Research Article / *Araştırma Makalesi*

Ege Journal of Medicine / *Ege Tıp Dergisi* 2019; 58 (4): 363-369

Digital subtraction angiography and multislice computed tomography angiography for cervicocranial vessels: comparison of radiation doses

Servikokranial damarlar için dijital subtraksiyon anjiografi ve multislice bilgisayarlı tomografi anjiografi radyasyon dozlarının karşılaştırılması

H. İbrahim Özdemir[1] Celal Çınar[1] Halil Bozkaya[1]
Selçuk Topal[2] İsmail Oran[1]

[1] Ege University, Faculty of Medicine, Department of Radiology, Bornova / Izmir
[2] Bitlis Eren University, Faculty of Science and Literature, Department of Mathematics, Bitlis

Abstract

Aim: In this study our purpose was to compare the digital subtraction angiography (DSA) and computed tomography angiography (CTA) techniques in terms of the superiority of diagnosis and radiation doses.

Materials and Methods: Forty-six patients (21 men, 25 women) who were subjected to both digital subtraction angiography (DSA) and computed tomography (CT) neck-brain angiographic examinations between January and December 2014 were screened retrospectively. Radiation dose records taken from the cards provided by DSA and CT devices were reviewed. The total DSA [DSA+ tri-dimension (3D) DSA], DSA, 3D-DSA and CTA dose reports were examined separately. Generated 3D images were evaluated by two radiologists who had experience in neuro radiology and interventional radiology at least for five years. Independent samples test and in dual comparisons the paired samples test, were used for statistical analyses.

Results: Comparison made between DSA and CTA radiation doses has found that the total dose of total DSA (DSA+3D DSA) was three times and the DSA doses were two times higher than the CTA dose. There was no statistical difference between 3D DSA and CTA doses. CTA is less sensitive than DSA; four of 68 intracranial aneurisms could not be demonstrated with CTA. The radiation doses received by patients did not change with gender.

Conclusion: CTA contains less radiation doses in the diagnosis of intracranial aneurisms, but its sensitivity, however, is lower than DSA.

Keywords: Computed tomography angiography, digital subtraction angiography, tri-dimension digital subtraction angiography, aneurysm, radiation doses.

Öz

Amaç: *Bu çalışmada amacımız tanı ve radyasyon dozlarının üstünlüğü açısından dijital subtraksiyon anjiyografi (DSA) ve bilgisayarlı tomografi anjiyografi (CTA) tekniklerini karşılaştırmaktır.*

Gereç ve Yöntem: *2014 yılı Ocak-Aralık tarihleri arasında hem DSA hem de CTA ile boyun-beyin anjiyografik muayeneye tabi tutulan 46 hasta (21 erkek, 25 kadın) retrospektif olarak tarandı. DSA ve CT cihazları tarafından sağlanan kartlardan alınan radyasyon dozu kayıtları gözden geçirildi. Toplam DSA (DSA + 3D-DSA), DSA, 3D-DSA ve CTA dozu raporları ayrı ayrı incelendi. Oluşturulan üç boyutlu görüntüler en az beş yıl nöroloji ve girişimsel radyolojide tecrübesi olan iki radyolog tarafından değerlendirildi. İstatistiksel hesaplamalarda Independent samples testi, ikili karşılaştırmalarda ise paired samples testi kullanıldı.*

Bulgular: *DSA ve CTA radyasyon dozları arasında yapılan karşılaştırmada, toplam TDSA dozunun [DSA + 3 boyutlu (3D) DSA], CTA dozundan 3 kat fazla olduğu ve DSA dozunun, CTA dozundan 2 kat daha fazla olduğu bulundu. 3D DSA ve CTA dozları arasında istatistiksel bir fark yoktu. CTA, DSA'dan daha az duyarlı idi; 68 intrakranial anevrizmanın dördü CTA ile kanıtlanamadı. Hastalar tarafından alınan radyasyon dozları cinsiyetle değişmedi.*

Corresponding author: H. İbrahim Özdemir
Ege University, Faculty of Medicine, Department of Radiology,
Bornova / Izmir
E-mail: *ozdemir.egeli@gmail.com*
Received: 10.07.2018 Accepted: 12.10.2018

Sonuç: *CTA intrakranial anevrizma tanısında daha az radyasyon dozu içerir, ancak duyarlılığı DSA'dan daha düşüktür.*

