

MULTI SYSTEM COMPARISON OF PATIENT DOSES IN INTERVENTIONAL RADIOLOGY

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INTRODUCTION

- Dose - Area Product (DAP) and entrance dose measurements were carried out simultaneously in a sample of 335 patients using five different angiographic units.
- Skin doses were also measured for some examinations using TLD's
- Variation of patient doses with the radiation output of the angiographic systems is also investigated

MATERIAL AND METHOD

PROCEDURES WERE PERFORMED
WITH THE FOLLOWING EQUIPMENT

- 2 Siemens Multistar Top (S_1 , S_2)
- 2 Siemens Neuro Star Top (S_3 , S_4)
- 1 GE Advantx DX Vascular (S_5)

CATEGORIZATION OF CLINICAL PROCEDURES

Angiographic Procedures		System 1	System 2	System 3	System 4	System 5
Single Projection Studies						
Hepatic	Diagnostic	5	...	...	...	...
	Therapeutic	14	...	...	1	3
Thoracic	Diagnostic	3	...	...	...	2
Renal	Diagnostic	7	3	...	2	5
	Therapeutic	5	...	...	2	2
Lower Extremity	Diagnostic	27	26	...	4	11
	Therapeutic	7	...	...	...	6
Upper Extremity	Diagnostic	9	1	...	...	...
	Therapeutic	6	...	...	...	2
Multiple Projection Studies						
Cerebral	Diagnostic	43	13	34	11	9
	Therapeutic	4	...	23	...	1
Carotid	Diagnostic	17	5	5	4	4
	Therapeutic	2	...	4	2	1
Sub Total:		149	48	66	26	46

TOTAL = 335

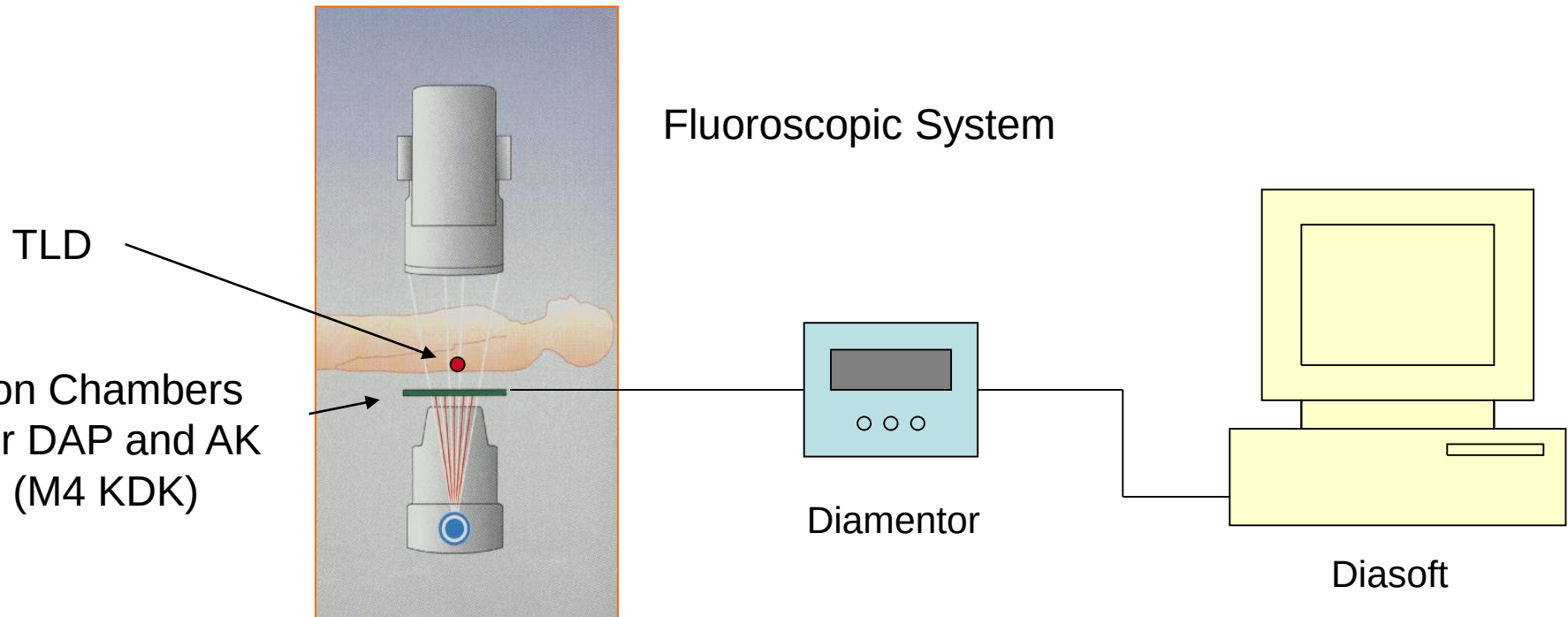
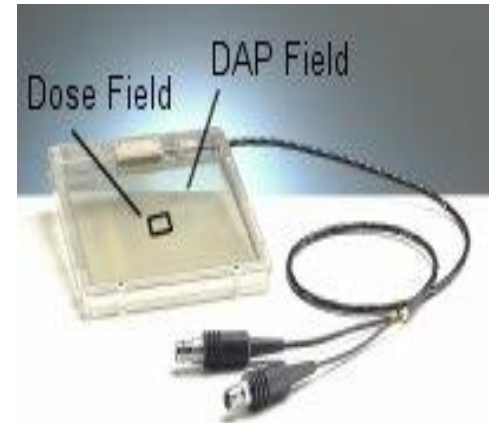
DOSIMETRIC SYSTEMS

TLD-100

- Skin dose measurement

DIAMENTOR M4KDK

- Measurement DAP
- Measurement of Air-Kerma at a specific point



INITIAL CALIBRATIONS

(For each system)

DAP and Air Kerma Calibrations

- Determine the calibration factor for DAP and AK using a reference ion chamber (Radcal chamber)**
- Repeat the measurements for different tube voltages and X-ray fields**

Measurement of Table Attenuation Factors

TLD Calibrations

Batch to batch variability is within the $\pm 10\%$

PERFORMANCE MEASUREMENT OF ANGIOGRAPHIC UNITS

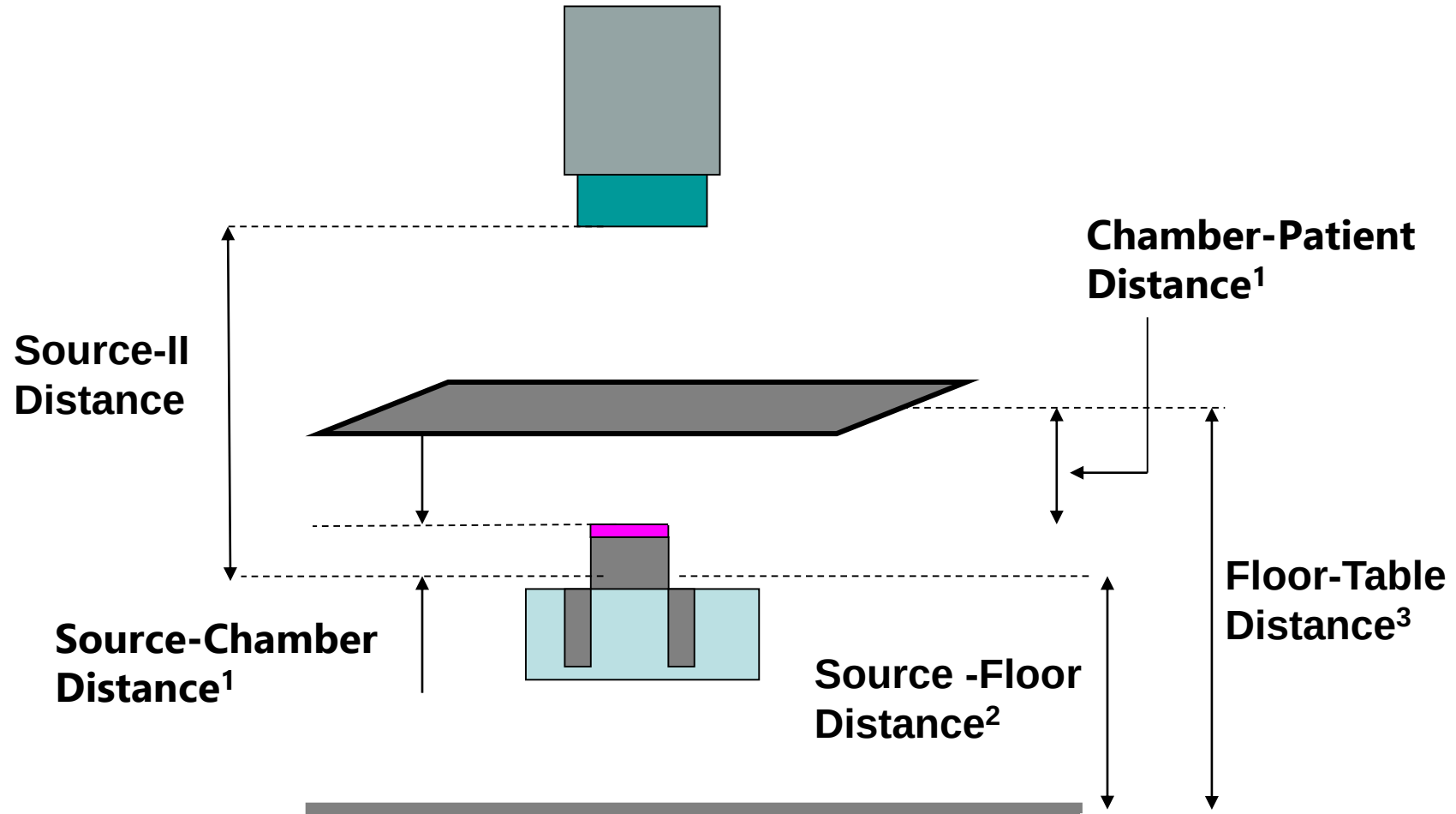
- X-ray Generator tests (kVp, Tube output etc.)
- HVL
- Patient Entrance Dose measurements¹
- Image Intensifier Input Dose measurements¹
- Beam Collimation and Alignment test
- Image Quality Tests
 - Field size measurements
 - Low and High Contrast tests
 - Spatial resolution test

