Does grid-controlled fluoroscopy lower patient doses during adult cardiac procedures?

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\textbf{Abstract:} \textit{Purpose:} Commercial companies advertise grid–controlled fluoroscopy as a tool that significantly lowers patient and consequently staff doses. In the haemodynamic unit of Athens General Hospital, a Philips Allura FP10 digital flat panel system equipped with a grid-controlled X-ray tube has been installed in 2004. Twenty months later, the grid ceased to function and the question arose whether the X-ray tube should be replaced. Since the cost of grid-controlled X-ray tube is very high, it was decided that the laboratory should continue working as long as the X-ray tube would function. \textit{Material and Method:} Since interventional procedures are known to be associated with high radiation doses, patient doses are routinely recorded. The data include fluoroscopy time, number of images acquired, as well as the total and fluoroscopic Dose-Area-Product (DAP) dose delivered to patient. From our dose records patient doses collected during Coronary Angiography (CA) and Percutaneous Transluminal Coronary Angioplasty (PTCA) with and without the grid-controlled fluoroscopy present were compared on a total sample of 998 patients. \textit{Results:} The analysis of the results showed that (a) no statistically significant patient dose increase was noticed with grid not in use, (b) the difference in fluoroscopy time was not statistically significant for CA procedures, while it was statistically significant for PTCA procedures and (c) for both kinds of procedures the difference in number of frames, with and without the grid in use, was statistically significant (more frames when grid not in use). \textit{Conclusion:} The results of this study suggest that hospital administrators may question the costly investment on grid-controlled X-ray tubes, with the deficient function of which -during adult cardiac diagnostic and therapeutic interventions-, patient dose does not increase, even when more frames are recorded.
1. Introduction

Fluoroscopy produces real-time images, directly visible to the eye during an X-ray examination, thus making it a very powerful diagnostic tool. However, due to the length of the fluoroscopic examinations, the exposure rate must be kept much lower than in common radiography, 100-200 times lower than when exposing film or storage phosphor cassettes [1].

The radiologist can control the overall real-time fluoroscopy and the number of recorded images that comprise the examination and hence the resultant patient’s total radiation exposure. Radiation exposure due to fluoroscopy can be further reduced by using pulsed fluoroscopy rather than the conventional, continuous fluoroscopy. Pulsed fluoroscopy has multiple available pulse rates (number of radiation beam pulses per second) and pulse widths (duration of each pulse). Multiple studies proved that pulsed fluoroscopy decrease considerably the radiation exposure [2-7]. However, in order to optimise radiation exposure, one needs not only to reduce radiation exposure but also to maintain an acceptable image quality.

Pulsed fluoroscopy is produced either by kVp pulsed fluoro or grid-pulsed fluoro. The kVp pulsed fluoro, where kVp voltage to the X-ray tube anode is turned on and off at the pulse rate, typically 4±15 pulses/s [8] presents some electrical engineering complexities which are associated with the rapid turning on and off such high voltages. Thus, kVp-pulsed fluoro may produce low kVp X-ray tails (at the rise and fall of each X-ray pulse). These low-energy tails would produce smearing of temporal resolution in the image of moving objects, and because of their very low energy, these tails would then also deliver unnecessarily high exposures to the patient's skin.

In grid-pulsed fluoro, the X-ray tube anode is kept continuously energized at the kVp voltage, but the electron beam in the X-ray tube can be sharply turned on or off using a grid (essentially a metal cup) that surrounds the X-ray tube filament. Grid switching involves only low voltages, which has not therefore the electrical engineering complexities that are involved in the pulsing of the high-voltage anode kVp circuit. Because grid-pulsing should produce no leading or trailing low-energy tails on the X-ray pulses, grid-pulsed fluoroscopy presents both improved temporal resolution and an absence of the objectionable excess radiation dose from X-ray pulse tails. This is particularly useful when very short exposures with rapid transitions are needed e.g. in cinefluorography [9-10].