Anahtar Sözcükler: *Bilgisayarlı tomografi anjiyografi, dijital subtraksiyon anjiyografi, 3 boyutlu dijital subtraksiyon anjiyografi, anevrizma, radyasyon dozları.*

Introduction

Saccular intracranial aneurisms, known as abnormal ballooning and pouching of cerebral arteries, are the primary causes of high morbidity and mortality rates. Their incidence rate in adults is about 1-5 %. They are seen in adults between 55-60 years of age more frequently. Information related to formation, development, growth and rupture of intracranial aneurisms is limited. Well known histological finding is that tunica media, the middle muscular layer of the artery, becomes thinner and constitutes a structural defect. When hemodynamic factors are added to these defects aneurism develops at the arterial branches in the subarachnoid space or at the bifurcation region. It is known that hypertension and smoking affect the development of aneurism. As a result of rupture of intracranial aneurism sub-arachnoid hemorrhage develops and 45% of patients die within 30 days. Today aneurisms can be detected before rupture through advanced non-invasive imaging techniques. Since aneurisms cause mass effect before rupture they present symptoms in the form of cranial nerve palsy and brain stem compression (1).

There are three methods that reveal intracranial aneurisms and enable identification of their morphologic characteristics. The first is Computed Tomography Angiography (CTA), which is performed after intravenous contrast; second one is Magnetic Resonance Angiography (MRA) and the third is Digital Subtraction Angiography (DSA) which is performed with intra-arterial catheter and is the gold standard. MRA is not used in certain critical patients since it takes long time. In fact, the high quality catheter angiography is an unquestionable method. Other two methods (CTA, DSA) include ionizing radiation. CTA is a noninvasive method while DSA is an invasive method (1,2). The risk for development of neurologic complications, even in experienced hands, is between 1 and 2.5 %. In elderly patients with atherosclerosis, thromboembolic complications may develop (3).

Despite DSA possesses advanced level of 3D characteristics, it is an invasive method when compared with CTA and MRA. Because CTA and MRA are less invasive they should be the first approach in non-ruptured aneurisms.

In this study our purpose was to compare the DSA and CTA techniques in terms of the superiority of diagnosis and radiation doses.

Materials and Methods

Any support or help was not obtained from the companies or organizations mentioned in this study. This was a retrospective study and the patients examined had no relation with the companies or organizations mentioned.

46 patients having subarachnoid hemorrhage (21 men, 25 women) who were subjected to both DSA and CT neck-brain angiographic examination between January 2014 and December of 2014 were screened retrospectively. Radiation dose records taken from the cards provided by DSA and CT devices were reviewed. The dose reports of DSA, 3D angiography and CT angiography applied to each patient were reviewed separately and registered. As a requirement of hospital circulation, since some of the patients were included in Siemens brand CT device and others in General Electric brand CT device, the dose data related to two separate CT devices could be compared. Thus, DSA, 3D-DSA, CTA (Siemens and General Electric) angiographic dose data were compared according to dose reports provided by each device. In addition, aneurism number and size were compared according to DSA and CTA examination results reported by neuro radiologist. In CT neck-brain angiographic tests the contrast medium of 80 ml was given at a rate of 3.5 ml/s with the help of 20-gauge catheter and automatic injector.

Image Analysis: The CT angiography images were evaluated on work station (Somatom Definition, Siemens Healthcare, Erlangen-Germany) and the 3D images constituted with help of AWL server -2 (Discovery CT750 HD, General Electric Company, Wisconsin-USA) program were evaluated and reported by 2 radiologists who had 5 years experience in neuroradiology and interventional radiology. Images were assessed separately by subjecting to processes such as 3D, Maximum Intensity Projection, Volume Rendering, Multi planar Reconstruction Post-Processing.