1 : For all exposure modes

DATA ACQUISITION

- DAP and AK measurements were recorded separately for each projection.
- TLD's were replaced to a single point on the skin where the maximum exposure was expected
- Position of the patient and irradiation geometry were continuously observed and recorded (PA, LLAT etc.)
- Fluoroscopic exposure parameters were recorded online
- Radiographic exposure parameters were recorded retrospectively

MEASURED PARAMETERS



1 : Input to Diamentor for each system

2 : Determined for each system

3 : Read during acquisition for the assessment of source-patient distance

RECORDED PARAMETER FOR FLUOROSCOPIC EXPOSURE

Num.	FIELD	PROJ.	II _{fov} ¹	ANGLE ²	mA	kVp
1	Carotid	PA	40	0 ⁰	5.5	75
2	Carotid	OBL	28	40 ⁰	7.8	82

T _{FLUORO} ³	FOV ⁴	D _{II} ⁵	D _{TAB} ⁶	DAP ⁷	ED ⁸
15	23x23	90	80	0.689	4.89
20	15x10	90	80	0.998	6.23

1 : II magnification factor

2: II Angle

3 : Total fluoroscopy time

4 : Exposed field of view on patient entrance surface¹
(measured from the monitor with a calibration scale)

5 : Image intensifier – focus distance (cm)¹

6 : Table – Floor distance (cm)

7 : Dose-Area Product (Gy-cm²)

8 : Entrance surface dose (mGy) from AK measurement

1: Not used in this work

RECORDED PARAMETER FOR FLUOROSCOPIC EXPOSURE FOR EACH PROJECTION

- 1 : II magnification factor
- 2 : Total fluoroscopy time
- 3 : Exposed field of view on patient entrance surface
(measured from the monitor with a calibration scale)
- 4 : Image intensifier – focus distance (cm)
- 5 : Table – Floor distance
- 6 : Dose-Area Product (Gy-cm²)
- 7 : Entrance surface dose (mGy) from AK measurement

RECORDED PARAMETER FOR RADIOGRAPHIC EXPOSURE FOR EACH PROJECTION

- 1 : Number of frames per second
- 2 : Total number of frames
- 3 : II magnification factor
- 4 : II Angle
- 5 : Dose-Area Product (Gy-cm²)
- 6 : Entrance surface dose (mGy)

RECORDED PARAMETER FOR RADIOGRAPIC EXPOSURE

No	FIELD	PROJ. ¹	# OF FRM. ²	II _{FOV} ³	ANGLE ⁴		
1	Carotid	PA	15	28	0 ⁰		
2	Carotid	RLAT	17	40	90 ⁰		
	mAs	kVp	FOV ⁵	D _{II} ⁶	D _{TAB} ⁷	DAP ⁸	ED ⁹
	625	70	23x23	90	85	10.589	58.4
	633	85	23X23	90	85	11.386	60.6

1: Projection

2 : Total number of frames

3 : II magnification factor

4 : II Angle

5 . Exposed field of view on patient entrance surface
(measured from the monitor with a calibration scale)

6 : Image intensifier – focus distance (cm)

7 : Table – Floor distance (cm)

8 : Dose-Area Product (Gy-cm²)

9 : Entrance surface dose (mGy)

REPORTING OF RESULTS

PATIENT

ID no.	:	Patient-Detector distance :
Name	:	Focus-Floor distance :
Surname	:	Focus-Detector distance :
Age and sex	:	
Weight, Height and Thickness :		

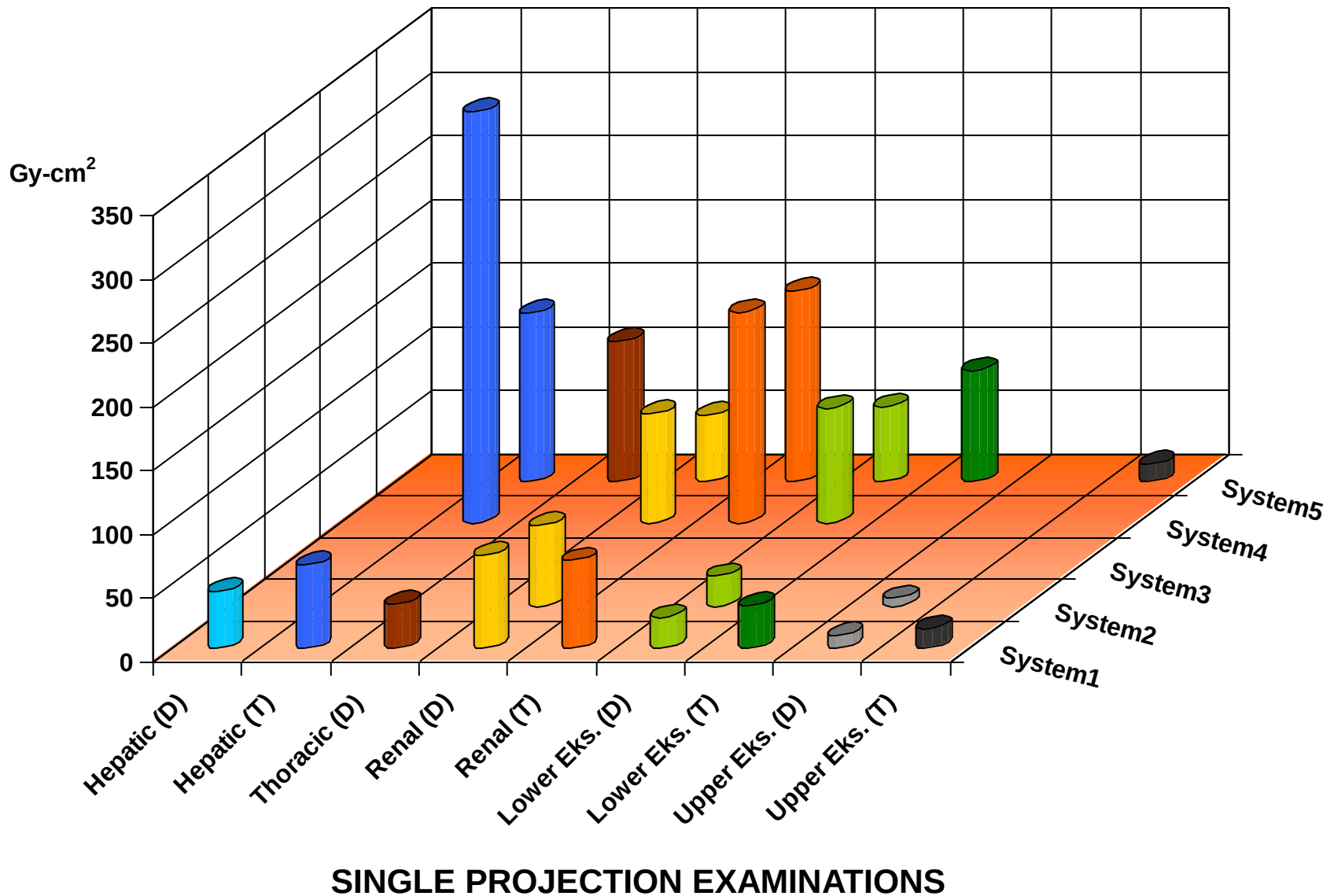
Total Fluoroscopy Time	:
Time percentages for Radiographic and fluoroscopic exposures	:
DAP for each projection	:
Percentage of DAP for radiography and fluoroscopy	:
Total Number of radiographic frames	:
kVp variation for Radiographic and fluoroscopic exposures	:
Patient entrance dose ¹	:
Patient skin dose from TLD reading	:
Effective doses calculated from DAP and entrance surface dose ²	:

