The data provided were specific to the individual clinician’s performance in the main procedural subclasses performed in the SAWMH cardiac imaging facility (diagnostic CA, studies of coronary artery bypass grafts, angioplasty procedures, electrophysiology studies and device implant procedure). Table 1 provides a summary of the information provided to each cardiologist at the various intervals. Data were categorized into procedure type with the information regarding each procedure comprising an analysis of the radiation metric available. As described in this table, the content of the feedback varied at each interval, however, it was delivered in the form of a written report containing graphical and tabular data that compared the individual clinicians radiation use (procedural volume along with median and inter-quartile range) for each of the procedural sub-classes in which they were involved. In addition to the radiation use information shown in Table 1, the feedback in 2004 and 2005 also outlined a range of strategies that could be applied to reduce radiation use as well as comparisons with external benchmarks (where available).

<table>
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<th>Feedback date</th>
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<th>Group</th>
</tr>
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<tr>
<td></td>
<td>Annual volume</td>
<td>Current year</td>
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<tr>
<td>November 2002</td>
<td>Yes</td>
<td>FT</td>
</tr>
<tr>
<td>November 2003</td>
<td>Yes</td>
<td>FT and DA</td>
</tr>
<tr>
<td>November 2004/2005</td>
<td>Yes</td>
<td>FT, DA and DAP*</td>
</tr>
</tbody>
</table>

*aCurrent year’ refers to analysis of data for procedures performed in the 12 months prior to the feedback report while ‘Previous year’ relates to the 12 months prior to that. The radiation metrics comprised summaries of FT, digital acquisition frame count (DA) and dose area product (DAP).
Study data

Records available for review related to adult diagnostic CA imaging procedures undertaken at SA WMH in the period from January 1997 to December 2005. Data for each procedure comprised basic patient details (age and gender), a measure of radiation use in the form of total case fluoroscopy time (FT) as well as clinical diagnostic details describing the extent of any disease present. It is acknowledged that more sophisticated measures of radiation use are available such as number of frames acquired, dose area product, peak skin dose and effective dose, however, these were not recorded in the period prior to the radiation safety course in October 2001 and hence were not available for study. In any event as general practice at SA WMH is for the cardiologist to have direct control over the use of fluoroscopy, measures of FT will better reflect clinician attitude to radiation use. Due to the variation in radiation dose associated with differing levels of case complexity [20], analysis of radiation use over time was limited to only those cases with minimal disease burden.

To allow trends to be fully analysed, only procedures performed by cardiologists working consistently throughout the entire study period were included. Therefore, of the 32 cardiologists performing procedures in the SA WMH Cardiac Catheter Theatre (CCT) during the period of study, 22 were excluded as they: commenced after January 1997 (4), ceased work at SA WMH around the time of the education intervention (2), made only sporadic use of the facilities (4) or were very low volume (<10 cases per year) users of the facility (12). Therefore, in total, procedures performed by 10 experienced cardiologists (accounting for 77% of the total CA volume) have been considered. Across the period of study, procedures were performed in two identically configured image intensifier equipped catheterization laboratories. Towards the end of 2004, a third catheterization laboratory employing a digital flat panel detector was commissioned. After applying the various inclusion criteria, the study involved analysis of radiation use in 2029 procedures with 1012 procedures occurring before delivery of the education. Analysis of patient data relating to these procedures did not reveal any major trend in either patient age or gender throughout the period of this study.

For this study, the benchmark defining high radiation use has been set at an FT equivalent to the 75th percentile of the group radiation use in the period prior to the mandated radiation safety training course (a level of 2.8 min of FT per case). Use of the 75th percentile FT value as a benchmark level conforms to the model proposed for the establishment of diagnostic reference levels in radiology [12]. An additional sensitivity analysis was performed to assess the impact of using alternative threshold values such as the median and 25th percentile FT values.