CTA Examination: Patients were examined with two separate CT devices. One was care dose CT with 128 slices (Somatom Definition, Siemens Healthcare, Erlangen-Germany). Scan parameters for neck-brain CTA were; kVp: 120, mA: dose modulated, rotation time: 0.3 sec, thicness: 0.6 mm, pitch:0.8, coverage: 76.8 mm, kernel filter: 326f medium smooth, matrix:512*512 and FOV: 230 mm. The other was low dose CT with 64 slices (Discovery CT750 HD, General Electric Company, Wisconsin-USA). The scan parameters for neck-brain CTA were; kVp: 120, mA: dose modulated, rotation time: 0.5 sec, thickness: 0.625 mm, pitch: 0.984, coverage: 40 mm, kernel filter: standard, matrix: 512*512 and FOV: 230 mm. For each patient intra-venous iodinated non-ionic contrast medium was used with the help of automatic injector. Before and after contrast medium also 20 ml saline was injected into each patient. To generate 3D reformatted images, CTA data were transferred to an independent workstation (Syngo Workplace, Siemens Healthcare and AWL server - 2, General Electric Company).

DSA Examination: DSA and 3D DSA were performed with femoral catheterization by the Seldinger technique. 8 mL of iodinated non-ionic contrast medium was used per acquisition; usually consisted of one antero-posterior, one lateral, and one or two oblique views. The spatial resolution was 0.32 × 0.32 mm. 3D DSA data were transferred to an independent workstation for generation of 3D reformatted images. The scan parameters for neck-brain DSA were; kVp: 70, mA:46, scan time:10 sec, number of images:12-20 frames. 3D-DSA were; kVp: 85, mA:125, scan time:12 sec.

Image Analysis: All images including 3D images were evaluated by the two radiologists whose have experience in neuro-radiology and interventional radiology at least 5 years. Images subjected to post-processing operations (3D, maximum intensity projection, volume rendering, multi planar reconstruction) were analyzed separately.

Radiation Doses (DSA): The dose values in DSA device are given in a format of DAP (Dose Area Product) and as a cGy-cm² unit. Generally, in fluoroscopy, angiography and radiography systems, the DAP (Dose Area Product) dose indicator is used. In order to find out the radiation dose that patient received from DAP dose indicator in terms of mSv, it should be multiplied by a correction factor. In DSA, a generalized conversion coefficient “c” is used for head-neck angiography.

Therefore, effective dose (ED);

ED= c * DAP (Gy-cm²), mSv (3)

The radiation dose received by the patient for that test is determined as mSv through the formula mentioned above.

In our study the dose values obtained from DSA device in DAP (cGy-cm²) format were first divided into 100 so that it can be converted into mGy-cm² unit. From multiplication of DAP doses taken from TDSA, DSA and 3D-DSA dose-estimation device’s software by this correction factor, the effective doses (ED) (mSv) were calculated and used in this study. In this research the 0.071 value that was given in ICRP 103 report and seems as the average of the values given in other publications was used (Table-3) (4).

Radiation Doses (CTA): Radiation doses of CT examination were obtained from the dose reports provided by each device’s software program (General Electric-CT, Siemens CT, Toshiba DSA). When dose reports were examined two separate key dose indicators were used during calculation of effective dose (ED). Dose reports were provided by CTA devices in the DLP (Dose Length Product) format. In CT devices the CT dose reports are given in DLP format and as a mG-cm unit (3,4). As can be understood from the below formula, DLP doses are determined by multiplication of volumetric Computed Tomography Dose Indices (CTDI) belonging to each slice with the length of area scanned.

DLP (mGy-cm) = CTDIvol (mGy) x scan length (cm) (5).

In order to estimate the effective dose (ED) from DLP dose indicator given in CT devices, it should be multiplied by “k” conversion coefficient calculated separately for each anatomic area.

Therefore;

ED= k * DLP (mGy-cm), mSv (5,6).

Through this formula the radiation dose received by the patient for that test is determined as mSv. In our study dose values obtained from CT devices in DLP (mGy-cm) format are multiplied by 0.0031 (k coefficient) effective doses (mSv) and used (Table 3,4).

Statistical Analysis: Statistical analysis was performed with SPSS (SPSS version 12.0, SPSS). Descriptive variables, descriptive statistics and the comparison of data were used in Independent Samples T test, Pared Samples T test and One Samples T test. Interactive Scatterplot was used as a graphic.

To assess the diagnostic performance of DSA compared with CTA in the detection of intracranial aneurisms, data were analyzed on a per-patient basis to differentiate patients. In addition, the detectability of individual aneurisms was analyzed on a per aneurism basis. Ability to detect aneurisms with various diameters also was analyzed.