1 : Calculated from AK and recorded parameters

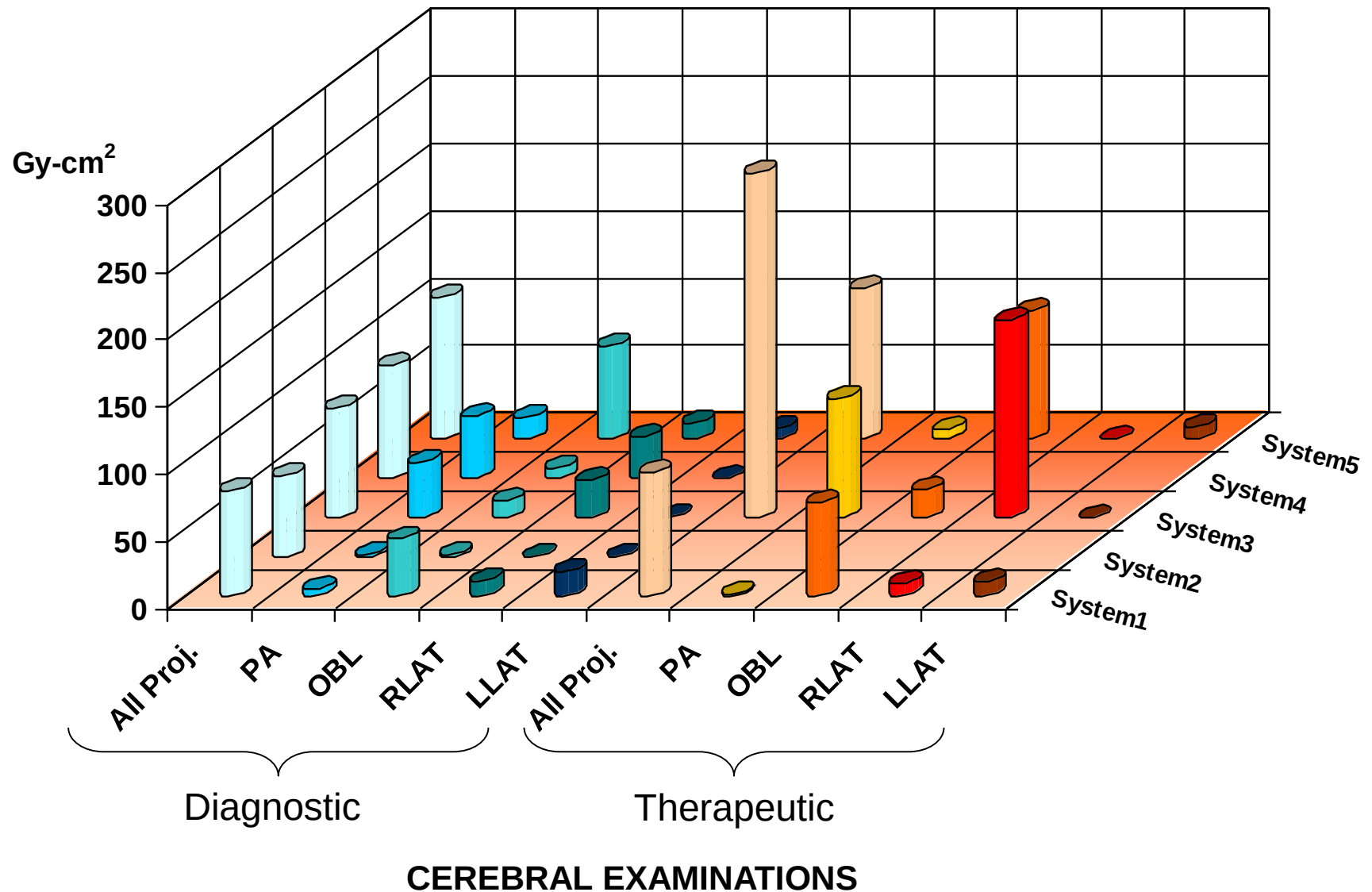
2 : Calculated from recorded parameters and NRPB tables