Data analysis

Clinician radiation use summaries (median and interquartile range) were determined for the two periods pre- and post-radiation safety training. These data were analysed to determine whether differences existed in overall use patterns. While this analysis is useful in determining the significance of changes in radiation use between the two periods, it does not provide any indication of the timing of any changes.

To provide this analysis, techniques taking into account procedure date have been used to explore the change in frequency of cases exceeding the defined benchmark over time. The graphical techniques used involve the cumulative expected minus observed (E – O) chart [21] and cumulative sum (CUSUM) chart [22].

The cumulative E – O chart is a very basic form of CUSUM chart. As the description implies, the chart is derived by cumulatively summing the difference between the expected and observed outcomes of a procedure. The expected outcome in this analysis is the average probability that a case will involve an FT exceeding the stated benchmark, while the observed outcome is either 1 or 0 depending on whether it actually does (or does not). As we have used the 75th percentile FT (2.8 min) as our benchmark, the expected probability is 0.25. This type of chart is good for visual inspection as it shows, over time, how many events more or less have been observed compared with what was expected.

The CUSUM chart is constructed by cumulatively summing the difference between the observed and expected values related to the parameter being monitored. The resultant sum is compared with a predefined decision threshold (‘h’) and is said to signal when the threshold is breached (this normally triggers a review of the factors contributing to the outcome change). After a signal (and subsequent investigation), the CUSUM is reset to zero and monitoring continued. The chart used in this analysis is the double-sided CUSUM described by Steiner and Cook [23], which is based on the log-likelihood ratio. The log-likelihood ratio is derived using the expected and observed outcomes described previously. As applied in this analysis, these charts provide a running statistical analysis, updated after each procedure, that simultaneously tests the hypotheses that the odds of a case involving prolonged FT has doubled or halved.

These charts were selected for their abilities to identify subtle sustained changes in a process with the E – O chart being used for its ease of interpretation while the CUSUM provides a more robust statistical analysis of the significance of any change.

Data from the 1012 procedures performed prior to delivery of the education were used to establish baseline measures for individual cardiologists and group performance. As such, the cardiologists acted as their own controls for individual and group performance analysis. For the CUSUM chart, the ‘h’ value (alarm level) for the two charts has been set at an average run length to signal while in control ($ARL_0$) of 5 years. This design criterion results in an ‘h’ value of 4.4 for charts monitoring group performance with a doubling or halving in the odds being reached with average run lengths of 11 and 24 weeks, respectively.
Statistical notes

Due to the skewed nature of the data distributions in this study, the median and interquartile range have been used to describe population central tendency and dispersion. The Mann–Whitney ‘U’-test has been used to assess the difference between two patient populations. In all cases, a statistical significance level of 5% has been used.

Results

Table 2 provides a summary of the individual FTs for cardiologists prior to and following radiation safety education (October 2001) and introduction of radiation use feedback (annually from November 2001). Analysis shows that median FT for the group decreased significantly from 2.1 to 1.7 min ($P < 0.001$). On an individual basis, absolute radiation use per case decreased for all cardiologists, but the change was not significant for three.

The E–O chart (Fig. 1) and CUSUM chart (Fig. 2) show trends in radiation use for the cardiology group from January 1997 to December 2005. The top chart in Fig. 2 is a running test assessing whether the odds of a patient undergoing a procedure involving an FT exceeding the target threshold has doubled; while the lower chart tests whether the odds have halved. In the period prior to the radiation safety training intervention (October 2001), the radiation use pattern of SAWMH clinicians was relatively stable. The two alarm signals (alarm level breaches) noted in the pre-education period of the CUSUM charts are most likely due to the accumulation of random chance events. Consideration of the CUSUM design shows an ARL$_0$ of 5 years was used to stratify the two groups of data. Reference to the E–O chart confirms that these alarm signals were correlated with short-term clusters of high FT cases. Additional graphs for the patient population central tendency and dispersion. The Mann–Whitney ‘U’-test has been used to assess the difference between two patient populations. In all cases, a statistical significance level of 5% has been used.