Results

In our study, as seen in demographic data of patients, DSA and CTA test results of 46 patients who were diagnosed with arterial aneurism were scrutinized. The sizes of aneurism were found between 1 and 12 mm (mean 5.73 mm) in DSA and between 2 and 14 mm (mean 6.50 mm) in CTA. When CTA reports and results were examined it was identified that aneurisms (less than 2 mm) present in 4 patients were overlooked and the aneurism size measured was found to be slightly higher. The number of detected aneurism was 68 and 64 for DSA and CTA, respectively. The diagnostic sensitivity of CTA was, therefore, 93 % when DSA was accepted as gold-standard.

When dose data averages were checked, the dose area product (DAP) radiation dose averages belonging to TDSA, DSA and 3D DSA tests were found 6901, 4618, and 2283 cGy-cm² respectively. After gray conversion was performed, the mean equivalent doses obtained as a result of multiplication with the conversion coefficient given for neck-brain DSA (c:0.071) were found to be 4.9, 3.3 and 1.6 mSv respectively (Table 1,2).

When CTA dose data averages were checked the dose length product (DLP) radiation dose average was found as 490 mGy-cm (CT(128): 413, CT(64): 493). The mean equivalent CTA dose obtained as a result of multiplication with the conversion coefficient determined for neck-brain CTA (k:0.0031) was found as 1.5 mSv (CT(128): 1.3, CT(64): 1.5) (Table-1). Graph showing the radiation doses (mSv) according to imaging technique (DSA vs CTA) is seen in Figure-1.

As a result of statistical analyses; when inter-system equivalent radiation dose values (mSv) were compared, significant radiation dose differences were detected between TDSA-CTA (p=0.000), DSA-CTA (p=0.000), CT(128)-CT(64) (p=0.003). However, any significant difference could not be found in comparison of 3D DSA and CTA (p=0.129). There was no difference in radiation dose distinction according to gender.

Discussion

This study was carried out through dose card technique taken from software system of devices used. The dose studies performed previously were carried out using dosimetry technique on phantom or human-equivalent models. In a 3D-DSA dose study carried out by Kyriakou et al., using C-arm Flat Panel Detector CT and phantom, they found a good correlation (R:0.953) between CTDIw, DLP, and DAP values (7). Again, Christner et al., used DLP values in their Dual Energy CT dose estimation study and in Volume CT dose index study (6,8). In our study DLP values obtained from CTDIx values for CTA and DAP for DSA were used.

For DSA devices, DAP correction coefficient was found between 0.03 and 0.09 in different publications (9,10,11). It was given as 0.071in ICRP 103 (2009) reports (Table-2).

For CTA devices, DLP correction coefficient “k” for head-neck CTA examination was given as 0.0031 in various publications (Tables-3,4).

Table-1. According to radiation data obtained from devices and patient-specific dose cards, DSA and CTA doses calculated by multiplying with ***c*** ve ***k*** coefficient.

ΔDSA (DSA+3D-DSA	46	6901	69.01	0.071	4.90			
	46	4618	46.18	0.071	3.28			
	46	2283	22.83	0.071	1.62			
CTA CT(128)+CT(64)	46					469	0.0031	1.45
	14					413	0.0031	1.28
	32					493	0.0031	1.53

ΔDSA: Total Digital Substruction Angiography**, DSA:** Digital Substruction Angiography, **3D-DSA:** Three-Dimension Angiography, **CTA:** Computed Tomography Angiography**, CT** (128)**:** Computed Tomography Seimens**, CT** (64)**:** Computed Tomography General Electric**, DAP**: Dose Area Product, **DLP**: Dose Length Product, **ED**: Effective Dose.