RESULTS OF PATIENT STUDIES

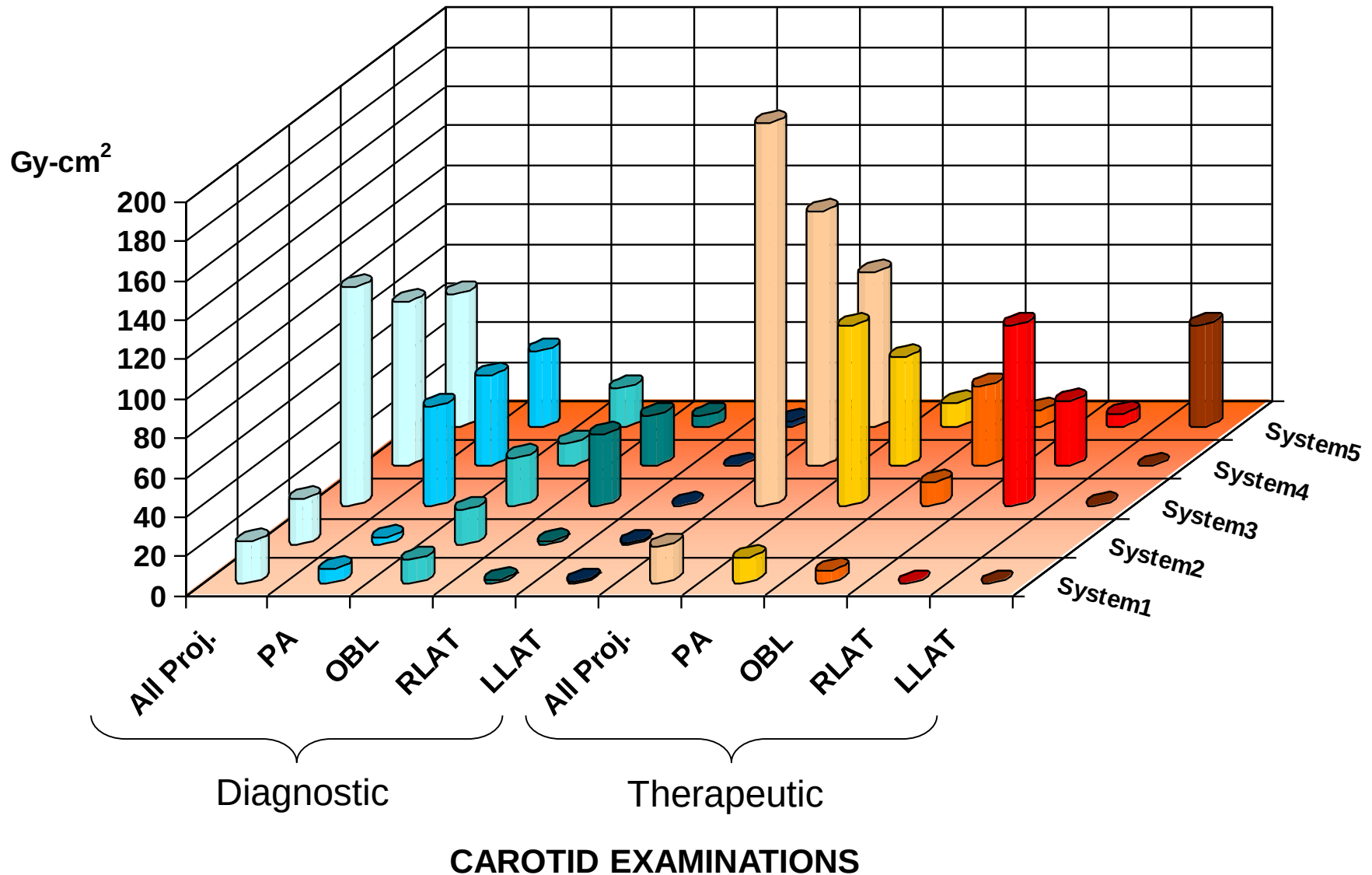
MEAN OF TOTAL – DAP – VALUES



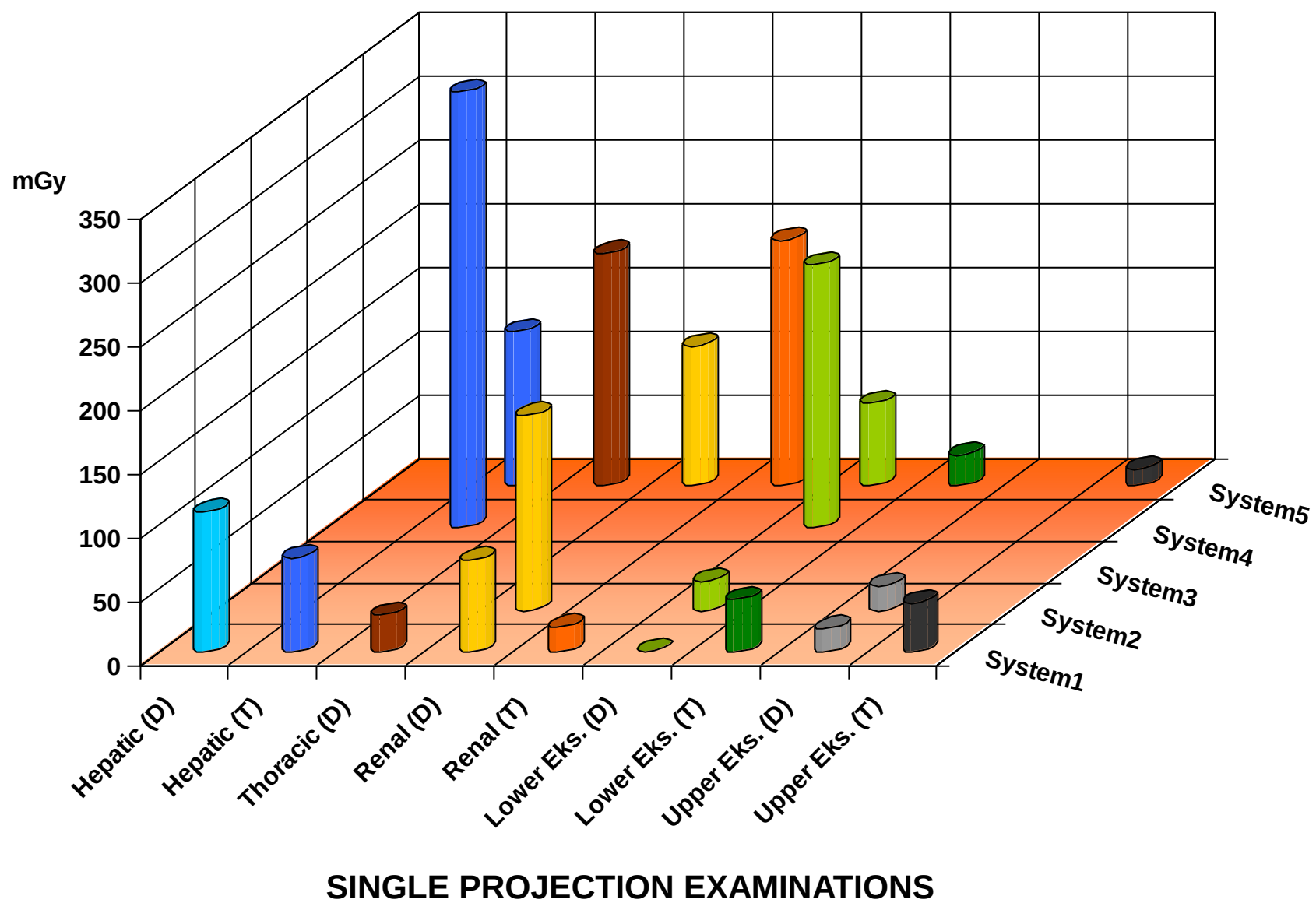
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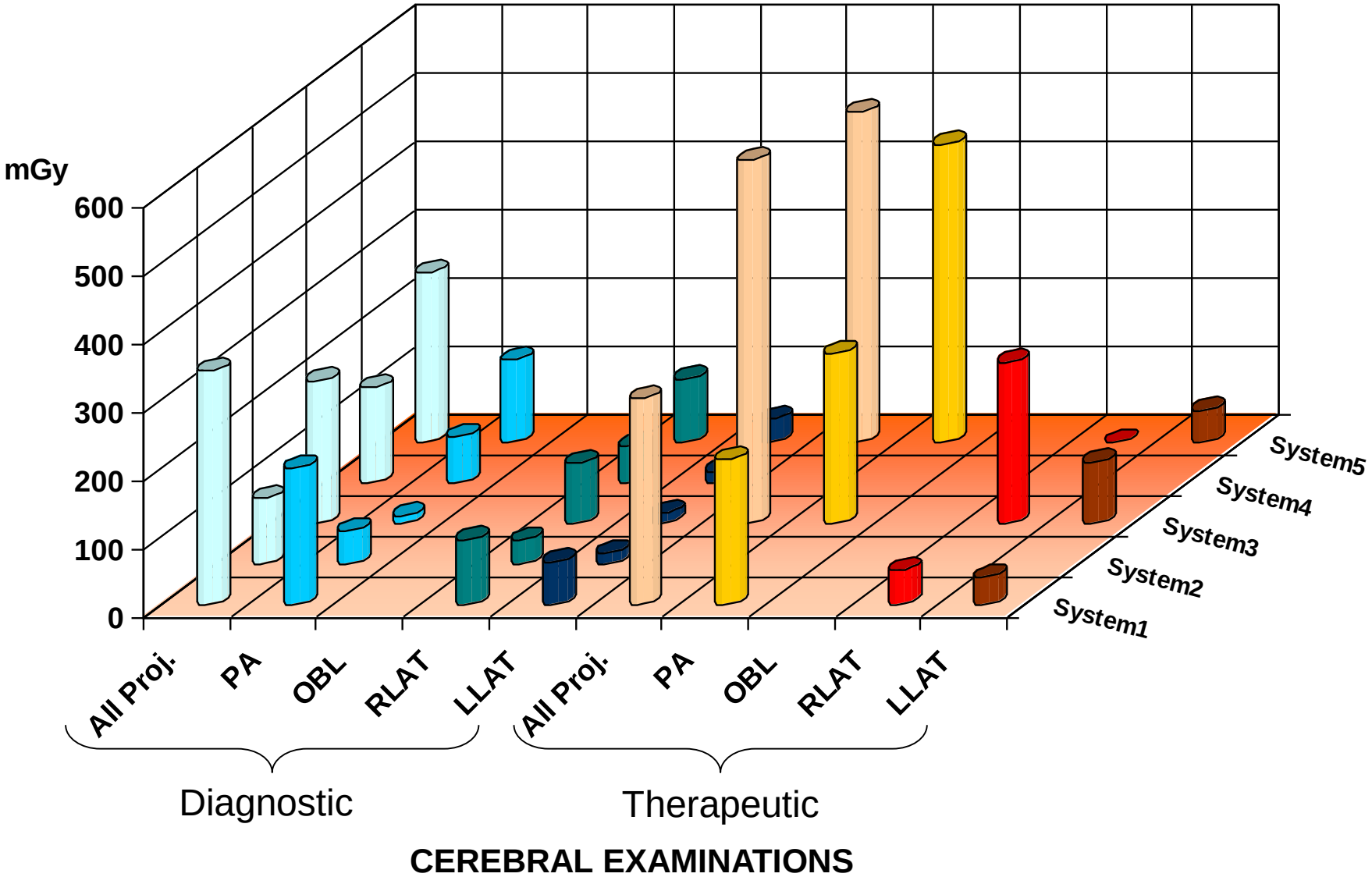
MEAN OF TOTAL – DAP – VALUES