Discussion

Review of data presented in Table 2 suggests that significant change in overall radiation use, as indicated by FT, has been achieved in the 4 years following the radiation safety training course ($P < 0.001$). At an individual level, a reduction in FT has been noted by all cardiologists with seven achieving reductions that were significant ($P < 0.05$). This bulk analysis of data, however, is misleading as it could be interpreted that education alone was the change agent (the point in time used to stratify the two groups of data). Reference to the E–O chart (Fig. 1) and the CUSUM (Fig. 2) charts provides a clearer identification of when change took place and for how long the change was sustained. These charts show that in the first few months following radiation safety training, there was a rapid favourable impact on FT. This initial change was not sustained, however, and the graphs indicate a return to the pre-education FT levels. From the group perspective, sustained change in radiation use does not appear to have been established until some time after the second personalized feedback report in November 2002 (with the first signal occurring August 2003). There was also a delay between the third personalized feedback report and a reduction in radiation use. These delays in radiation reduction are suggestive of a gradual change in the cardiologists’ behaviour. A more discrete time point of change is difficult to detect for a

<table>
<thead>
<tr>
<th>Cardiologist</th>
<th>Pre-education</th>
<th>Post-education</th>
<th>$P$ Value</th>
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<tbody>
<tr>
<td></td>
<td>$n$</td>
<td>FT (min)</td>
<td>$n$</td>
</tr>
<tr>
<td>C1</td>
<td>69</td>
<td>2.1 (1.7–2.7)</td>
<td>75</td>
</tr>
<tr>
<td>C2</td>
<td>56</td>
<td>2.7 (2.2–3.5)</td>
<td>102</td>
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<tr>
<td>C3</td>
<td>123</td>
<td>1.4 (1.2–1.9)</td>
<td>131</td>
</tr>
<tr>
<td>C4</td>
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<td>2.1 (1.8–2.8)</td>
<td>160</td>
</tr>
<tr>
<td>C5</td>
<td>154</td>
<td>1.8 (1.5–2.5)</td>
<td>106</td>
</tr>
<tr>
<td>C6</td>
<td>124</td>
<td>2.1 (1.8–2.8)</td>
<td>199</td>
</tr>
<tr>
<td>C7</td>
<td>63</td>
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<td>50</td>
</tr>
<tr>
<td>C8</td>
<td>160</td>
<td>2.0 (1.6–2.7)</td>
<td>100</td>
</tr>
<tr>
<td>C9</td>
<td>87</td>
<td>2.5 (2.1–3.4)</td>
<td>78</td>
</tr>
<tr>
<td>C10</td>
<td>24</td>
<td>2.4 (1.9–3.3)</td>
<td>16</td>
</tr>
<tr>
<td>Overall</td>
<td>1012</td>
<td>2.1 (1.6–2.8)</td>
<td>1017</td>
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</table>

*Conducted in November 2001. FT (min) are expressed as the median and inter-quartile range.
group of 10 individuals since each cardiologist would be exploring different ways of performing CA in light of receiving feedback regarding their individual radiation use. The improvement in performance, however, was sustained for the remaining period of analysis.

For individual cardiologists, the response to the various change interventions has been markedly different. The E–O charts for cardiologists C3, C6 and C8, respectively, show no effect, delayed improvement and prompt change in response to the education intervention. The response of C3 needs to be highlighted as this individual started with the lowest FT and as such may have already been operating as efficiently as is possible without compromising clinical practice. For C8, it is possible that education alone was a sufficient trigger to stimulate change while for C6 the additional encouragement to change coincided with the provision of quantitative feedback and the likely demonstration that group use of radiation was changing. However, it cannot be discounted that other factors may have influenced practice change over this period. For example, some of the cardiologists in this study perform cardiac imaging procedures in other facilities. Therefore, it is conceivable that techniques used to reduce radiation may have been transferred from other hospitals to SA WMH on an individual basis. In addition, heightened awareness of radiation protection issues brought about through local legislative changes [24] and the release of key practice standards, guidelines and reports [4, 5, 25] within the same time period as the education intervention might have also heightened the cardiologists’ awareness of radiation use and therefore could have contributed to a change in behaviour.

