**Patient radiation exposure for endovascular deep venous interventions**

Chung Sim Lim1, 5, Saima Waseem1, 5, Tamer El-Sayed1, 2, James Budge1, Justina Silickas1, 2, Belen Quintana1,Narayanan Thulasidasan3, Narayan Karunanithy4, Stephen A Black1, 2

1. Department of Vascular Surgery, Guy’s and St Thomas’ Hospital NHS Foundation Trust, London, United Kingdom
2. Academic Department of Vascular Surgery, School of Cardiovascular Medicine and Sciences, King’s College London, BHF Centre of Excellence, Guy’s and St Thomas’ Hospital NHS Foundation Trust, London, United Kingdom
3. Department of Interventional Radiology, Guy’s and St Thomas’ Hospital NHS Foundation Trust, London, United Kingdom
4. School of Biomedical Engineering & Imaging Sciences, King’s College London, London, United Kingdom
5. Joint first author

**Corresponding author:**

Mr Stephen A Black

Consultant Vascular Surgeon

Academic Department of Vascular Surgery

First Floor, North Wing

St Thomas’ Hospital

Westminster Bridge Road

London SE1 7EH

United Kingdom

Tel No: +44 (0)20 7188 2574

Fax No: +44 (0)20 71881094

Email: stephen.black@gstt.nhs.uk

**Abstract**

*Background*

Endovascular deep venous interventions for central venous outflow obstruction may expose the patients to significant ionizing radiation over time. The study aimed to assess the cumulative radiation exposure to patients who underwent common endovascular deep venous interventions for acute and chronic central venous outflow obstructive diseases; namely deep vein thrombosis (DVT) thrombolysis, unilateral chronic iliofemoral venous stenting, and inferior vena cava (IVC) reconstruction in a single tertiary referral unit.

*Methods*

Patients who had DVT thrombolysis of upper extremity (UE DVT) and lower extremity (LE DVT), unilateral chronic iliofemoral venous stenting, and endovascular IVC reconstruction between 1 May 2012 and 31 July 2017 in a single unit were retrospectively reviewed. Demographic data, anatomical DVT, imaging, technical details of the index procedure, follow-up, and estimated radiation exposure measured in dose-length product (DLP), dose-area product (DAP) and fluoroscopy time (FT) from related computed tomography and interventions were collected and analyzed. Mann Whitney test was performed to assess for statistical differences between subgroups. P<0.05 was considered significant.

*Results*

In total, 20 (UE DVT thrombolysis), 91 (LE DVT thrombolysis), 56 (unilateral chronic iliofemoral venous stenting), and 39 (endovascular IVC reconstruction) patients were included in the study, with the following median (range) ages; 39 (20 -67) years, 44 (15 – 78) years, 45 (20 – 80) years, and 35 (18 -73) years, respectively. The median (range) cumulative DAP for the index DVT thrombolysis was 9.2 (0.2 – 176.0) Gycm2 for LE DVT, and 2.0 (0.1 – 11.7) Gycm2 for UE DVT (P<0.0001). The median (range) cumulative FT for the index thrombolysis was 981 (20–4890) seconds and 837 (19 – 2895) seconds for LE DVT and UE DVT, respectively (P=0.18). For unilateral chronic iliofemoral venous stenting, the median (range) cumulative DAP and FT was 32.4 (0.1 – 289.6) Gycm2 and the median FT was 660 (246 - 4200) seconds, respectively. Meanwhile, the median (range) cumulative DAP and FT for the endovascular IVC reconstruction was 60.8 (2.5 – 269.1) Gycm2 and 2846 (836 – 11682) seconds, respectively. During follow-up, 10.0% (UE DVT thrombolysis), 39.6% (LE DVT thrombolysis), 57.1% (unilateral chronic iliofemoral venous stenting) and 51.3% (endovascular IVC reconstruction) of patients had secondary procedures requiring fluoroscopy. The median (range) DAP for secondary procedures during follow-up was 6.6 (0.8 186.5) Gycm2, 1.9 (0.2 – 111.7) Gycm2 and 24.3 (0.2 – 157.5) Gycm2 for LE DVT thrombolysis, unilateral chronic iliofemoral venous stenting and endovascular IVC reconstruction, respectively.

*Conclusions*

Patient radiation exposure for endovascular deep venous interventions for central venous outflow obstruction measured in DAP and FT appeared to be less than and at most similar to anatomically comparable arterial interventions in the literature. However, these patients were usually much younger than those with arterial diseases, and may need secondary interventions involving further radiation exposure in their lifetime. Further studies should investigate the long-term side-effects of radiation exposure in these patients and ways of reducing it including the use of IVUS and the routine use of magnetic resonance imaging technology.

