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research article

Typical air kerma area product values for trauma orthopaedic surgical procedures

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Background. The aim of study was to establish the typical radiation quantity values for the most common trauma orthopaedic surgical procedures and to compare them with reference values of equivalent procedures performed in other institutions. In addition, we assess the impact of image intensifier and flat panel detector technology used for fluoroscopically guidance on patient exposure.

Materials and methods. Five most frequently performed fluoroscopically guided trauma orthopaedic procedures in University Medical Centre Ljubljana were analysed. Data on 199 cases over a 6 months period from December 2016 to June 2017 were gathered retrospectively. Study covered 40 dynamic hip screw fixations (DHS), 23 proximal femoral nail insertions (PFN), 20 proximal humeral nail insertions (PHN), 77 partial hip endoprosthesis implantations (PEP) and 39 percutaneous posterior spine fixations (PPS). The median and average along with the first and third quartile values of air kerma area product (KAP) for each procedure type were calculated as well as median and average value of fluoroscopy screening time.

Results. Typical KAP value for dynamic hip screw fixation was set at 0.52 $Gycm^2$; for proximal femoral nail insertion at 0.53 $Gycm^2$ and for proximal humeral nail insertion at 0.26 $Gycm^2$. For implantation of partial endoprosthesis typical KAP value utilizing flat panel technology was set at 0.08 $Gycm^2$ and at 0.21 $Gycm^2$ when the image intensifier technology was used. Typical KAP value for percutaneous posterior spine fixation was set at 1.26 $Gycm^2$, using flat panel technology and at 3.98 $Gycm^2$ using image intensifier technology.

Conclusions. Established typical KAP levels of surgical orthopaedic procedures in traumatology will serve as a valuable tool for further radiation exposure optimization.

Key words: typical value; fluoroscopy; air kerma-area product; trauma orthopaedic procedures

Introduction

The use of fluoroscopy in orthopaedic theatres has significantly increased over the past decade.[1] Benefits of intra-operative fluoroscopy include the indirect visualisation of anatomy, which enables many orthopaedic procedures to be performed using minimally invasive techniques, thus reducing morbidity and patient hospital stay. Using fluoroscopy guidance procedures are performed with greater ease, in less time and with less traumatisation of patient tissues.[2,3] Fluoroscopy guidance is performed by employing conventional image intensifier (II) or flat panel detector (FPD) for x-ray detection. Improvements in technology of C-arms give more opportunities for optimisation and call for additional skills of operator. In addition well known practical tool for optimization of diagnostic radiological procedures are diagnostic reference levels (DRL).[4] DRLs are values of radiation quantities used to indicate whether, in routine conditions, the amount of radiation used for a specified radiological procedure is unusually high or low for that procedure. To assist the implementation of optimisation process in a single facility, typical values of radiation quantity might be introduced. A typical value is defined as the median of the radiation quantity distribution and can be used as a guide to encourage further optimisation in a facility by providing a local comparator, in a similar manner to local DRLs. Typical values may be set also to provide a comparator linked to a new technology or technique for a single facility. Due to advances in technology and techniques DRL or typical values should be regularly updated.[5]

Materials and methods

The primary objective of our research was to establish typical KAP values for five the most commonly fluoroscopically guided trauma orthopaedic procedures performed in University Medical Centre Ljubljana:

- dynamic hip screw fixation (DHS),
- proximal femoral nail insertion (PFN),
- proximal humeral nail insertion (PHN),
- partial hip endoprosthesis implantation (PEP) and
- percutaneous posterior spine fixation (PPS).

Procedures were guided by fluoroscopy units equipped with either image intensifier (II) based or flat panel detector (FPD) based technology. DHS fixations and PFN insertions were guided by FPD-based unit, while PHN insertions were guided by II - based unit. Also, the performance of both technologies were compared for PEP implantation and PPS fixation. Data in this retrospective study was acquired in a time interval from December 2016 to June 2017 from University Medical Centre Ljubljana. To establish the typical values for each procedure we gathered data of patient age, patient body weight, air kerma area product (KAP) and fluoroscopic screening time (FT) for each of 199 procedures. The inclusion criterion was body weight 60–90kg. Median, average and third quartile values for KAP and median and average values for FT were calculated for five listed fluoroscopically guided trauma orthopaedic procedures. Statistical analysis was performed using IBM SPSS Statistics, version 23. Mann-Whitney U test was applied to test the significant differences in KAP and FT. A p-value < 0.05 was used to indicate statistical significance. Established typical values were compared to reference levels of similar procedures presented in literature. National Ethics Committee approval for study performance was not required, due to the retrospective nature of the study of anonymized data and prior consent of Clinical Institute of Radiology, University Medical Centre Ljubljana.