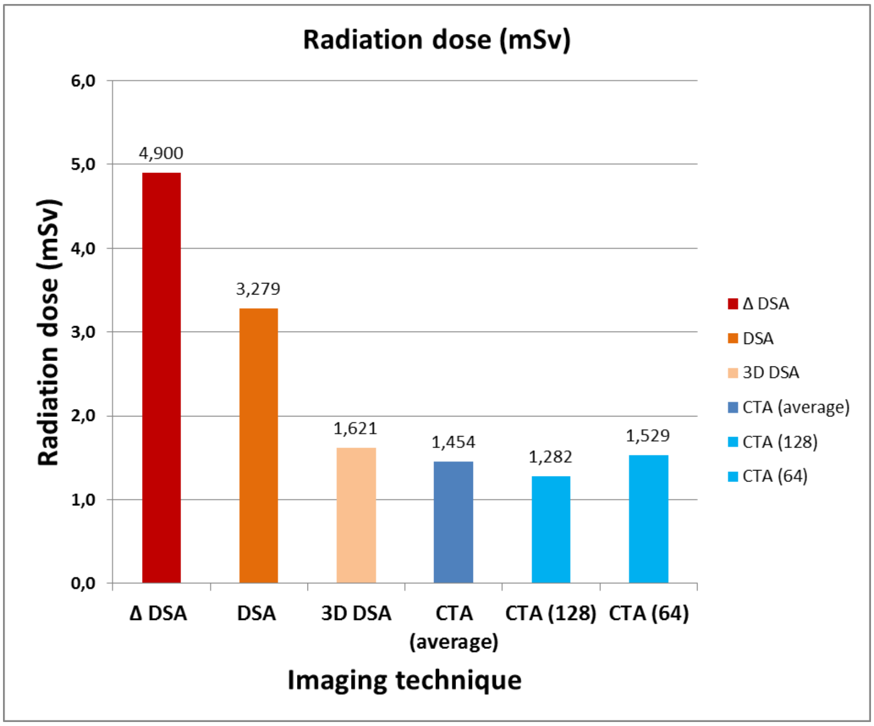

Figure-1. According to imaging technique (DSA vs CTA) graph shows the radiation doses (mSv).

Table-2. Comparison of dose parameters and published ***c*** coefficients (ED/DAP) for cervico-cranial DSA.

	DAP (Gy * cm^2)	ED (mSv)	*c* coefficients (ED/DAP) (mSv/[Gy *cm^2])
Koyama et al. 2010 (10)	—	0.47–1.2	—
Kim et al. 2012 (3)	5.99–9.61	0.38–0.87	0.06–0.09
Bai et al. 2013 (12)	9.4 ± 2	0.30 ± 0.08	0.03–0.035
Sanchez et al. 2014 (11)	11.75–23.5	0.83–1.6	0.09
ICRP 103 2009	23.5	1.65	**0.071**

Taken from Sanchez et al 2014 (11). **DAP**: Dose Area Product, **ED**: Effective Dose.

Table-3. Comparison of published ***k*** coefficients in CT.

	***k* coefficients (ED/DLP) (mSv / [mGy-cm])**			
Anatomic Region	Jessen et al. 1999 (5)	EC 2004 (16)	EC 2004, Appendix B (17)	EC 2004, Appendix C (17) and NRPB-W67 (18)
Head	0.0021	0.0023	0.0023	0.0021
Head and neck				**0.0031**
Neck	0.0048	0.0054		0.0059
Chest	0.014	0.017	0.018	0.014
Abdomen	0.012	0.015	0.017	0.015
Pelvis	0.019	0.019	0.017	0.015

Taken from McCollough et al 2010 (14). **DLP**: Dose Length Product, **ED**: Effective Dose.

Table-4. Normalized effective dose values per dose-length product (DLP) over various body regions and patient age.

	***k coefficient*: Effective dose per DLP (mSv (mGy cm)) by age**				
Region of body	**0**	**1**	**5**	**10**	**Adult**
Head & neck	0.013	0.0085	0.0057	0.0042	**0.0031**
Head	0.011	0.0067	0.0040	0.0032	0.0021
Neck	0.017	0.012	0.011	0.0079	0.0059
Chest	0.039	0.026	0.018	0.013	0.014
Abdomen & pelvis	0.049	0.030	0.020	0.015	0.015
Trunk	0.044	0.028	0.019	0.014	0.015

Taken from EC 2004; Appendix C (17), NRPB-W67 (18), EC 2008; RP No:154 (19) and Report of AAPM Task Group 23, Report No: 96, 2008 (20). **DLP**: Dose Length Product.

The mean CTA dose of 1.5 mSv, obtained from the results of the study was found close to cerebral CTA effective dose values (1-2 mSv) presented in AAPM reports (20).