Cardiac catheterization procedures are known to expose patients to high levels of radiation [3-4, 11-12]. Moreover, the increasing number of therapeutic procedures using X-ray radiation is a cause for concern about patients’ radiation exposure as they are known to require lengthy fluoroscopy times as well as a considerable number of radiographic exposures.

Commercial companies advertise that “… pulsed fluoroscopy and grid controlled fluoroscopy (GCF) system is regulated by a highly advanced in-pulse control circuit that optimises each pulse independently. The grid switched X-ray tube combined with Philips in-pulse control eliminates exposures that are too short or too long …. Thus GCF fluoroscopy may offer a 80–90% decrease in radiation dose to patients” [13].

2. Material and Method

In the haemodynamic unit of Athens General Hospital, a Philips Allura FP10 digital flat panel system equipped with a grid-controlled X-ray tube has been installed in 2004. Twenty months later, the grid ceased to function and the question arose whether the X-ray tube should be replaced. Since the cost of grid-controlled X-ray tube is very high, it was decided that the laboratory should continue working as long as the X-ray tube functioned.
Since interventional procedures are known to be associated with high radiation doses, patient doses are routinely recorded. The data gathered include fluoroscopy time, number of images acquired, as well as the total and fluoroscopic Dose-Area-Product (DAP) dose delivered to patient. Moreover information on cumulative dose and number of runs is provided by the system.

Patient doses were collected during 561 Coronary Angiographies (CA) and 437 Percutaneous Transluminal Coronary Angioplasties (PTCA). From this data, 725 cases were recorded with the grid present whereas 273 cases were recorded after the grid ceased to function.

In order to determine the possible reduction in patients’ exposure during real medical practice as a result of the use of grid pulsed fluoroscopy, the data collected were compared by using the t-test (when distribution was close to normal) as well as by using the Wilcoxon-Mann-Whitney rank sum test for the majority of the comparisons. The latter is a nonparametric comparison procedure that tests hypotheses about differences between two independent populations that are not necessarily distributed normally. The statistical tool applied was the trial version of “analyse-it” statistical methods software for Microsoft Excel (Analyse-it Software, Ltd) [14].

It should be also noted that the same group of cardiologists conducted the CA and PTCA examinations during both monitoring periods. Therefore, possible variations in technique between the two patient groups that may affect dose (such as collimation, patient-image distance and use of magnification and angled views) are minimal.

Results

The analysis of the results was performed (separately for CA and PTCA procedures) on four series of data: DAP fluoroscopic (dap fl), DAP total (dap total), fluoroscopy time [FT(min)] and the number of frames (fr) during fluorography.

The median value of each data group was used as this is proved to represent better patient dose and fluoroscopy time distributions [15].

Descriptive plots (figures 1-4) showed a statistical summary of the relative values including confidence intervals (CI), outlier box plots, mean diamonds, interquartile ranges (IQR), numbers of data (n), quartiles, means, medians, standard deviations (SD) and standard errors (SE).

The F-statistic table gave the variance ratio between the two compared values while t-statistic or Mann-Whitney’s Z-statistic (where appropriate) table gave the probability level for the existence of a statistically significant difference between the two data samples.

In Table 1, median values of DAP fl, DAP total, fluoroscopy time (ft) and number of frames (fr), for PTCA and CA procedures, with and without grid are presented.
Figure 1: DAP fluoro statistical summary concerning the difference in values with and without tube grid (a) during PTCA and (b) during CA.
Figure 2: DAP total statistical summary concerning the difference in values with and without tube grid (a) during PTCA and (b) during CA.
**Figure 3**: Fluoroscopy time FT statistical summary concerning the difference in values with and without tube grid (a) during PTCA and (b) during CA.
Figure 4: Number of frames (fr) statistical summary concerning the difference in values with and without tube grid (a) during PTCA and (b) during CA
Table 1: Median values of DAP fl, DAP total, fluoroscopy time (ft) and number of frames (fr), for PTCA and CA procedures, with and without grid