Results

Radiation exposure parameters of 199 trauma orthopaedic surgical procedures were analysed. Study covered 40 DHS fixations, 23 PFN insertions, 20 PHN insertions 77 PEP implantations and 39 PPS fixations. The median and average along with the first and third quartile values of KAP for each procedure type were calculated, as well as median and average value of fluoroscopy screening time. Statistical data of patient body weight (BW), KAP and FT are displayed in Table 1, while KAP distributions are shown in Figure 1.

Average age of patients who underwent the DHS fixations, PFN insertions and PHN insertions were 78, 87 and 67 years, respectively. Out of 77 partial hip endoprosthesis implantations a group of 22 patients underwent procedure which was fluoroscopically guided with FPD, while for the other group of 55 patients II was used. Average age of the patients was 78 years and 77 years for first and second group of patients, respectively. Mann-Whitney U test confirmed that no statistical differences between body mass distributions for two groups of patients who underwent procedures using different fluoroscopy detection technology exist ($p = 0.308$). Mann-Whitney U test showed statistically significant difference in KAP values ($p < 0.001$) as well as in FT ($p < 0.001$) between two groups of procedures using different fluoroscopy technologies (FPD and II) in favour of FPD.

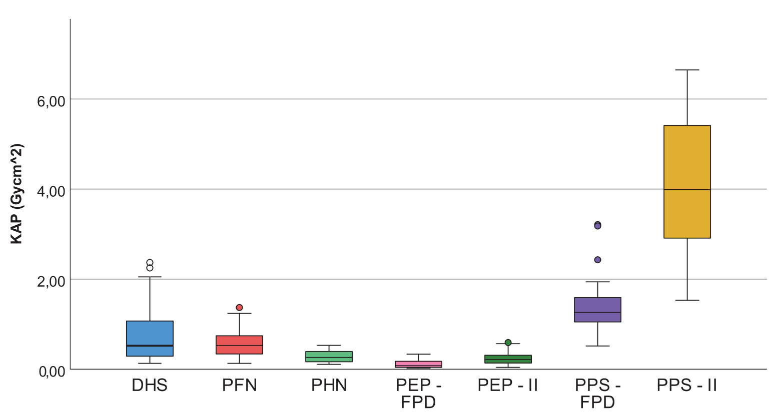

FIGURE 1. Distribution of kerma area product (KAP) data (minimum, first quartile, median, third quartile, and maximum) for 40 dynamic hip screw fixations (DHS), 23 proximal femoral nail insertions (PFN), 20 proximal humeral nail insertions (PHN), 77 partial hip endoprosthesis implantations utilizing flat panel detector (FPD) (22) and image intensifier (II) (55) for fluoroscopically guidance and 39 percutaneous posterior spine fixations (PPS) utilizing FPD (21) and II (18) for fluoroscopically guidance.

TABLE 1. Statistical data of patient body weight, KAP and fluoroscopy screening time for 40 DHS fixations, 23 PFN insertions, 20 PHN insertions, 77 PEP implantations utilizing FPD (22) and II (55) for fluoroscopically guidance and 39 PPS fixations utilizing FPD (21) and II (18) for fluoroscopically guidance