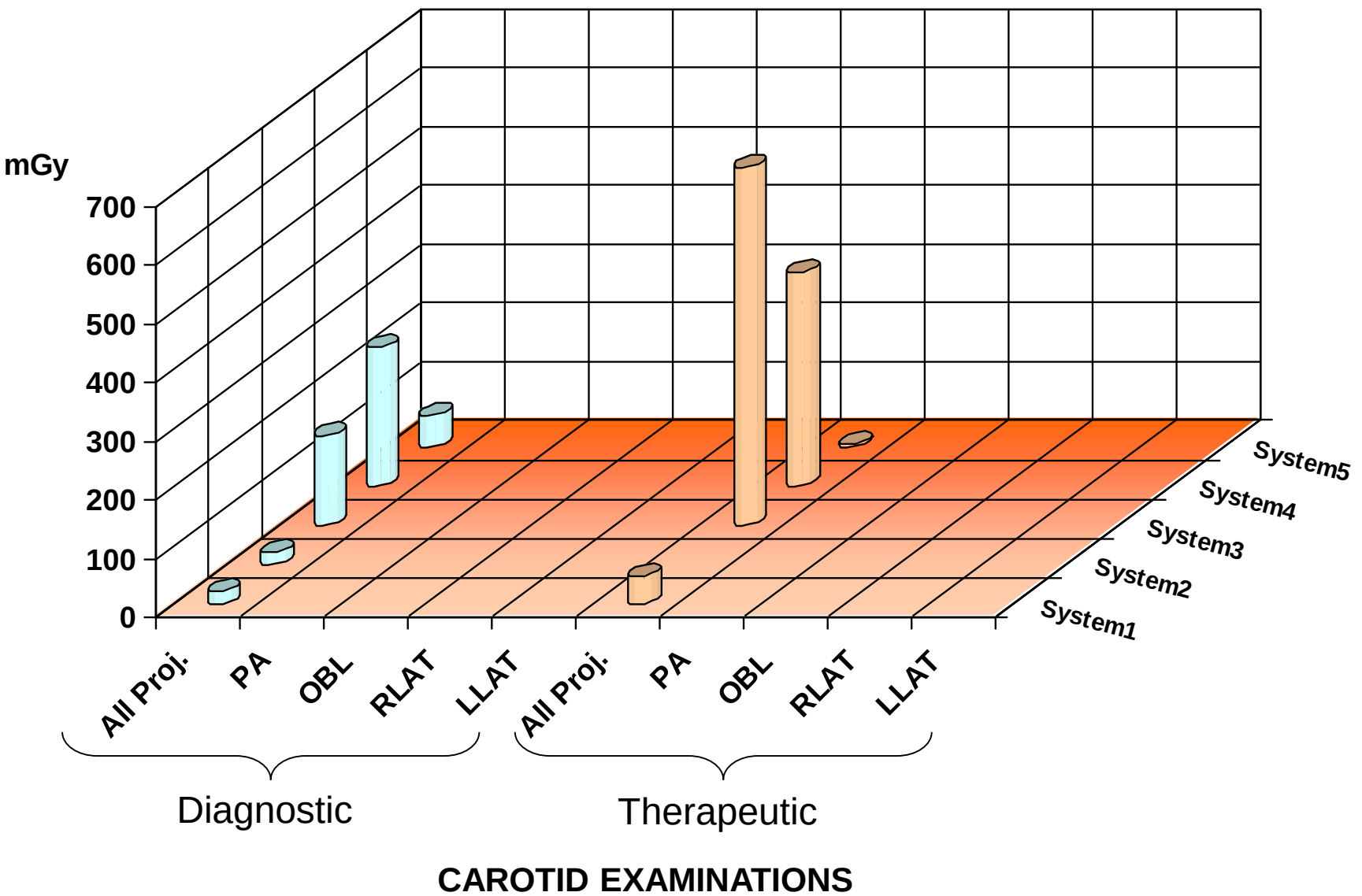
MEAN OF SKIN DOSES MEASURED WITH TLD



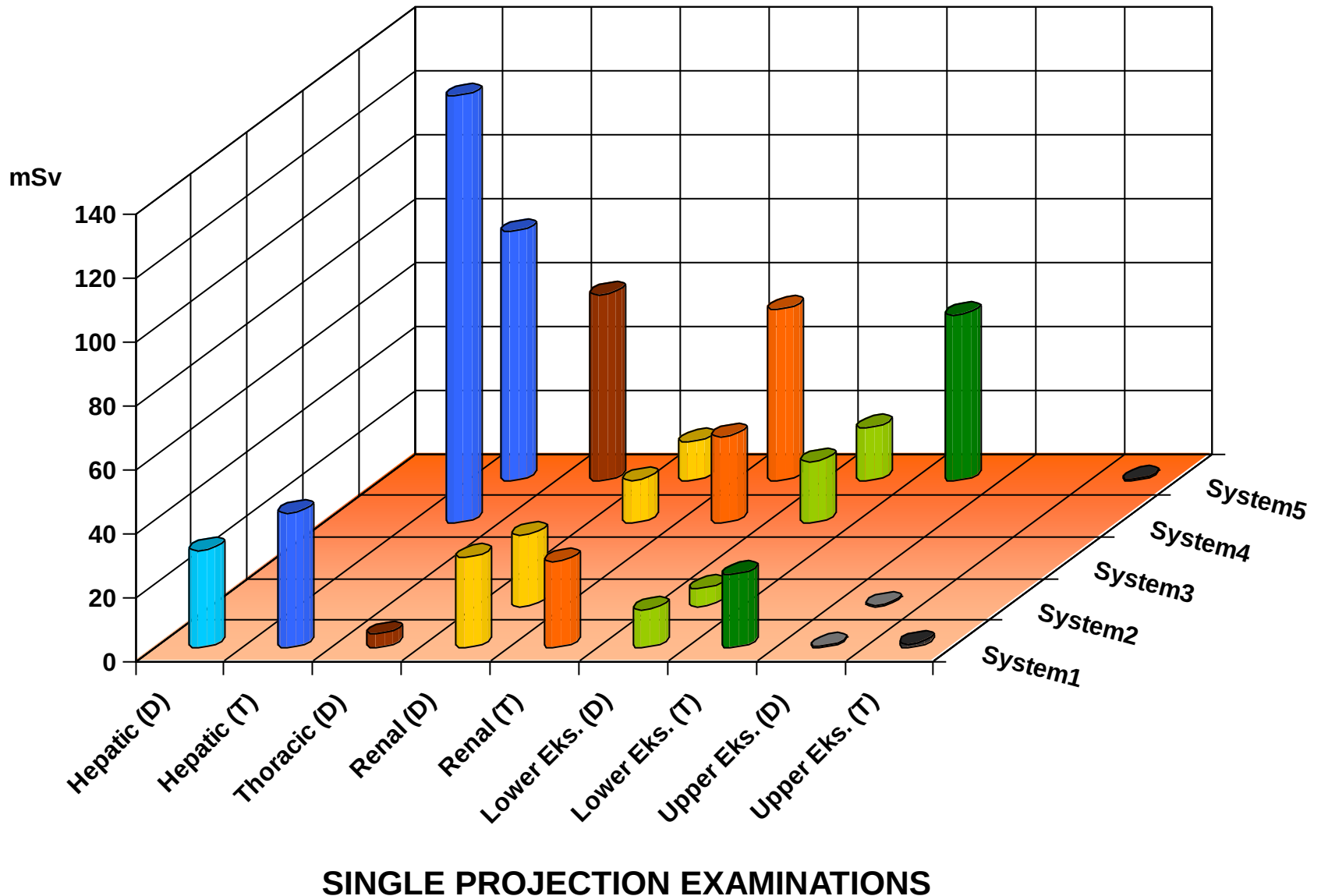
MEAN OF SKIN DOSES MEASURED WITH TLD



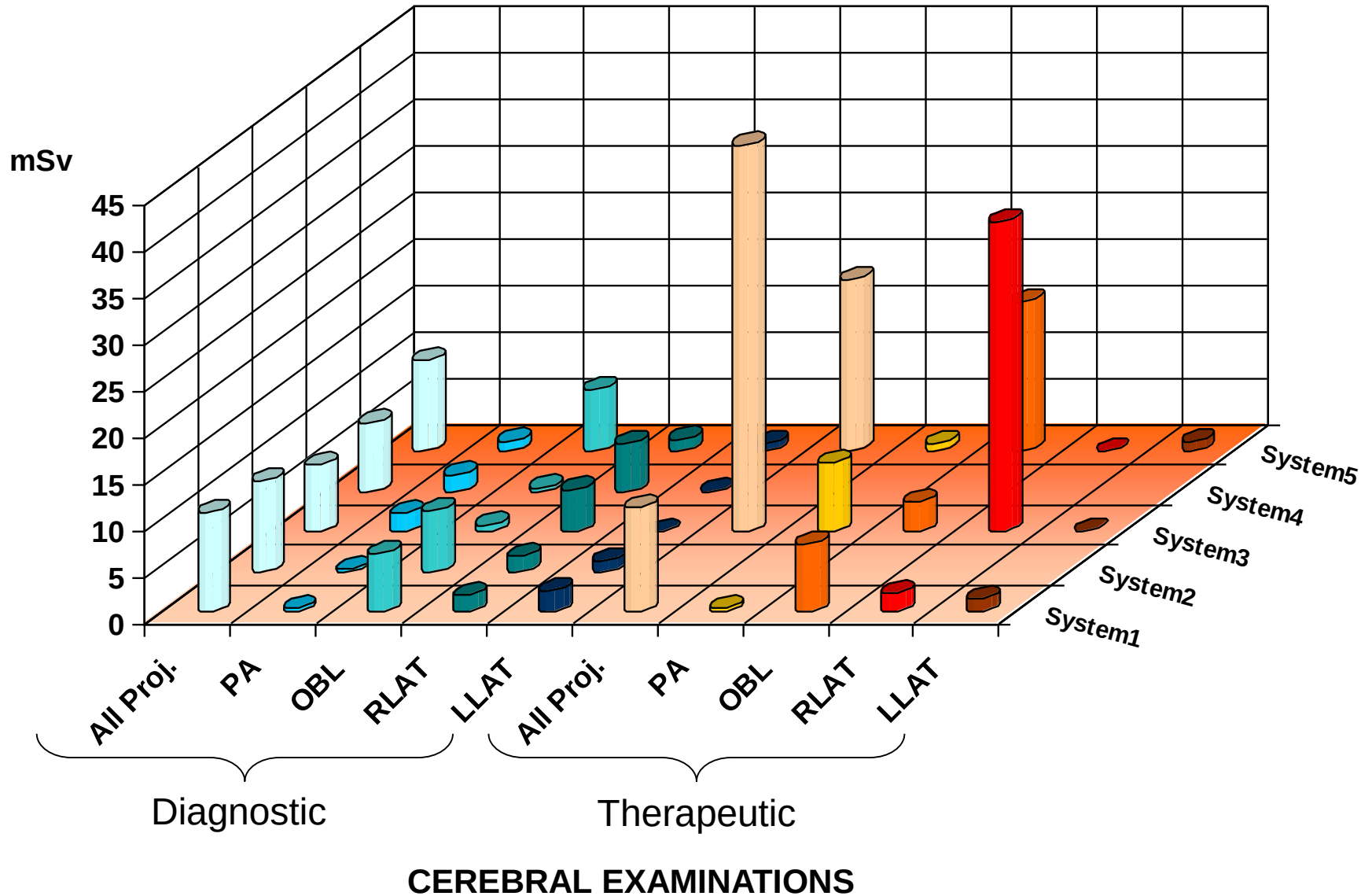
MEAN OF SKIN DOSES MEASURED WITH TLD



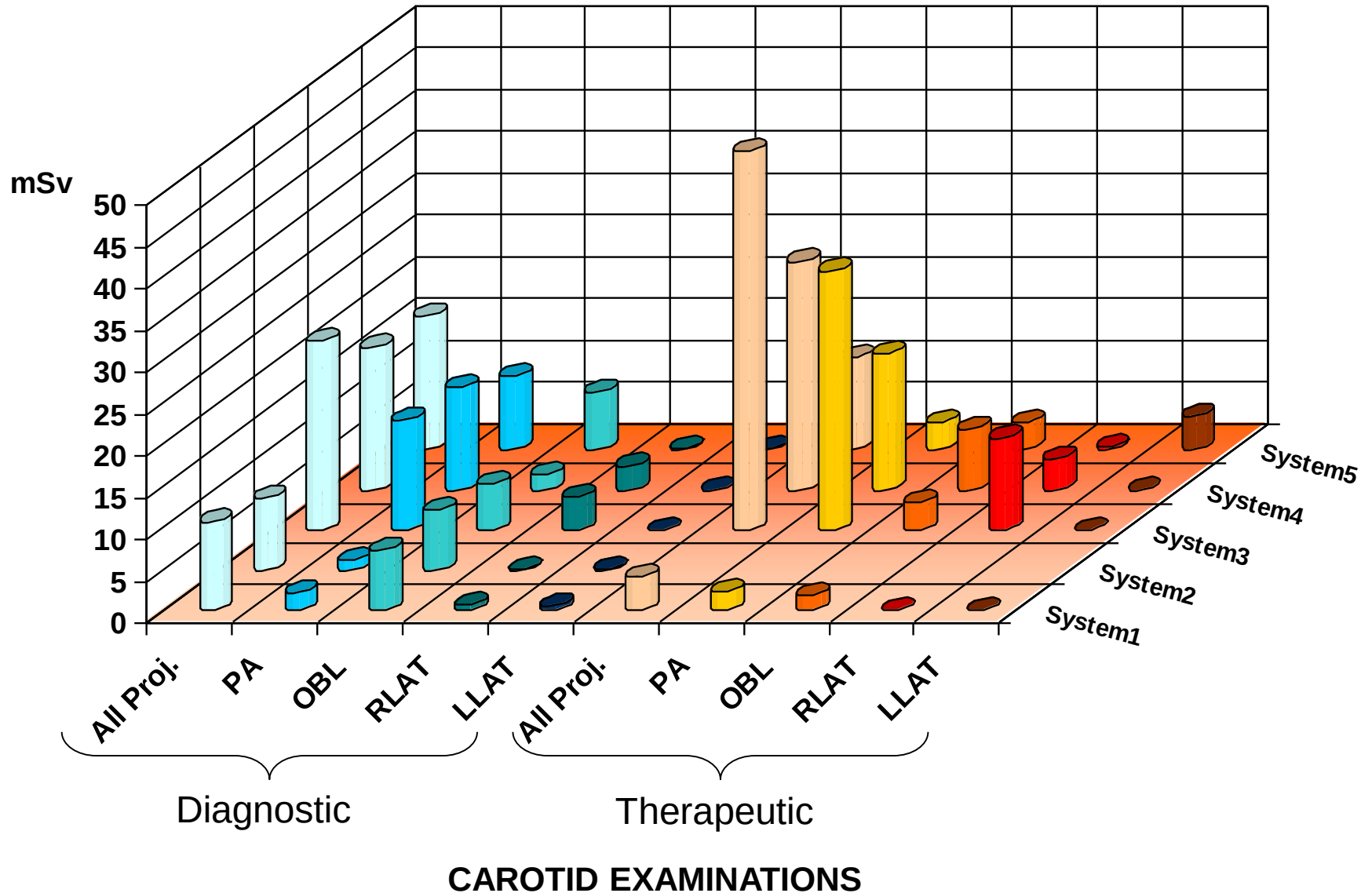
MEAN OF EFFECTIVE DOSES CALCULATED FROM ENTRANCE DOSE MEASUREMENTS



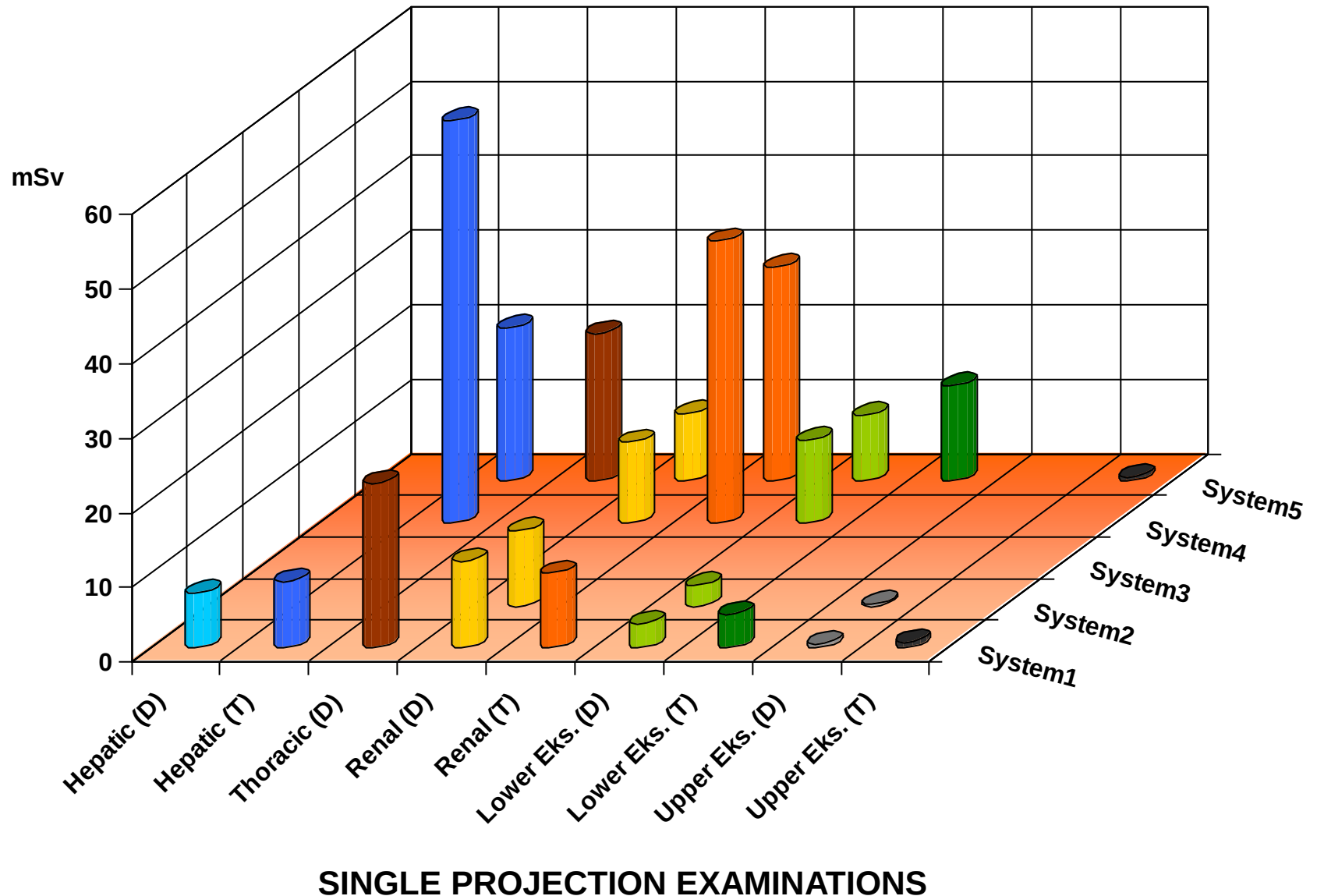
MEAN OF EFFECTIVE DOSES CALCULATED FROM ENTRANCE DOSE MEASUREMENTS



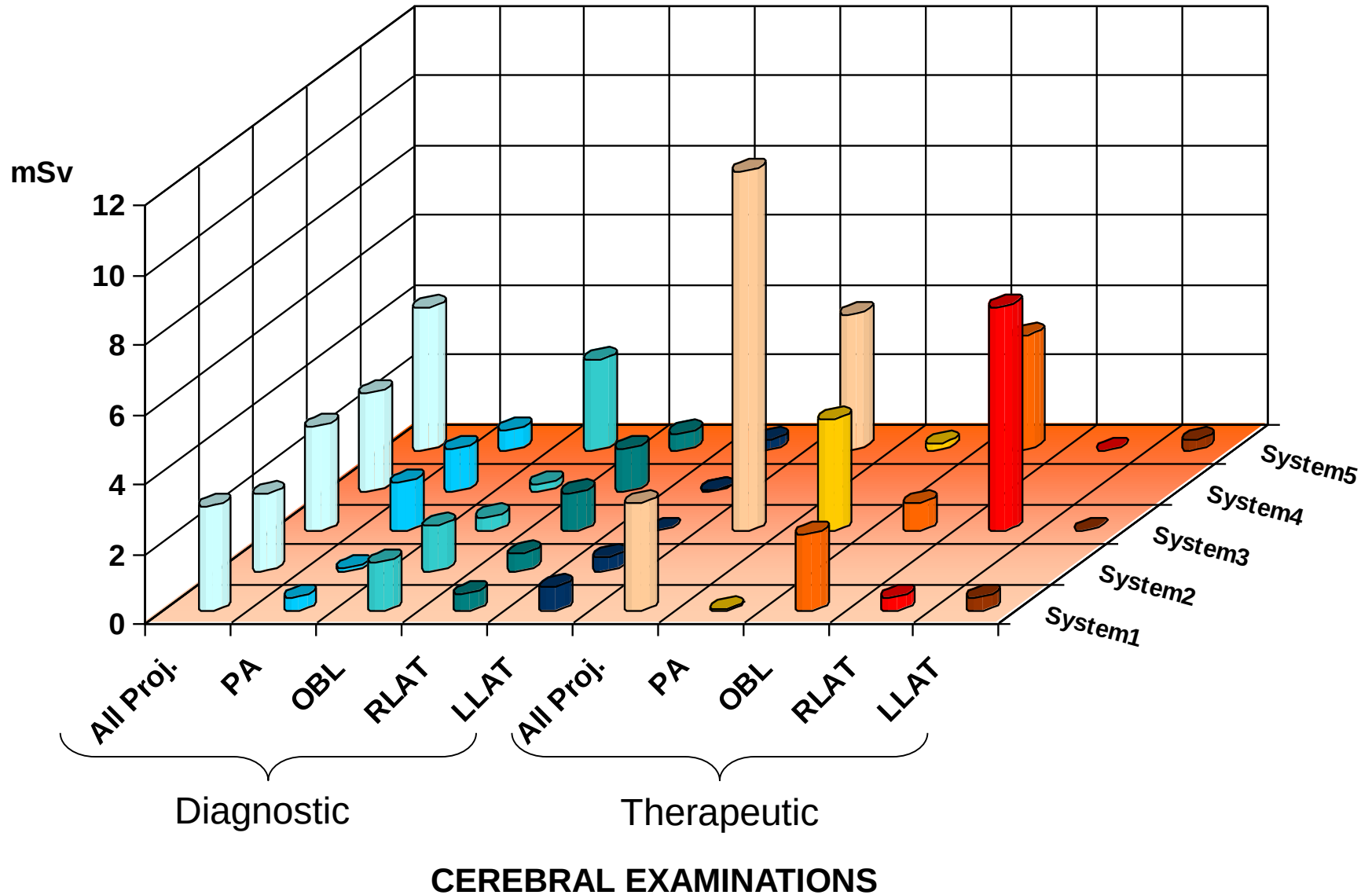
MEAN OF EFFECTIVE DOSES CALCULATED FROM ENTRANCE DOSE MEASUREMENTS



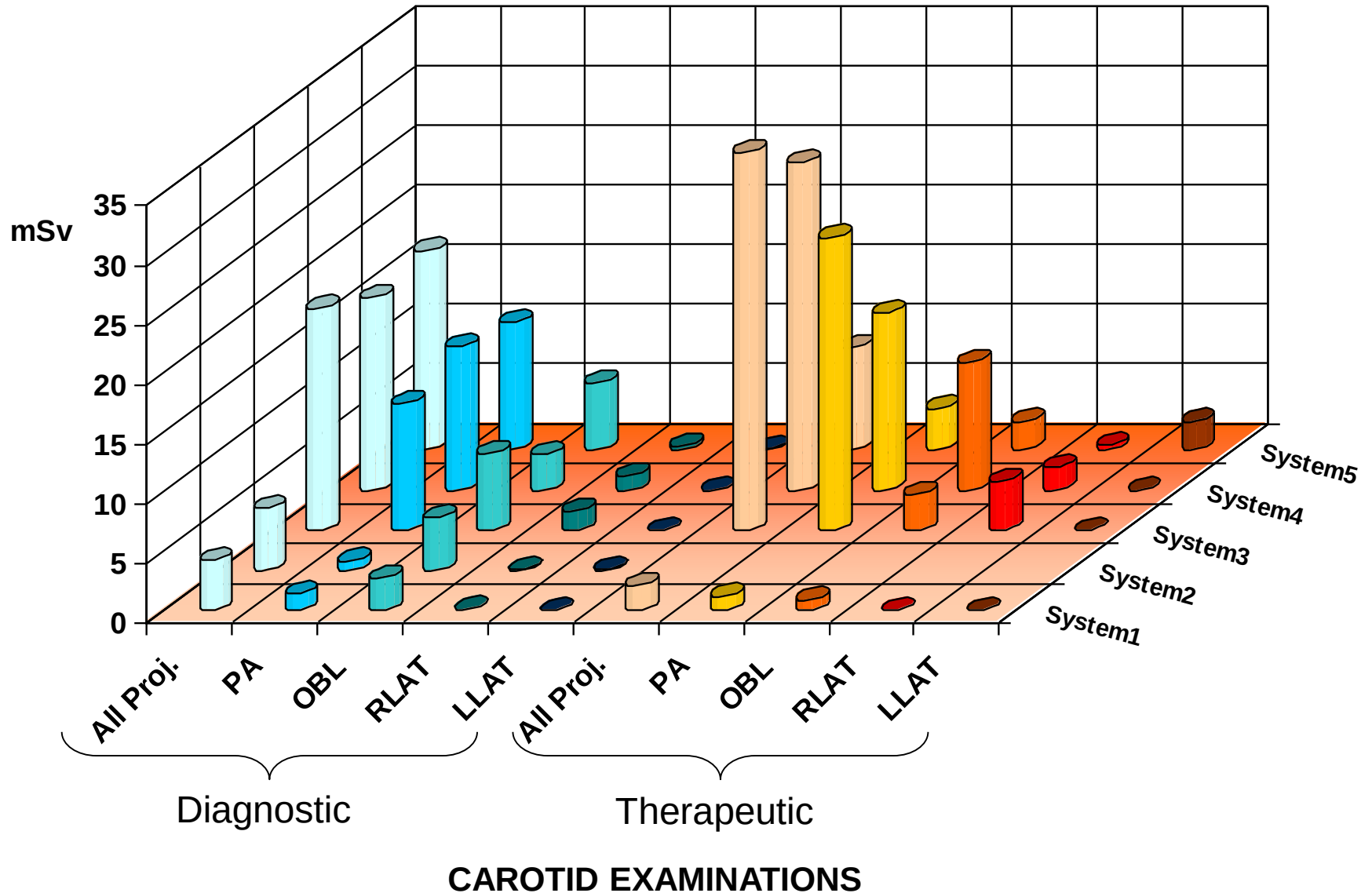
MEAN OF EFFECTIVE DOSES CALCULATED FROM DAP MEASUREMENTS



MEAN OF EFFECTIVE DOSES CALCULATED FROM DAP MEASUREMENTS



MEAN OF EFFECTIVE DOSES CALCULATED FROM DAP MEASUREMENTS



COMPARISON OF TOTAL DAP, FLUORO TIME kVp, AND FRAME NUMBERS

Angiographic Procedures		Parameters	System 1	System 2	System 3	System 4	System 5