**Key words**

Deep vein thrombosis, central venous outflow, venous stent, thrombolysis, ionizing radiation, post-thrombotic syndrome

**Introduction**

Recent advances in imaging, endovascular and stent technology have revolutionized the treatment of acute and chronic central venous outflow obstruction. There is increasing evidence to support that endovascular deep venous interventions for central venous outflow obstruction including deep vein thrombosis (DVT) thrombolysis, iliofemoral venous stenting and inferior vena cava (IVC) reconstruction are safe and clinically beneficial to certain patient groups1-7. This has led to endovascular deep venous interventions increasingly being performed in the last decade8.

These interventions require the use of fluoroscopy, hence the patients (and operators) are exposed to radiation. In addition, these patients are often exposed to ionizing radiation from their diagnostic and later follow-up or surveillance imaging. Some patients may also require adjunctive and/or secondary interventions that involve the use of fluoroscopy including percutaneous thrombolysis, and balloon angioplasty with or without stenting to maintain the venous luminal patency9-11. Furthermore, patients who undergo endovascular deep venous interventions are often relatively younger than those having arterial procedures1-4, 6. The long term patency of endovascular deep venous interventions remains unclear, hence the cumulative ionizing radiation exposure and its potential side-effect are also unknown. Recent data from long term follow-up of aneurysm patients has suggested a potential significant risk from cumulative ionizing radiation12. Therefore, the aim of the study was to assess the cumulative radiation exposure to patients who underwent common endovascular deep venous interventions for acute and chronic central venous outflow obstructive diseases; namely DVT thrombolysis, unilateral chronic iliofemoral venous stenting, and IVC reconstruction in a single tertiary referral unit.

**Methods**

Patients

Patients who had catheter-directed thrombolysis (CDT) and pharmacomechanical thrombolysis (PMT) for acute DVT involving the upper extremity (UE DVT group) and lower extremity (LE DVT group), unilateral chronic iliofemoral venous stenting, and endovascular IVC reconstruction were sampled within specific periods between 1 May 2012 and 31 July 2017. This was to ensure that sufficient follow-up was available and as heterogeneous a cohort as possible in a single unit were identified for analysis. For DVT thrombolysis, only patients who had DVT involving the IVC, iliac vein and/or CFV (LE DVT group), and superior vena cava (SVC), brachiocephalic vein (with or without the involvement of the internal jugular vein), and subclavian vein (SCV) (UE DVT group) were included in the study. Patients who previously had deep venous intervention and reconstructive surgery including stenting of the ipsilateral extremity were excluded from the study. For unilateral chronic iliofemoral venous stenting, only patients who had no ipsilateral previous iliofemoral venous stenting were included. Similarly, for endovascular IVC reconstruction, only patients with no previous iliocaval or iliofemoral venous stenting were included.

Data collection

Data collected included demography (age and gender), anatomical involvement (highest level of involved vein and laterality), pre-index procedure computed tomography (CT) and related endovascular procedures, the estimated CT radiation dose (measured in dose-length product, DLP), technical details of the index procedure, adjunctive interventions, estimated fluoroscopic radiation dose measured in dose-area product (DAP) and fluoroscopy time (FT), follow-up or post-index procedure CT and secondary endovascular procedures. For DVT thrombolysis, the terms “index procedure” covers all the procedures when thrombolysis was initiated, “check thrombolysis”, and “completion of thrombolysis” that might include adjunctive interventions (e.g. stenting and IVC filter insertion and removal) that were performed at the same time. DAP and DLP refer to the radiation absorbed by irradiated tissue multiplied by the area and length, respectively irradiated which gives a rough estimation of the risk of stochastic effects13-15.

Operating theatres and C-arm

All the procedures were either performed in the interventional radiology angio-suites or hybrid operating theatre with the following ceiling-mounted C-arm systems; the Siemens Axiom Artis dTA (Siemens Healthcare, Erlangen, Germany) and Siemens Artis zee (Siemens Healthcare, Erlangen, Germany) in the angio-suites, and the Philips Alura Xper FD20 (Philips Healthcare, Eindhoven, Netherlands) in the hybrid operating theatre. Default settings used were a pulse rate of 3.0 and 7.5 pulses/second for background fluoroscopy in the angio-suites and hybrid operating theatre, respectively, and two frames/second for digital subtraction angiography (DSA) acquisitions for all rooms. The fluoroscopy equipment was controlled by a trained radiographer for each procedure.

Endovascular techniques

All endovascular deep venous procedures were carried out by vascular surgeons and/or interventional radiologists in the single unit.

*DVT thrombolysis*

Ipsilateral popliteal vein was the preferred choice of percutaneous venous access for the LE thrombolysis. Ipsilateral brachial, basilic and cephalic vein were used as access sites for the UE thrombolysis. Patients were positioned prone when popliteal access was used, and supine for all other access sites during interventions. The decision on the method of thrombolysis (CDT or PMT), the delivery (boluses, continuous or both) and dose of tissue plasminogen activator, use of intravascular ultrasound (IVUS), duration of thrombolysis, and any adjunctive interventions including balloon angioplasty and stenting was made at the discretion of the clinician performing the procedure; depending on the individual case and the operators’ experience. In the cases involving PMT these included the use of AngioJet™ thrombectomy system (Boston Scientific, Marlborough, MA, USA), EKOS EkoSonicTM Acoustic Pulse Thrombolysis (EKOS Corporation, Bothell, WA, USA), manual thrombo-aspiration or a combination of these methods.