When DSA's aneurism diagnosing sensitivity is accepted as gold standard, the aneurism diagnosing sensitivity of CTA found in our study (0.95) is considerably high and consistent with other studies. In terms of diagnosis of intracranial aneurism, the CTA and DSA methods have been compared in the literature. Studies conducted related to this topic demonstrated that the diagnostic sensitivity and specificity of intracranial aneurisms through CTA was between 0.77-0.99 and 0.87-1.00, respectively (21-28). Sensitivity of CTA in diagnosing aneurism less than 3 mm was found between 0.40-0.91 (23, 24, 29). In separate studies where CTA and DSA were compared, Zhang and Lu et al., stated that CTA could be used in the diagnosis of aneurisms below 3 mm in diameter (9).

For the imaging of cervico-cerebral vessels, the effective dose according to Manninen AL et al., was 4.85 mSv for CTA and 3.60 mSv for DSA (30). In our study radiation doses were found as 1.5 mSv for CTA and as 3.3 mSv for DSA. As can be understood from the results, our CTA doses were found to be about 3 times lesser and DSA doses slightly more reduced than IRCP 103. When the DSA and CTA dose differences are examined, it is seen that TDSA doses are excessive more than 3 folds (4.9 -1.5 mSv) and DSA doses more than 2 folds (3.3-1.5 mSv). Manninen et al., found effective DSA doses 5 folds higher for cranial angiography and 4 folds higher for cranio-cervical angiography compared to effective CTA doses (30).

It is thought that the dose difference of 0.3 mSv (1.3 - 1.6 mSv) between CT(128) and CT(64) [which seems in favor of CT(128)] would result from unequal patient number or differences of CT slice row.

Conclusion

CTA contains less radiation doses in the diagnosis of intracranial aneurisms, its sensitivity, however, is lower than DSA. When interventional risks are taken into consideration, CTA can be recommended instead of conventional angiography for diagnostic purposes.

References

1. Brisman JL, Song JK, Newell DW. Cerebral aneurism. N Engl J Med. 2006;355(9):928-39.
2. Schievink WI. Intracranial aneurisms. N Engl J Med. 1997; 336 (1): 28-40.
3. Kim S, Sopko D, Toncheva G, Enterline D, Keijzers B, Yoshizumi TT. Radiation dose from 3D rotational X-ray imaging: organ and effective dose with conversion factors. Radiat Prot Dosimetry. 2012; 150 (1): 50-4.
4. The 2007 Recommendations of the International Commission on Radiological Protection. Ann ICRP. 2007; 37 (2-4): 1-332.
5. Jessen KA, Shrimpton PC, Geleijns J, Panzer W, Tosi G. Dosimetry for optimisation of patient protection in computed tomography. Appl Radiat Isot. 1999; 50 (1):165-72.
6. Christner JA, Kofler JM, McCollough CH. Estimating effective dose for CT using dose-length product compared with using organ doses: consequences of adopting International Commission on Radiological Protection publication 103 or dual-energy scanning. AJR Am J Roentgenol. 2010; 194 (4): 881-9.