Hepatic	D	Total DAP (Gy.cm ²)	44.4(2.5-142.2)	...	...	...	...
		Average kVp	72(60-84)	...	...	...	...
		Total Fl. Time (min)	3.2(1.0-4.7)	...	...	...	...
		# of Radiographic Fr.	59(11-125)	...	...	...	...
	T	Total DAP (Gy.cm ²)	65.2(14.0-204.2)	...	...	322.9	132.4(62.8-254.3)
		Average kVp	75(65-80)	...	...	82	73(65-90)
		Total Fl. Time (min)	7.7(1.8-12.9)	...	...	13.7	16.4(4.7-33.8)
		# of Radiographic Fr.	58(17-182)	...	...	231	75(33-130)
Thoracic	D	Total DAP (Gy.cm ²)	34.6(24.1-41.7)	...	...	...	110.2(62.0-158.3)
		Average kVp	71(70-72)	...	...	...	90(90-90)
		Total Fl. Time (min)	8.0(1.3-13.0)	...	...	...	24.9(9.2-40.5)
		# of Radiographic Fr.	72(35-102)	...	...	...	121(68-174)
Renal	D	Total DAP (Gy.cm ²)	73.0(25.2-171.5)	63.6(41.1-101.9)	...	86.2(80.3-92.1)	52.4(12.8-97.2)
		Average kVp	82(75-90)	78(75-85)	...	65(57-72)	86(75-90)
		Total Fl. Time (min)	5.2(1.4-14.0)	1.7(1.2-2.0)	...	3.3(3.0-3.5)	3.0(1.5-4.1)