*Unilateral chronic iliofemoral venous stenting*

Ipsilateral mid femoral vein was the preferred percutaneous venous access when performing iliofemoral venous stenting for chronic occlusive disease. Other access sites included right internal jugular vein, and rarely ipsilateral great saphenous vein or common femoral vein. Patients were positioned supine for all interventions. Only uncovered stents were used. IVUS was routinely used in all the endovascular iliac or iliocaval reconstructions. IVC filters were not routinely inserted.

*Endovascular IVC reconstruction*

Bilateral popliteal vein was the preferred percutaneous venous accesses for thrombolysis of acute DVT involving the IVC. Bilateral mid femoral vein with or without internal jugular vein punctures was the preferred percutaneous venous accesses for IVC reconstruction for chronic occlusive diseases. Patients were positioned prone when popliteal access was used, and supine for all other access sites during interventions. The stent configurations used were (i) double barrel stents from the iliofemoral veins into the IVC if the diseases involved the IVC segments up to the renal veins; (ii) straight stents if the diseases involved only the suprarenal segment of the IVC; or (iii) double barrel stents from both iliofemoral veins into straight stents in the suprarenal segment of the IVC if the whole IVC was involved. Very occasionally, stent system from unilateral iliofemoral vein extending into the IVC had to be used if the contralateral iliac system was unable to be crossed with guidewires. Only uncovered stents were used. IVUS was routinely used in all the endovascular IVC reconstruction with stents. IVC filter was not routinely inserted.

Follow-up

Patients who had successful endovascular deep venous interventions for central venous outflow obstructive diseases were routinely followed-up with duplex ultrasonography and clinically (day 1, week 2, week 6, month 3, month 6, month 12, and annually). Patients who had endovascular IVC reconstruction also routinely had CT venography on day 1 post-operatively. Other radiological imaging modalities would only be used in selective cases. We did not routinely screen for malignancy in all the cases presented with acute DVT although patients might receive targeted investigation based on clinical suspicion. In general, during follow-up, patients with acute or sub-acute (within 4-6 weeks) re-occlusion of the large deep veins or stents would be treated with percutaneous thrombolysis with or without balloon venoplasty / stenting. Patients with clinical and/or radiological suspicion of significant in-stent restenosis (ISR) would be further investigated with percutaneous venography and IVUS. Once the significant ISR was confirmed, balloon venoplasty with or without stent realigning or extension would be performed.

*Statistical analysis*

Data was collected and analyzed using Microsoft Excel for Mac version 15.15 (Microsoft Corp, Redmond, Washington, USA) and GraphPad Prism version 7.00 for Mac (GraphPad Software, La Jolla California USA). Simple statistical analyses were performed to determine total and percentages, median and ranges depending on the variables. Statistical analyses comparing the differences between subgroups were performed using Mann Whitney test.

**Results**

Patient demography

Table 1 summarizes the patient demography, anatomical involvement and etiology of the central venous obstructive disease requiring endovascular intervention in this study

Pre-index procedure patient radiation exposure

Table 2 summarizes the number of patients who had pre-index procedure CT and diagnostic venography with or without other interventions, and the radiation exposure measured in DLP and DAP, respectively for patients who had DVT thrombolysis, unilateral chronic iliac venous stenting, and IVC reconstruction. The pre-index procedure interventions included venoplasty of in-flow veins, and attempted stenting.

Index procedure

*DVT thrombolysis*

Table 3 summarizes the methods of thrombolysis performed. IVC filter was inserted in 8 cases (8.8%) in the LE DVT, all early in our practice, and none in the UE DVT group. Majority of the patients in the LE DVT group had venous stenting during the index thrombolysis (n=72; 79.1%). In contrast, no stent was used in the UE DVT group. The median (range) cumulative DAP for the index thrombolysis was 9.2 (0.2 – 176.0) Gycm2 for the LE DVT group, and 2.0 (0.1 – 11.7) Gycm2 for the UE DVT group (P<0.0001). Meanwhile, the median (range) cumulative FT for the index thrombolysis was 981 (20 – 4890) seconds and 837 (19 – 2895) seconds for the LE DVT and UE DVT group, respectively (P=0.18). There was no significant difference in the DAP and FT when compared between patients who had CDT and those with PMT in both UE and LE DVT.