	Min	Q1	Median	Average ± SD	Q3	Max
DYNAMIC HIP SCREW FIXATIONS (DHS)						
BW [kg]	60		70	72 ± 9		90
KAP(FPD)[Gycm²]	0.13	0.29	**0.52**	0.71 ± 0.56	1.07	2.37
FT [s]	17		43	46 ± 20		96
PROXIMAL FEMORAL NAIL INSERTIONS (PFN)						
BW [kg]	60		70	73 ± 9		90
KAP(FPD)[Gycm²]	0.13	0.34	**0.53**	0.60 ± 0.34	0.74	1.37
FT [s]	26		45	48 ± 18		96
PROXIMAL HUMERAL NAIL INSERTIONS (PHN)						
BW [kg]	60		80	78 ± 8		90
KAP(II) [Gycm²]	0.11	0.16	**0.26**	0.28 ± 0.14	0.41	0.53
FT [s]	19		55.5	66.7 ± 37.9		175
PARTIAL HIP ENDOPROSTHESIS IMPLANTATIONS (PEP)						
BW(FPD) [kg]	60		77.5	76 ± 7		90
BW(II) [kg]	60		80	78 ± 7		90
KAP(FPD)[Gycm²]	0.03	0.04	**0.08**	0.12 ± 0.09	0.17	0.33
KAP(II)[Gycm²]	0.04	0.13	**0.21**	0.24 ± 0.14	0.31	0.60
FT(FPD) [s]	1.0		3.0	4.0 ± 3.6		19.0
FT(II) [s]	1.0		5.0	6.9 ± 4.4		21.0
PERCUTANEOUS POSTERIOR SPINE FIXATIONS (PPS)						
BW(FPD) [kg]	60		75	75 ± 6		90
BW(II) [kg]	60		75	76 ± 10		90
KAP(FPD)[Gycm²]	0.52	0.91	**1.26**	1.44 ± 0.74	1.63	3.21
KAP(II) [Gycm²]	1.53	2.80	**3.98**	4.12 ± 1.69	5.53	6.65
FT(FPD) [s]	28		71	80 ± 40		182
FT(II) [s]	42		110	115 ± 54		215

BW = body weight; FPD = flat panel detector; FT = fluoroscopic screening time; II = image intensifier; KAP = kerma area product; Q1 = first quartile; Q3 = third quartile

Out of 39 percutaneous posterior spine fixation a group of 21 patients underwent procedure which was fluoroscopically guided with FPD while for the other group of 18 patients II was used. Average age of the patients was 65 years and 64 years for first and second group of patients, respectively. Mann-Whitney U test confirmed that no statistical differences between body mass distributions for two groups of patients who underwent procedures utilizing different detector technologies exist ($p = 0.922$). Mann-Whitney U test showed statistically significant difference in KAP values ($p < 0.001$) as well as in FT ($p = 0.040$) between two groups of procedures using different fluoroscopy technology (FPD and II) in favour of FPD.

Discussion

The purpose of this study was to establish the typical KAP values for chosen trauma orthopaedic surgical procedures and to compare them with reference values of equivalent procedures performed in other institutions. In addition, the impact on patient exposure of two different image detector technologies used for fluoroscopy guidance were analysed for PEP implantation and PPS fixations.

Dynamic hip screw fixation

For DHS fixations we established the median and average KAP values at 0.52 Gycm², and 0.71 Gycm²,

TABLE 2. Comparison of diagnostic reference levels (DRL) with literature - dynamic hip screw fixations (DHS)

DYNAMIC HIP SCREW FIXATIONS (DHS)	Median KAP (Gycm²)	Average KAP (Gycm²)	Median FT (s)	Average FT (s)	BW (kg)
Our study	0.52	0.71	43	45.6	73
Hardman *et al.*, (2015)[6] 1. hospital	/	0.65		46.1	70
Hardman *et al.*, (2015)[6] 2. hospital	/	1.01		55.3	70
Hardman *et al.*, (2015)[6] 3. hospital	/	3.94		92.4	70
Hardman *et al.*, (2015)[6] 4. hospital	/	1.24		61.5	70
Hardman *et al.*, (2015)[6] – all	/	1.57		60.4	70
Rashid *et al.*, (2017)[7]	0.67		36		

BW = body weight; FT = fluoroscopic screening time; KAP = kerma area product

respectively, while median and average FT duration was 43.0 s and 45.6 s, respectively. Patient's average body weight was 73 kg. Table 2 shows the comparison of our results with results from the literature.

We compared the results of our study with similar study, performed by Hardman *et al.* performed in four major reference hospitals in London.[6] Our average KAP value was similar to value set in first reference hospital, while in others their values were higher. To broaden the analysis, we performed the comparison of FT durations. Only in the first reference hospital the FT was similar to ours, while in the others their FT were longer. The results are in line with the findings based on average KAP values comparison.

Hardman *et al.* also established average KAP value using data from all four institutions and set the value at 1.57 Gycm², while our average KAP value was set at 0.71 Gycm².

In addition, findings of the study performed by Rashid *et al.*[7] were compared to our results. Their median value of KAP is slightly higher while FT is shorter. Most probable reasons for differences are chosen exposure parameters, pulse frequency, collimation, use of fixed exposure parameters when metal implant is in field of view or patient's constitution. Due to unavailability of data from literature we were not able to evaluate the impact.