7. Kyriakou Y, Richter G, Dörfler A, Kalender WA. Neuroradiologic Applications with Routine C-arm Flat Panel Detector CT: Evaluation of Patient Dose Measurements. AJNR Am J Neuroradiol. 2008; 29 (10): 1930-6
8. Huda W, Mettler FA. Volume CT dose index and dose-length product displayed during CT: what good are they? Radiology. 2011; 258 (1): 236-42.
9. Zhang LJ, Wu SY, Niu JB, Zhang ZL, Wang HZ, Zhao YE, et al. Dual-Energy CT Angiography in the Evaluation of Intracranial Aneurisms: Image Quality, Radiation Dose, and Comparison With 3D Rotational Digital Subtraction Angiography. AJR Am J Roentgenol. 2010; 194 (1): 23-30.
10. Koyama S, Aoyama T, Oda N, Yamauchi-Kawaura C. Radiation dose evaluation in tomosynthesis and C-arm cone-beam CT examination with an anthropomorphic phantom. Med Phys. 2010; 37 (8): 4298-306.
11. Sanchez RM, Vano E, Fernández JM, Moreu M, Lopez-Ibor L. Brain Radiation Doses to Patients in an Interventional Neuroradiology Laboratory. AJNR Am J Neuroradiol. 2014; 35 (7): 1276-80.
12. Bai M, Liu X, Liu B. Effective patient dose during neuroradiological C-arm CT procedures. Diagn Interv Radiol. 2013; 19 (1): 29-32.
13. ICRP Publication 105. Radiation protection in medicine. Ann ICRP. 2007; 37 (6): 1-63.
14. McCollough CH, Christner JA, Kofler JM. How effective is effective dose as a predictor of radiation risk? AJR Am J Roentgenol. 2010; 194 (4): 890-6.
15. Jessen, KA, Shrimpton, PC, J. Geleijns, J, Panzer, W, Tosi, G. Dosimetry for optimisation of patient protection in computed tomography. Applied Radiation and Isotopes. 1999; 50 (1): 165-72.
16. Bongartz G, Golding SJ, Jurik AG, Leonardi M, van Persijn van Meerten E, Rodríguez R, Schneider K, Calzado A, Geleijns J, Jessen KA, Panzer W, Shrimpton PC, Tosi G. European Guidelines for Multislice Computed Tomography. Funded by the European Commission. Contract number FIGM-CT2000-20078-CT-TIP. March 2004.
17. Shrimpton P. Assessment of patient dose in CT. In: EUR. European guidelines for multislice computed tomography funded by the European Commission 2004: contract number FIGMCT2000-20078-CT-TIP. Luxembourg, Luxembourg: European Commission, 2004:Appendix C.
18. Shrimpton PC, Hillier MC, Lewis MA, Dunn M. Doses from computed tomography (CT) examinations in the UK: 2003. Br J Radiol. 2006; 79 (948): 968-80.
19. EC 2008. Radiatıon Protection No:154. European Guidance on Estimating Population Doses from Medical X-Ray Procedures. Luxembourg, 2008.
20. AAPM Report No:96. Report of AAPM Task Group 23 of the Diagnostic Imaging Council CT Committee. USA, 2008.
21. Dammert S, Krings T, Moller-Hartmann W, Ueffing E, Hans FJ, Wilmes K, et al. Detection of intracranial aneurisms with multislice CT: comparison with conventional angiography. Neuroradiology. 2004; 46 (6): 427-34.
22. Kouskouras C, Charitanti A, Giavroglou C, Foroglou N, Selviaridis P, Kontopoulos V, Dimitriadis AS. Intracranial aneurisms: evaluation using CTA and MRA: correlation with DSA and intraoperative findings. Neuroradiology. 2004; 46 (10): 842-50.
23. Chappell ET, Moure FC, Good MC. Comparison of computed tomographic angiography with digital subtraction angiography in the diagnosis of cerebral aneurisms: a meta-analysis. Neurosurgery. 2003;52(3):624-31.
24. White PM, Wardlaw JM, Easton V. Can noninvasive imaging accurately depict intracranial aneurisms? A systematic review. Radiology. 2000; 217 (2): 361-70.
25. White PM, Teasdale EM, Wardlaw JM, Easton V. Intracranial aneurisms: CT angiography and MR angiography for detection prospective blinded comparison in a large patient cohort. Radiology. 2001; 219 (3): 739-49.
26. Okahara M, Kiyosue H, Yamashita M, Naqatomi H, Hata H, Saginova T, et al. Diagnostic accuracy of magnetic resonance angiography for cerebral aneurisms in correlation with 3D-digital subtraction angiographic images: a study of 133 aneurisms. Stroke. 2002; 33 (7): 1803-8.
27. Harrison MJ, Johnson BA, Gardner GM, Welling BG. Preliminary results on the management of unruptured intracranial aneurisms with magnetic resonance angiography and computed tomographic angiography. Neurosurgery. 1997; 40 (5): 947-55.
28. Bederson JB, Awad IA, Wiebers DO, Piepqras D, Haley EC Jr, Brot T, et al. Recommendations for the management of patients with unruptured intracranial aneurisms: a statement for healthcare professionals from the Stroke Council of the American Heart Association. Stroke. 2000; 31 (11): 2742-50.
29. Tipper G, U-King-Im JM, Price SJ, Trivedi RA, Cross JJ, Higgins NJ, et al. Detection and evaluation of intracranial aneurisms with 16-row multislice CT angiography. Clin Radiol. 2005; 60 (5): 565-72.
30. Manninen AL, Isokangas JM, Karttunen K, Siniluoto T, Nieminen MT. A Comparison of Radiation Exposure between Diagnostic CTA and DSA Examinations of Cerebral and Cervicocerebral Vessels. AJNR Am J Neuroradiol. 2012; 33 (11): 2038-42.