*Unilateral chronic iliofemoral venous stenting*

The median cumulative DAP of the index procedure was 32.4 (0.1 – 289.6) Gycm2 and the median FT was 660 (246 - 4200) seconds. The median (range) DAP for stenting in patients with a May Thurner’s lesion and post-thrombotic syndrome (PTS) was 20.3 (0.1 - 267.7) Gycm2 and 67.3 (0.1 - 289.6) Gycm2, respectively (p=0.0756). The median (range) FT for stenting in patients with May Thurner’s lesion and PTS was 504 (246 – 1626) seconds and 912 (492 - 4200) seconds, respectively (p<0.0001).

*IVC reconstruction*

The number of patients with different stent configurations for IVC reconstruction is shown in Figure 1. The median (range) cumulative DAP and FT for the endovascular IVC reconstruction for all patients was 60.8 (2.5 – 269.1) Gycm2 and 2846 (836 – 11682) seconds, respectively. There was no significant difference in the cumulative DAP and FT between procedures performed as acute versus chronic (P=0.50 and P=0.73, respectively). The median (range) cumulative DAP for the cases involving supra-renal IVC stenting 128.1 (25.8 – 269.1) Gycm2 was significantly higher than those of infra-renal IVC of 27.2 (2.5 – 184.1) Gycm2 (P=0.0005). Similarly, the median (range) cumulative FT for the cases involving the supra-renal IVC stenting 3575 (1063 – 11682) seconds was significantly longer than those of only infra-renal IVC of 2494 (836 – 4120) seconds (P=0.04).

Follow-up imaging and interventions

Table 4 shows the duration of follow-up, number of patients who had post-index procedure CT and follow-up endovascular procedures, and the radiation exposure measured in DLP and DAP, respectively for patients who had DVT thrombolysis, unilateral chronic iliac venous stenting, and IVC reconstruction.

**Discussion**

Ionizing radiation including X-ray can cause cell injury by inducing deoxyribonucleic acid (DNA) damage with potential adverse side-effects including skin erythema, cataracts, permanent epilation, delayed skin necrosis and cancers16-19. It is likely that the long-term adverse clinical significance correlates with the cumulative dose of ionizing radiation exposure although many other factors including recovery interval between radiation exposures, parts of the body being exposed, and age, sex and genetic of the patients may play important roles16, 18, 19.

Several studies have reported the radiation exposure to patients who underwent minimally invasive procedures such as percutaneous coronary intervention, endovascular aortic aneurysm repair, and percutaneous angioplasty and stenting of peripheral arteries13, 15, 17, 20-22. A systematic review that examined the peri-procedural radiation exposure to patients and staff reported that the mean DAP was 79.5 Gycm2 (range 4.3 – 619 Gycm2) for a regular infrarenal EVAR20. In a study from Jones and colleagues, 22 of 320 patients undergoing elective EVAR and 4 of 64 undergoing emergent EVAR required an additional procedure, which added 31.8 Gycm2 and 49.9 Gycm2 of radiation, respectively, to the patient17. Spira and colleagues reported the DAP and FT in a broad spectrum of therapeutic angiographic procedures, comparing two angiographic systems; analogue image intensifiers and modern flat panel detectors13. For the latter system, the overall mean DAPs and FTs reported for UE and LE procedures were; DAP 29.7 Gycm2 and FT 1123.5 seconds (percutaneous transluminal angioplasty (PTA)); DAP 86.3 Gycm2 and FT 1066.8 seconds (PTA and stent); and DAP 21.2 cGycm2 and FT 542.9 seconds (intra-arterial thrombolysis). In another study by Miller and colleagues, the reported DAP for PTA pelvis, PTA abdomen, PTA and stent pelvis, and vena caval filter were 171.4 Gycm2, 157.5 Gycm2, and 53.9 Gycm2, respectively21, 22.

Prior to this study, it was unclear the estimated cumulative X-ray exposure in patients undergoing endovascular deep venous interventions for acute and chronic central venous outflow obstruction. In this study, we investigated patient radiation exposure in DVT thrombolysis, unilateral chronic iliofemoral venous stenting and endovascular IVC reconstruction because there is emerging evidence supporting their efficacy and safety in some patient groups, hence they are increasingly being carried out to treat acute and chronic central venous outflow obstruction1-7. Despite there is a relatively large body of literature on the arterial interventions, very little is known the patient radiation exposure in endovascular deep venous interventions. This is the first study that estimated and reported patient radiation exposure on endovascular deep venous interventions for chronic venous outflow obstruction, at least when they are performed based on the current technology and expected standards. Understanding the patient radiation exposure in such interventions that are increasingly being carried out and likely to get more and more complex will help clinicians and other responsible radiation safety officers to develop strategies to minimize risk of ionizing radiation exposure to both patients and operators.