While this study has been limited to analysing trends in FT associated with low disease burden diagnostic CA, it will be important to determine whether the radiation awareness

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**Figure 1** Cumulative E–O chart showing FT for all cardiologists over a period of 9 years (January 1997 to December 2005). Also shown are the trends in FTs for cardiologists 3, 6 and 8. The mandatory radiation safety training course occurred in October 2001 (dotted line). Timing of provision of personalized feedback is indicated by the letter ‘A’.

**Figure 2** Double-sided CUSUM chart monitoring changes in rate of FTs exceeding the entire cardiologist group benchmark time (75th percentile). Radiation safety training course indicated by the vertical dotted line with timing of personalized feedback indicated by the letter ‘A’. Solid dots indicate that the alarm limits have been reached, at which point the chart has been reset to zero and monitoring continued.
strategy and reporting system translates into dose reductions in more complex angiography cases, angioplasty and electrophysiology studies where higher levels of radiation use are expected. The magnitude of the absolute dose reduction is small but cardiology patients typically undergo multiple imaging and intervention procedures with potential for large cumulative doses. Physicians should attempt to minimize dose at all exposure points and this type of radiation awareness strategy might have potential value for broader algorithms to minimize patient, clinician and associated procedural staff risk by promoting lower radiation interventions where feasible.

One conclusion that might be drawn from this evidence is that knowledge of radiation risk or of effective radiation reduction strategies does not necessarily in itself lead to a better appreciation of individual case-based radiation issues or alternately may not translate into a clear motivating factor or mechanism for behaviour change. Programmes relying predominantly on guidelines and education may not be the most effective course of action to reduce radiation use, although these factors may be prerequisites for a successful change environment or intervention. Studies on individual behaviour modification [3, 19] and clinical outcomes improvement [7, 26] indicate the need for additional interventions to promote change.

As for how the cardiologists were practically able to reduce their radiation use, the education course delivered in October 2001 covered strategies that could be employed to reduce case radiation use. This information was reinforced through a practical session conducted as part of the education programme. Although the full list of radiation use reduction techniques covered included some that would not be expected to have a direct effect on case fluoroscopy use (such as collimation, frame rate selection and projection orientation), other techniques such as reducing the number of views employed, minimizing the X-ray on time and maximizing the use of the last image hold facility do have clear links to FT. As noted in the description of material provided to the cardiologists in their annual feedback, the information provided included both summaries of individual radiation use (comparing this to internal and external benchmark data) as well as supplementary material that reiterated the radiation risk reduction strategies presented in the initial education and practical sessions. It is likely that the combination of information on personal comparative radiation use and recommendations on how to reduce this use (without impacting on clinical outcomes) was an important component in driving change in this instance. Private or confidential reporting systems do not utilize the ‘name and shame’ behaviour attributed to public reporting. Private reporting systems of this type provide objective benchmarking, tools to reinforce practice and represent a collegiate form of education that employs a team approach with a focus on continued improvement. All the cardiologists in this study were highly experienced with long-established behaviour patterns for performing angiography. It appears that the benchmarking system gave each participant a mechanism to challenge their own established patterns of behaviour and a motivation to change.

Our study has not explored the factors that motivated change in the cardiologist group but an analysis of these factors is planned. Motivation to improve patient outcomes is likely to underlie all successful changes but factors specific to this intervention such as competitive behaviour, demonstration of feasibility of improvement, quantitative tools and team support for the change process may be relevant. Removal of barriers to change and patterns of behaviour might also have facilitated improvement.

Quantitative confidential individual performance reporting against group and reported benchmarks was an effective tool for initiating and sustaining change in radiation use amongst a group of experienced cardiologists. This intervention appeared superior to previous approaches employing guidelines and general radiation safety education.

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References