		# of Radiographic Fr.	62(28-190)	63(52-73)	...	93(73-113)	46(33-56)
	T	Total DAP (Gy.cm ²)	68.7(39.2-119.5)	...	...	165.3(103.0-228)	149.4(107-192)
		Average kVp	76(70-80)	...	...	83(81-84)	95(90-100)
		Total Fl. Time (min)	5.2(1.8-10.9)	...	...	10.7(7.2-14.1)	21.6(14.7-28.4)
		# of Radiographic Fr.	84(36-126)	...	...	170(168-171)	84(69-99)
Lower Ekstremitiy	D	Total DAP (Gy.cm ²)	24.0(4.8-83.4)	23.9(4.4-61.0)	...	90.4(9.0-190.2)	58.7(11.7-169.4)
		Average kVp	69(55-80)	67(60-75)	...	67(66-70)	88(63-99)
		Total Fl. Time (min)	2.1(0.9-7.0)	1.0(0.3-1.8)	...	4.7(2.1-8.5)	3.7(1.5-13.1)
		# of Radiographic Fr.	86(50-131)	59(38-93)	...	165(90-261)	99(60-261)
	T	Total DAP (Gy.cm ²)	33.4(0.5-73.0)	...	...	...	87.3(11.4-210.5)
		Average kVp	68(54-78)	...	...	...	88(80-100)
		Total Fl. Time (min)	4.5(0.2-12.6)	...	...	...	18.7(8.7-43.0)
		# of Radiographic Fr.	73(14-117)	...	...	...	76(36-117)