In this study, the estimated patient radiation exposure measured in DAP and FT for deep venous interventions is less than or at most just similar to anatomically comparable endovascular arterial procedures; DVT thrombolysis and unilateral chronic iliofemoral venous stenting to peripheral arterial revascularisation, and IVC reconstruction to EVAR 13, 17, 21, 22 14, 20. Table 5 summarises the patient radiation exposure in DAP and FT for index deep venous interventions found in this study when compared to anatomical comparable arterial interventions reported in the literature13 20. Furthermore, as with arterial interventions, patients who undergo endovascular deep venous interventions may need adjunctive procedures, surveillance and later secondary interventions, as shown in this study, which would increase the cumulative radiation exposure to the patients9-11. The EVAR trial which compared endovascular and open repair of abdominal aortic aneurysm, reported an increased incidence of malignancy in patients treated endovascularly after 15 years of follow-up12. Worryingly, the patients who undergo deep venous interventions are likely to be in the younger age group than those who needed arterial interventions. These patients potentially receive more radiation from their longer surveillance or follow-up imaging and secondary interventions that require the use of ionizing radiation than their arterial counterparts. Moreover, there is also more time for the potential side-effects of the DNA damage from the ionizing radiation exposure to manifest when compared with their arterial counterparts.

Therefore, it is important that all the clinicians who carry out endovascular procedures should keep the radiation exposure to their patients and themselves to the minimal. Dose awareness and training in radiation protection are fundamental for the clinicians for minimising patient and occupational radiation exposure14, 16, 20. The use of low-dose and pulsed fluoroscopy, and appropriate protective equipment on the patients and operators would reduce radiation exposure16, 20. Improving the digital technology of the imaging system that can improve the resolution of the images without needing to increase the radiation dose certainly helps16. Other methods including the use of IVUS and fusion imaging technology may potentially reduce the need of venography, and are currently being studied to evaluate if this may reduce the radiation exposure further23, 24. The use of and improvement in imaging modalities that do not use ionizing radiation including duplex ultrasonography and MRI for diagnostic and surveillance purposes would may also lead to a reduction in patient cumulative radiation exposure17, 25, 26.

There are several limitations in this study. Firstly, this is a single centre retrospective study with relatively small number of patients, hence potential biases cannot be ruled out inclusive of the potential absence of imaging done at referring centres and our preference for MRV which reduces cumulative radiation dose.

Secondly, DAP, DLP and FT are exposure radiation indices that only provides theoretical radiation risk estimate which does not factor in individual variations in susceptibility to radiation damage14-16. DAP, DLP and FT measurements were easily obtained as they are automatically computed by the modern fluoroscopy and CT units13-16, 25. Furthermore, many studies on radiation exposure including those for endovascular arterial interventions reported their findings with these indices, allowing comparison of finding between studies to be done easily13-15, 20-22, 25.

**Conclusions**

Patient radiation exposure for endovascular deep venous interventions for central venous outflow obstruction measured in DAP and FT appeared to be less than and at most similar to anatomically comparable arterial interventions in the literature. However, these patients were usually much younger than those with arterial diseases, and may need secondary interventions involving further radiation exposure in their lifetime. Therefore, further studies should investigate the long-term side-effects of radiation exposure in these patients and ways of reducing it including the use of IVUS and magnetic resonance imaging technology.

**References**

**1.** Murphy EH, Johns B, Varney E, Raju S. Endovascular management of chronic total occlusions of the inferior vena cava and iliac veins. *J Vasc Surg Venous Lymphat Disord.* 2017;5(1):47-59.

**2.** Neglen P, Hollis KC, Olivier J, Raju S. Stenting of the venous outflow in chronic venous disease: long-term stent-related outcome, clinical, and hemodynamic result. *J Vasc Surg.* 2007;46(5):979-990.

**3.** Razavi M, Marston W, Black S, Bentley D, Neglen P. The initial report on 1-year outcomes of the feasibility study of the VENITI VICI VENOUS STENT in symptomatic iliofemoral venous obstruction. *J Vasc Surg Venous Lymphat Disord.* 2018;6(2):192-200.

**4.** Lichtenberg MKW, de Graaf R, Stahlhoff WF, Ozkapi A, Rassaf T, Breuckmann F. Venovo venous stent in the treatment of non-thrombotic or post-thrombotic iliac vein lesions - short-term results from the Arnsberg venous registry. *Vasa.* 2018:1-6.

**5.** Comerota AJ. Pharmacologic and Pharmacomechanical Thrombolysis for Acute Deep Vein Thrombosis: Focus on ATTRACT (CME). *Methodist Debakey Cardiovasc J.* 2018;14(3):219-227.

**6.** Vedantham S, Goldhaber SZ, Julian JA, Kahn SR, Jaff MR, Cohen DJ, Magnuson E, Razavi MK, Comerota AJ, Gornik HL, Murphy TP, Lewis L, Duncan JR, Nieters P, Derfler MC, Filion M, Gu CS, Kee S, Schneider J, Saad N, Blinder M, Moll S, Sacks D, Lin J, Rundback J, Garcia M, Razdan R, VanderWoude E, Marques V, Kearon C. Pharmacomechanical Catheter-Directed Thrombolysis for Deep-Vein Thrombosis. *N Engl J Med.* 2017;377(23):2240-2252.