<table>
<thead>
<tr>
<th></th>
<th>grid</th>
<th></th>
<th>no grid</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>PTCA</td>
<td>CA</td>
<td>PTCA</td>
<td>CA</td>
</tr>
<tr>
<td>Number of cases</td>
<td>344</td>
<td>381</td>
<td>93</td>
<td>180</td>
</tr>
<tr>
<td>DAP fl (cGy*cm^2)</td>
<td>45936</td>
<td>11918</td>
<td>55669</td>
<td>14146</td>
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<tr>
<td>DAP total (cGy*cm^2)</td>
<td>96860</td>
<td>37244</td>
<td>107643</td>
<td>39337</td>
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<tr>
<td>FT (min)</td>
<td>13,5</td>
<td>4,0</td>
<td>15,24</td>
<td>4,1</td>
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<tr>
<td>Fr</td>
<td>1000</td>
<td>483</td>
<td>1204</td>
<td>530</td>
</tr>
</tbody>
</table>

In Table 2, the variance ratio and the probability level of significance of the difference between corresponding values are shown.

Bold numbers indicate that this value of the difference is statistically significant i.e. for: (a) fluoroscopic time during PTCA, (b) and (c) number of frames during both PTCA and CA. For frames, t-test suited better as their distribution is closer to normal.

Table 2: Results of statistical analysis for the difference of corresponding values

<table>
<thead>
<tr>
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<th>PTCA difference</th>
<th>CA difference</th>
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<tbody>
<tr>
<td>DAP fl</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variance ratio</td>
<td>1,25</td>
<td>2,03</td>
</tr>
<tr>
<td>95% CI</td>
<td>0,89 - 1,70</td>
<td>1,57 - 2,60</td>
</tr>
<tr>
<td>Z-stat (p)</td>
<td>-0,77 (0,441)</td>
<td>-0,05 (0,963)</td>
</tr>
<tr>
<td>DAP tot</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variance ratio</td>
<td>1,00</td>
<td>1,11</td>
</tr>
<tr>
<td>95% CI</td>
<td>0,71 - 1,37</td>
<td>0,86 - 1,42</td>
</tr>
<tr>
<td>Z-stat (p)</td>
<td>-1,00 (0,318)</td>
<td>-0,78 (0,434)</td>
</tr>
<tr>
<td>FT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variance ratio</td>
<td>1,01</td>
<td>1,30</td>
</tr>
<tr>
<td>95% CI</td>
<td>0,71 - 1,37</td>
<td>1,00 - 1,66</td>
</tr>
<tr>
<td>Z-stat (p)</td>
<td>-1,93 (0,054)</td>
<td>0,50 (0,620)</td>
</tr>
<tr>
<td>Fr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variance ratio</td>
<td>0,84</td>
<td>0,58</td>
</tr>
<tr>
<td>95% CI</td>
<td>0,59 - 1,14</td>
<td>0,45 - 0,75</td>
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<tr>
<td>t-stat (p)</td>
<td>-3,32 (0,0012)</td>
<td>-3,29 (0,0011) (equal variances) (unequal variances)</td>
</tr>
</tbody>
</table>
3. Discussion

Research groups have published data showing that pulsed fluoroscopy offers a significant decrease in radiation dose delivered to patient [2-7]. Brown et al [8] have compared radiation exposure levels of grid-pulsed versus kVp-pulsed fluoroscopy quoting 230 mrad/min in a “grid-pulsed hospital” and 1010 and 1870 mrad/min in two “kVp-pulsed hospitals”.

The scientific papers published so far [8, 16-20] compare patient dose values before and after the installation of new X-ray equipment with which dose decreases by factors ranging between 4.0 – 7.5. However, the technical and dosimetric characteristics of the previous and new equipment used, during fluoroscopy and fluorography, could not be compared to each other in a straightforward way.

In this study, the same X-ray equipment (and the same cardiologists’ team) was used with the X-ray grid-controlling unit in and out of function. The statistical analysis of the results followed.

4. Conclusion

The results of this study suggest that hospital administrators may question the costly investment on grid-controlled X-ray tubes for their haemodynamic units since the decrease in patient’s dose has been proved to be not statistically significant during adult cardiac diagnostic and therapeutic interventions.

Acknowledgments

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REFERENCES