Proximal femoral nail insertion

For PFN insertion we established the median and average KAP value at 0.53 Gycm² and 0.60 Gycm², respectively, median and average FT were set at 45 s and 48 s respectively. Average patients BW was 73 kg. Table 3 shows the comparison of our results with results from literature.[8-10]

The results of our study were compared to research conducted by Roux *et al.*[8], in one of the French hospitals, utilizing conventional II detector. Despite the shorter FT, their average KAP value was higher. This effect could most probably be attributed to different detector technologies, while we used FPD. Unfortunately, they did not report patients BW data, so we could not perform any further comparison or establish the reasons for differences in KAP values.

Pillai and Jain[9] completed their research in a major Scottish hospital, employing conventional

TABLE 3. Comparison of proximal femoral nail insertions (PFN) median and average kerma area product (KAP) values and average fluoroscopic screening time (FT) with literature

PROXIMAL FEMORAL NAIL INSERTIONS (PFN)	Median KAP (Gycm²)	Average KAP (Gycm²)	Average FT (s)	BW (kg)
Our study	0.53	0.60	48	73
Roux *et al.* (2011)[8]	/	0.79	32	/
Pillai and Jain (2004)[9]	0.69	/	34	/
Salvia *et al.* (2011)[10]	/	/	60	/

BW = body weight

TABLE 4. Comparison of proximal humeral nail insertions (PHN) average fluoroscopic screening time (FT) with literature

PROXIMAL HUMERAL NAIL INSERTIONS	Median KAP (Gycm²)	Average KAP (Gycm²)	Average FT (s)	BW (kg)
Our study	0.26	0.28	67	75
Salvia *et al.*, (2011)[10]	/	/	42	/

BW = body weight; FT = fluoroscopic screening time; KAP = kerma area product

TABLE 5. Comparison of partial hip endoprosthesis implantations (PEP) exposure parameters using flat panel detectors (FPD) and image intensifier technology for fluoroscopy guidance

PARTIAL HIP ENDOPROSTHESIS IMPLANTATIONS	Median KAP (Gycm²)	Average KAP (Gycm²)	Median FT (s)	Average FT (s)	BW (kg)
Our research – FPD	0.08	0.12	3.0	4.0	75.7
Our research - II	0.21	0.24	5.0	6.9	77.7

BW = body weight; FT = fluoroscopic screening time; KAP = kerma area product

TABLE 6. Comparison of percutaneous posterior spine fixations (PPS) exposure parameters using flat panel detectors (FPD) and image intensifier (II) technology for fluoroscopy guidance

PERCUTANEOUS POSTERIOR SPINE FIXATIONS	Median KAP (Gycm²)	Average KAP (Gycm²)	Median FT (s)	Average FT (s)	BW (kg)
Our study - FPD	1.26	1.44	71	80	75
Our study - II	3.98	4.12	110	115	78
Roux *et al.*, (2011)[8]	/	10.35	/	158	/

BW = body weight; FT = fluoroscopic screening time; KAP = kerma area product

II detector. They established median KAP value at 0.69 Gycm^2, while we set median KAP value at 0.53 Gycm^2. Our average FT is longer compared to Scottish study. The comparison of results exhibited similar circumstances as seen in study by Roux *et al.*[8] Again, we attributed this outcome to difference in used detector technologies. Longer fluoroscopy duration in our institution could be the result of less experienced operators or different methodology of radiological practice.

Salvia *et al.*[10], performed their study in Santa Clara hospital, USA, using conventional II detector. They established the average FT for the procedure, which is longer, than the one in our study. Regrettably, any other parameters, such as KAP or patient constitution descriptors are not reported.

Proximal humeral nail insertion

For PHN insertion we established the median and average KAP values at 0.26 Gycm^2, and 0.28 Gycm^2, respectively, while median and average FT duration was 55.5 s and 66.7 s, respectively. Patient's average body weight was 75 kg. The comparison of our results with results from literature are shown in Table 4.

Salvia *et al.*[10] performed their study in Santa Clara hospital, USA, using conventional II detector. They established the average FT duration for procedure, which is much shorter, than the one in our study. Regrettably, they did not report any other parameters, such as KAP values or patient constitution descriptors. Due to the lack of comparable data, we can only conclude, that the reason for shorter duration of examination is probably the result of different method or more experienced staff.