**7.** Haig Y, Enden T, Grotta O, Klow NE, Slagsvold CE, Ghanima W, Sandvik L, Hafsahl G, Holme PA, Holmen LO, Njaaastad AM, Sandbaek G, Sandset PM. Post-thrombotic syndrome after catheter-directed thrombolysis for deep vein thrombosis (CaVenT): 5-year follow-up results of an open-label, randomised controlled trial. *Lancet Haematol.* 2016;3(2):e64-71.

**8.** Lim CS, Shalhoub J, Davies AH. Deep Venous Procedures Performed in the National Health Service in England between 2005 and 2015. *Eur J Vasc Endovasc Surg.* 2017;54(4):487-494.

**9.** Garcia MJ, Lookstein R, Malhotra R, Amin A, Blitz LR, Leung DA, Simoni EJ, Soukas PA. Endovascular Management of Deep Vein Thrombosis with Rheolytic Thrombectomy: Final Report of the Prospective Multicenter PEARL (Peripheral Use of AngioJet Rheolytic Thrombectomy with a Variety of Catheter Lengths) Registry. *J Vasc Interv Radiol.* 2015;26(6):777-785; quiz 786.

**10.** Enden T, Klow NE, Sandvik L, Slagsvold CE, Ghanima W, Hafsahl G, Holme PA, Holmen LO, Njaastad AM, Sandbaek G, Sandset PM. Catheter-directed thrombolysis vs. anticoagulant therapy alone in deep vein thrombosis: results of an open randomized, controlled trial reporting on short-term patency. *J Thromb Haemost.* 2009;7(8):1268-1275.

**11.** Park C, So BJ. Long-Term Results of Catheter-Directed Thrombolysis Combined with Iliac Vein Stenting for Iliofemoral Deep Vein Thrombosis. *Vasc Specialist Int.* 2015;31(2):47-53.

**12.** Patel R, Sweeting MJ, Powell JT, Greenhalgh RM. Endovascular versus open repair of abdominal aortic aneurysm in 15-years' follow-up of the UK endovascular aneurysm repair trial 1 (EVAR trial 1): a randomised controlled trial. *Lancet.* 2016;388(10058):2366-2374.

**13.** Spira D, Kirchner S, Blumenstock G, Herz K, Ketelsen D, Wiskirchen J, Wiesinger B. Therapeutic angiographic procedures: differences in dose area product between analog image intensifier and digital flat panel detector. *Acta Radiol.* 2016;57(5):587-594.

**14.** de Ruiter QM, Reitsma JB, Moll FL, van Herwaarden JA. Meta-analysis of Cumulative Radiation Duration and Dose During EVAR Using Mobile, Fixed, or Fixed/3D Fusion C-Arms. *J Endovasc Ther.* 2016;23(6):944-956.

**15.** Coles DR, Smail MA, Negus IS, Wilde P, Oberhoff M, Karsch KR, Baumbach A. Comparison of radiation doses from multislice computed tomography coronary angiography and conventional diagnostic angiography. *J Am Coll Cardiol.* 2006;47(9):1840-1845.

**16.** El-Sayed T, Patel AS, Cho JS, Kelly JA, Ludwinski FE, Saha P, Lyons OT, Smith A, Modarai B. Radiation Induced DNA Damage in Operators Performing Endovascular Aortic Repair. *Circulation.* 2017.

**17.** Jones C, Badger SA, Boyd CS, Soong CV. The impact of radiation dose exposure during endovascular aneurysm repair on patient safety. *J Vasc Surg.* 2010;52(2):298-302.

**18.** Brenner DJ, Doll R, Goodhead DT, Hall EJ, Land CE, Little JB, Lubin JH, Preston DL, Preston RJ, Puskin JS, Ron E, Sachs RK, Samet JM, Setlow RB, Zaider M. Cancer risks attributable to low doses of ionizing radiation: assessing what we really know. *Proc Natl Acad Sci U S A.* 2003;100(24):13761-13766.

**19.** Preston DL, Pierce DA, Shimizu Y. Age-time patterns for cancer and noncancer excess risks in the atomic bomb survivors. *Radiat Res.* 2000;154(6):733-734;discussion 734-735.

**20.** Monastiriotis S, Comito M, Labropoulos N. Radiation exposure in endovascular repair of abdominal and thoracic aortic aneurysms. *J Vasc Surg.* 2015;62(3):753-761.

**21.** Miller DL, Balter S, Cole PE, Lu HT, Schueler BA, Geisinger M, Berenstein A, Albert R, Georgia JD, Noonan PT, Cardella JF, St George J, Russell EJ, Malisch TW, Vogelzang RL, Miller GL, 3rd, Anderson J. Radiation doses in interventional radiology procedures: the RAD-IR study: part I: overall measures of dose. *J Vasc Interv Radiol.* 2003;14(6):711-727.