COMPARISON OF TOTAL DAP, FLUORO TIME kVp, AND FRAME NUMBERS

Upper Ekstremity	D	Total DAP (Gy.cm ²) Average kVp Total Fl. Time (min) # of Radiographic Fr.	10.2(3.1-27.9) 68(60-78) 5.7(1.0-13.8) 59(16-124)	6.7 65 4.2 45			
	T	Total DAP (Gy.cm ²) Average kVp Total Fl. Time (min) # of Radiographic Fr.	15.4(0.3-60.4) 69(60-80) 5.7(0.4-18.2) 61(1-116)				13.8(4.2-23.4) 75(65-85) 4.4(1.3-7.5) 25(11-39)
Cerebral	D	Total DAP (Gy.cm ²) Average kVp Total Fl. Time (min) # of Radiographic Fr.	78.4(38.3-132.0) 73(64-85) 5.5(1.5-18.0) 151(117-247)	60.5(49.7-86.1) 76(70-90) 2.3(1.5-5.0) 135(110-222)	81.3(26.5-183.7) 74(68-92) 11.9(1.7-33.0) 500(149-1088)	83.9(17.2-171.7) 73(69-85) 11.7(1.9-30.2) 497(115-1302)	105.0(57.2-224.9) 82(68-100) 10.9(3.2-31.2) 134(81-234)
	T	Total DAP (Gy.cm ²) Average kVp Total Fl. Time (min) # of Radiographic Fr.	91.6(67.1-118.3) 75(70-85) 8.2(3.8-11.2) 179(129-229)		255.7(93.2-422.7) 78(69-90) 50.2(8.7-140.0) 1264(526-1912)		111.7 75 14.1 141
Carotid	D	Total DAP (Gy.cm ²) Average kVp Total Fl. Time (min) # of Radiographic Fr.	21.0(2.3-82.4) 69(58-80) 4.9(1.3-17.0) 83(36-151)	22.8(13.6-35.1) 69(60-80) 2.3(1.4-2.9) 65(46-83)	110.3(72.1-148.5) 74(69-82) 16.6(7.9-26.7) 613(442-831)	83.2(50.8-134.1) 72(65-77) 16.3(10.5-22.7) 490(314-702)	67.7(18.3-123.2) 78(65-95) 9.3(4.5-13.2) 109(51-153)
	T	Total DAP (Gy.cm ²) Average kVp Total Fl. Time (min) # of Radiographic Fr.	15.0(12.2-17.9) 72(65-75) 8.6(7.2-9.9) 101(77-125)		193.8(130.2-328) 74(69-80) 50.1(38.4-76.8) 727(485-864)	129.1(95.5-162.6) 76(72-83) 29.4(25.8-32.9) 469(422-515)	73.9 89 21.5 170

COMPARISON OF PATIENT INPUT EXPOSURE¹

		Fluoroscopy (mGy / min)	Static Frame (mGy / frame)
System 1²		5.26 (69 kVp – 3.8 mA)	0.42 (73 kVp – 15 mAs)
System 2²		5.81 (70 kVp – 4.0 mA)	0.50 (73 kVp – 18 mAs)
System 3⁴	Tube A³	4.13 (70 kVp – 0.14 mAs)	0.34 (73 kVp – 10.9 mAs)
	Tube B³	3.54 (69 kVp – 0.14 mAs)	0.27 (73 kVp – 9.1 mAs)
System 4⁴	Tube A²	3.19 (68 kVp – 0.14 mAs)	0.21 (73 kVp – 8.0 mAs)
	Tube B³	4.05 (69 kVp – 0.14 mAs)	0.31 (73 kVp – 10.0 mAs)
System 5²		8.46 (80 kVp – 0.7 mA)	1.03 (80 kVp – 7.7 mAs)

¹ Only the exposure parameters used in patient studies are given. 2 mm of Cu is used as filter

² FOV = 40 cm

³ FOV = 33 cm

⁴ Pulsed Fluoroscopy 15 pulse/sec

COMPARISON OF IMAGE INTENSIFIER INPUT EXPOSURE¹

		Fluoroscopy ($\mu\text{Gy} / \text{min}$)	Static Frame ($\mu\text{Gy} / \text{frame}$)
System 1²		28.7 (69 kVp – 3.9 mA)	3.63 (73 kVp – 17 mAs)
System 2²		33.5 (70 kVp – 4.0 mA)	3.87 (73 kVp – 18 mAs)
System 3⁴	Tube A³	23.6 (70 kVp – 0.16 mAs)	3.05 (73 kVp – 12 mAs)
	Tube B³	23.5 (70 kVp – 0.15 mAs)	3.06 (73 kVp – 11 mAs)
System 4⁴	Tube A²	17.6 (68 kVp – 0.14 mAs)	2.22 (73 kVp – 7.4 mAs)
	Tube B³	22.2 (69 kVp – 0.16 mAs)	2.87 (73 kVp – 10.2 mAs)
System 5²		60.1 (81 kVp – 0.7 mA)	4.22 (80 kVp – 7.0 mAs)

¹ Only the exposure parameters used in patient studies are given. 2 mm of Cu is used as filter

² FOV = 40 cm

³ FOV = 33 cm

⁴ Pulsed Fluoroscopy 15 pulse/sec

SOME REMARKS

- With the exception of System 2, all others are located in a teaching hospitals
- Same senior radiologists are using System 1 and 2
- Same company is responsible from the technical service of systems 1, 2, 3 and 4
- Systems 3 and 4 are bi-plane
- System 1 ,2 and 5 are nearly 5 years, 3 and 4 are 1 year old

EVALUATION OF PATIENT DOSES

- **Patient exposures are higher at some examinations for System 5**

Tube output is higher

Lock of copper filter

- **System 4 gives higher doses to patients for single-projection studies.**

Very high number of radiographic frames are used

- **Considering the multi-projection studies, System 3 and 4 delivers the highest doses.**

3-D option increases the total number of frames

Use of secondary tube increases the right lateral exposure

- **Experience of the radiologist is an important factor.**

If the outputs of the System 1 and 2 are compared

EVALUATION OF PATIENT DOSES-Cont.

- **Effective doses calculated from AK measurements were found to be greater than the results of DAP measurements.**
 - Differences in organ dose conversion factors for effective dose calculations
 - Different response of M4KDK chamber for DAP and AK measurements at some exposure conditions
- **Up to 170 mSv (from AK measurements) and 54 mSv (from DAP measurements) of effective doses are found for some patient studies.**
- **Longest fluoroscopic exposures are observed in the therapeutically cerebral and carotid studies**
- **Up to 1.5 Gy of skin doses were measured for a cerebral projection**

COMPARISON OF EFFECTIVE DOSES WITH THE LITERATURE DATA

	TW ¹ (Min-Max)	Reference								
		2	3 ³	4	5	6	7	8	9	10
Hepatic	7.3 8.9-54.0	21.7	23							
Thoracic	19.8-22.1	11.9				16.3			3.7	
Renal	9.0-11.6 10.0-37.8	6.4-13.6	16			13.6	25	6		
Lower Eks.	2.8-11.1 4.5-12.8	7.4 ⁴	4	4	3.1	9 ⁵ 2.8 ⁶			3.5	
Upper Eks.	0.3-0.5 0.6-0.7	0.3							3.2	
Cerebral	2.8-4.1 3.1-10.3	7.4-10.5 ²	4						4.4	3.6
Carotid	4.2-18.6 2.1-31.6	4.9								

¹ This Work (upper line diagnostic, lower line therapeutic)

Effective doses calculated from DAP measurements

² Therapeutic procedure

³ Effective dose equivalent

⁴ Femoral angiography

⁵ Digital System

⁶ Analog System

REFERENCES

1. Hart D, Jones DG, Wall BF. Estimation of effective dose in diagnostic radiology from entrance surface dose and dose-area product measurements. NRPB Report 262. London: HMSO, 1994.
2. McParland BJ. A study of patient radiation doses in interventional radiological procedures. Br J Radiol 1998; 71: 175-85
3. Steele HR, Temperton DH. Patient doses received during digital subtraction angiography. Br J Radiol 1993; 66: 452-6.
4. Thwaites JH, Rafferty MW, Gray N, Black H, Stock B. A patient dose survey for femoral arteriogram diagnostic radiographic examinations using a dose-area product meter. Phys Med Biol 1996;43: 899-907
5. Castellano IA, McNeil JG, Thorp NC, Dance DR, Raphael MJ. Assessment of organ radiation doses and associated risk for digital femoral angiography. Br J Radiol 1995; 68: 502-7.
6. Hoskins PR, Gillespie J, Ireland HM. Patient dose measurements from femoral angiography. Br J Radiol 1996; 69: 1159-64.

REFERENCES

7. Mini RL, Schmid B, Schneeberger P, Vock P. Dose-area product measurements during angiographic X ray procedures. Radiat Prot Dosim 1999; 80:145-148.
8. Kemerink GJ, Kicken PJH, Schultz FW, Zoetelief J, Van Engelshoven JMA. Patient dosimetry in abdominal arteriography. Phy Med Biol 1999; 44: 1133-45.
9. Zoetelief J, Geleijns J, Kicken PJH, Thijssen MAO, Unnik JG. Diagnostic reference levels derived from recent surveys on patient dose for various type of radiological examinations in the Netherlands. Radiat Prot Dosim 1998; 80:109-114.
10. Marshall NW, Noble J, Faulkner K. Patient and staff dosimetry in neuroradiological procedures. Br J Radiol 1995;68:495-501.
11. Bor D., Sancak T., Olgar T. at all. Comparison of effective doses obtained from dose-area product and air kerma measurements in interventional radiology. Accepted for publication in BJR.