Partial hip endoprosthesis implantation

For PEP implantation guided by fluoroscopy unit with FPD detector we established the median, and average KAP values at 0.08 Gycm^2 and 0.12 Gycm^2, respectively, while median and average FT duration was 3 s and 4 s, respectively. Patient's average body weight was 75.7 kg.

For procedures performed by fluoroscopy unit equipped with II, we established the median and average KAP values at 0.21 Gycm^2 and 0.24 Gycm^2, respectively, while median and average FT duration was 5 s and 6.9 s, respectively. Patient's average body weight was 77.7 kg. Table 5 shows the exposure levels for PEP implantation for both detector technologies.

Applying the Mann Whitney U test, we showed that statistically significant difference in average KAP as well as in average FT exist between the two groups of procedures with different fluoroscopy technology used for guidance ($p < 10^{-3}$).

In procedures using II technology compared to procedures where FPD were employed KAP values were higher and FT were longer. One reason for higher KAP in procedures guided with fluoroscopy unit equipped with II is longer FT, however, it stands to reason, that the observed difference is due to the impact of improved FPD technology. In our study the x-ray generator maximum power output for II type was 2.3 kW, while for FPD type was 15 kW. It is worth to note that comparison is limited because quality of fluoroscopic image was not taken into consideration.

Percutaneous posterior spine fixation

For PPS fixations guided by fluoroscopy unit with FPD detector we established the median and average KAP values at 1.26 $Gycm^2$ and 1.44 $Gycm^2$, respectively, while median and average FT duration was 71 s and 80 s, respectively. Patient's average body weight was 75.0 kg.

For procedures performed by fluoroscopy unit equipped with II, we established the median and average KAP values at 3.98 $Gycm^2$ and 4.12 $Gycm^2$, respectively, while median and average FT duration was 110 s and 115 s, respectively. Patient's average body weight was 76 kg. Table 6 shows the exposure levels for PEP implantation for both detector technologies.

Applying the Mann Whitney U test we showed that statistically significant difference in average KAP as well as in average FT exist between the two groups of procedures using with different fluoroscopy technology for guidance ($p < 0.001$).

In procedures using II technology compared to procedures where FPD were employed KAP values were nearly three times higher while FT values were only one third longer. Besides shorter FT, FPD technology advantages compared to II technology has predominantly impact on KAP values. Consideration of fluoroscopy image quality would enable more specific findings.

We also compared our results with earlier mentioned study by Roux *et al.*[8], which conducted their research in one of the French hospitals, utilizing conventional II. Nearly three times lower average KAP in our sample and 1.5 times shorter FT duration were observed when comparing data obtained with II. This points to advantage of our method, however the conclusion may be misleading, because we were not able to evaluate impact of other procedure parameters, as they were not presented.

Conclusions

Based on retrospective study, typical KAP values were established for most frequently performed fluoroscopy guided trauma orthopaedic surgeries performed in University Medical Centre Ljubljana, Slovenia. Typical KAP values were set for DHS fixation using FPD technology for fluoroscopy at 0.52 $Gycm^2$, PFN insertion using FPD technology for fluoroscopy at 0.53 $Gycm^2$, PHN insertion using II technology for fluoroscopy at 0.26 $Gycm^2$. For PEP implantation we set DRLs at 0.08 $Gycm^2$ and 0.21 $Gycm^2$ for FPD and II technology used for guidance, respectively, as well as for PPS fixation at 1.26 $Gycm^2$ and 3.98 $Gycm^2$ for FPD and II technology used for guidance, respectively.

In addition, we showed that radiation exposure parameters are deceased if FPD technology for fluoroscopy guidance is used, which could be accredited to advanced performance characteristics of FPD compared to II.

Established typical KAP values were compared to values set in other institutions and reported in literature. Analysis showed that our typical values are mostly lower than those set in other hospitals, while fluoroscopy FT durations are sometimes marginally longer. This aspect indicates the direction for additional optimisation.

For further research we recommend the acquirement of additional data to get larger samples and improve the statistical parameters. Moreover, a more detailed description of exposure parameters, pulse frequency, collimation, filtration and patient's constitution, such as diameter of observed body part and patient body height for body mass index calculations as well as comparison of fluoroscopic image quality, would enable even more specific findings and conclusions.

It is important to be aware that typical values for fluoroscopy guided trauma orthopaedic surgeries are one of the steps in the overall process of optimization and can act as standards for clinical audits.

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