**22.** Miller DL, Balter S, Cole PE, Lu HT, Berenstein A, Albert R, Schueler BA, Georgia JD, Noonan PT, Russell EJ, Malisch TW, Vogelzang RL, Geisinger M, Cardella JF, George JS, Miller GL, 3rd, Anderson J. Radiation doses in interventional radiology procedures: the RAD-IR study: part II: skin dose. *J Vasc Interv Radiol.* 2003;14(8):977-990.

**23.** Maurel B, Hertault A, Sobocinski J, Le Roux M, Gonzalez TM, Azzaoui R, Saeed Kilani M, Midulla M, Haulon S. Techniques to reduce radiation and contrast volume during EVAR. *J Cardiovasc Surg (Torino).* 2014;55(2 Suppl 1):123-131.

**24.** Ephrem G, Lau JF, Meraj PM. The fluoro-less and contrast-less peripheral endovascular intervention: a concept for the future today. *Cardiovasc Revasc Med.* 2015;16(5):294-298.

**25.** Nyheim T, Staxrud LE, Jorgensen JJ, Jensen K, Olerud HM, Sandbaek G. Radiation exposure in patients treated with endovascular aneurysm repair: what is the risk of cancer, and can we justify treating younger patients? *Acta Radiol.* 2017;58(3):323-330.

**26.** Guo Q, Zhao J, Huang B, Yuan D, Yang Y, Zeng G, Xiong F, Du X. A Systematic Review of Ultrasound or Magnetic Resonance Imaging Compared With Computed Tomography for Endoleak Detection and Aneurysm Diameter Measurement After Endovascular Aneurysm Repair. *J Endovasc Ther.* 2016;23(6):936-943.

Helyar VG, Gupta Y, Blakeway L, Charles-Edwards G, Katsanos K, Karunanithy N. Depiction of lower limb venous anatomy in patients undergoing interventional deep venous reconstruction-the role of balanced steady state free precession MRI. Br J Radiol. 2018 Feb;91(1082):20170005

Table 1. The patient demography, anatomical involvement in terms of laterality and the most cranial vein involved, and etiology of the central venous obstruction disease requiring endovascular intervention. DVT: deep vein thrombosis; IVC: inferior vena cava

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Upper extremity thrombolysis** | **Lower extremity thrombolysis** | **Unilateral chronic iliofemoral venous stenting** | **Endovascular IVC reconstruction** |
| **Study period (years)** | 4 | 4 | 2 | 4.5 |
| **Number of patients** | 20 | 91 | 56 | 39 |
| **Male : Female** | 12 : 8 | 39 : 52 | 16 :40 | 27 : 12 |
| **Median age (range) in years** | 39 (20 – 67) | 44 (15 – 78) | 45 (20-80) | 35 (18-73) |
|  |  |  |  |  |
| **Laterality**  |  |  |  |  |
| *Left* | 6 (30.0%) | 72 (79.1%) | 49 (87.5%) |  |
| *Right*  | 14 (70.0%) | 15 (16.5%) | 7 (12.5%) |  |
| *Bilateral*  | 0 (0.0%)  | 4 (4.4%) |  |  |
|  |  |  |  |  |
| **Highest level of vein involvement** |  |  |  |  |
| *Supra-renal IVC* |  | 5 (5.5%) |  | 13 (33.3%) |
| *Infra-renal IVC* |  | 9 (9.9%) |  | 1. 66.7%)
 |
| *IVC Confluence* |  | 13 (14.3%) | 3 (5.4%) |  |
| *Common iliac vein* |  | 50 (54.9%) | 49 (87.5%) |  |
| *External iliac vein* |  | 12 (13.2%) | 4 (7.1%) |  |
| *Common femoral vein* |  | 2 (2.2%) | 0 (0.0%) |  |
| *Brachiocephalic +/- internal jugular vein* | 2 (10.0%) |  |  |  |
| *Subclavian vein* | 18 (90.0%) |  |  |  |
|  |  |  |  |  |
| **etiology** |  |  |  |  |
| Acute DVT | 20 (100%) | 91 (100%) |  | 6 (15.4%) |
| Chronic obstructive disease |  |  | 56 (100%) | 33 (84.6%) |
| Non thrombotic / compressive lesion |  |  | 27 (48.2%) | 31 (79.5%) |
| Post-thrombotic syndrome |  |  | 29 (51.8%) | 2 (5.1%) |

Table 2. Number of patients who had pre-index procedure computed tomography (CT) and diagnostic venography with or without other interventions, and the radiation exposure measured in dose-length product (DLP) and dose-area product (DAP), respectively. DAP: dose-area product; DLP: dose-length product; IVC: inferior vena cava.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Upper extremity thrombolysis** | **Lower extremity thrombolysis** | **Unilateral chronic iliofemoral venous stenting** | **Endovascular IVC reconstruction** |
| **Pre-index procedure CT** |  |  |  |  |
| Number of patients  | 6 (30.0%) | 49 (53.8) | 17 (30.4%) | 18 (46.2%) |
| Median (range) DLP per patient, Gycm  | 0.79 (0.23 – 1.60) | 0.87 (0.21 – 4.22) | 0.55 (0.10 -1.00) | 0.47 (0.24 -2.15) |
|  |  |  |  |  |
| **Pre-index procedure diagnostic venography +/- other interventions** |  |  |  |  |
| Number of patients | 0 | 0 | 17 (30.4%) | 13 (33.3%) |
| Median (range) DAP per patient, Gycm2 | - | - | 4.1 (0.1 -35.0) | 9.3 (1.3 – 234.2) |
| Fluoroscopy time (seconds) | - | - | 132 (6 – 444) | 102 (4 - 1590) |

Table 3. Methods of thrombolysis performed. CDT: catheter-directed thrombolysis, LE DVT: lower extremity deep vein thrombosis, PMT: pharmacomechanical catheter-directed thrombolysis, UE DVT: upper extremity deep vein thrombosis

|  |  |  |
| --- | --- | --- |
|  | **Number of patients** | **Percentage** |
| LE DVTCDTPMTAngiojet onlyEKOS onlyThrombo-aspiration onlyAngiojet + EKOSAngiojet + thrombo-aspirationUnknown | 55362371212 | 60.439.6 |
| UE DVTCDTPMTAngiojet onlyEKOS only | 15532 | 75.025.0 |

Table 4. Number of patients who had post-index procedure computed tomography (CT) and follow-up endovascular procedures, and the radiation exposure measured in dose-length product (DLP) and dose-area product (DAP), respectively. (DAP), respectively. DAP: dose-area product; DLP: dose-length product; IVC: inferior vena cava

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Upper extremity thrombolysis** | **Lower extremity thrombolysis** | **Unilateral chronic iliofemoral venous stenting** | **Endovascular IVC reconstruction** |
| **Median (range) duration of follow-up, month** | 4.3 (1 -19) | 16.4 (1 – 50) | 24 (1-37) | 11.4 (1 – 52) |
|  |  |  |  |  |
| **Post-index procedure CT** |  |  |  |  |
| Number of patients  | 6 (30.0%) | 34 (37.4%) | 7 | 26 (66.7%) |
| Median (range) DLP per patient, Gycm  | 0.71 (0.23 – 4.85) | 0.78 (0.11 – 3.28) | 0.27 (0.11 – 1.11) | 0.76 (0.27 – 6.21) |
|  |  |  |  |  |
| **Follow-up endovascular procedures** |  |  |  |  |
| Number of patients | 2 (10.0%) | 36 (39.6%) | 32 (57.1%) | 20 (51.3%) |
| Median (range) DAP per patient, Gycm2 | No data | 6.6 (0.8 – 186.5)  | 1.9 (0.2 – 111.7) | 24.3 (0.2 – 157.5) |
| Fluoroscopy time (seconds) | No data | 876 (96 – 12910 | 498 (7 – 1686) | 2560 (217 – 9647) |

Table 5. A summary of patient radiation exposure measured in dose-area product (DAP) and fluoroscopy time (FT) for index deep venous interventions in this study, and anatomically comparable common endovascular arterial procedures reported in the literature. Please note that the DAP and FT in this study and the literature are in median and mean, respectively. AAA: abdominal aortic aneurysm; DAP: dose-area product; EVAR: endovascular aortic aneurysm repair; FT: fluoroscopy time; IVC: inferior vena cava; LE: lower extremity; PTA: percutaneous transluminal angioplasty; UE: upper extremity

|  |  |
| --- | --- |
| **Venous interventions** | **Arterial interventions** |
| **Procedure** | **Median (range) DAP, Gycm2** | **Median (range) FT, seconds** | **Procedure** | **Mean (range) DAP, Gycm2** | **Mean FT, seconds** |
| **UE DVT thrombolysis** | 2.0 (0.1 – 11.7) | 837 (19 – 2895) | **PTA arm13** | 5.0 (0.5 – 49.7) | 384 |
| **LE VT thrombolysis** | 9.2 (0.2 – 176.0) | 981 (20 – 4890) | **PTA + stent (thigh)13** | 8.5 (7.0 – 10.4) | 756 |
| **Unilateral chronic iliofemoral venous stenting** | 32.4 (0.1 – 289.6) | 660 (246 - 4200) | **PTA + stent (pelvis)13**  | 66.9 (50.2 -89.1) | 535 |
| **Endovascular IVC reconstruction** | 60.8 (2.5 – 269.1) | 2846 (836 – 11682) | **EVAR (infra-renal AAA)20** | 79.5 (4.3 -619.0) | - |