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Radiation Exposure and Safety for the Electrophysiologist

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Abstract This review attempts to give practical advice for invasive electrophysiologists on personal radiation protection. Applying all measures of the “As low as reasonably achievable” ALARA concept should be a daily and indeed routine practice for all staff in the electrophysiology laboratory. A substantial number of technical options have been recently introduced which may enable the physician to lower the total radiation exposure significantly, but all require a substantial learning curve. Using these measures can arrive at very low or indeed close to ZERO fluoroscopy exposure even in complex ablation cases.

Keywords Radiation exposure · Catheter intervention · Electrophysiology · Safety

Introduction

As the first imaging modality of the living human body, x-rays or fluoroscopic imaging has been probably the most important technical tool in modern medicine (Roentgen). It allowed one to see the inside of the body, and after contrast injection even of soft tissues like the beating heart [1]. Most of today’s interventional procedures in cardiology are carried out under fluoroscopic imaging guidance [2]. The advent of novel 3D imaging technologies such as computed tomography has even allowed 3D reconstructions of an individual’s heart. However, these advances come at the cost of higher radiation exposure, which carries a risk of both stochastic (inducing malignancy) and deterministic effects (tissue reactions like erythema, hair loss and cataracts) [3].

Patient Exposure: Where does it Start and Where does it End?

Because of an increase of interventional procedures and imaging studies in the last decades, patients are being exposed to a substantial amount of radiation over their lifetime (Table 1) [2, 4, 5]. Whilst radiation exposure from cardiac interventions is only one of the many possible exposures for a given patient, more and more complex ablation procedures are carried with substantial exposure to it. Some procedures like catheter ablation of atrial fibrillation frequently requires more than one ablation procedure, thereby adding a substantial amount of radiation [6].

Comparisons of radiation exposure from imaging and catheter interventions are somewhat difficult to perform. In catheter interventions estimates of the radiation exposure require detailed knowledge of the exposed tissue, beam quality and radiographic projection. The radiation dose rate in air, the x-ray field size and the duration of exposure allow calculation of a dose area product (DAP) in centiGray centimeter squared, cGy cm^2. For a given projection, the DAP generally increases with patient BMI and exposure time. Using a factor of 0.2, one can roughly arrive at the effective dose in millisievert (mSv) [7]. However, most physicians simply refer to the radiation time in minutes when reporting their procedural parameters (ESC abstract EPIC). This however is over simplistic, underestimating the exposure in obese patients, whilst in children the radiation exposure may be overestimated [8, 9••]. Effective dose permits a comparison of radiation

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Table 1 Overview on various exposures to radiation (modified from Rogers et al. [40])

1-year natural background radiation	2.5 mSv
Chest x-ray examination	0.02 mSv
Intercontinental flight return trip	0.05 mSv
1 hr within 10 km from Fukushima (March 2011)	0.1 mSv
Coronary angiography	0.4 – 15 mSv
Radiofrequency catheter ablation	3.3 - 12 mSv
With additional dose-reduction measures	1.2 – 2.8 mSv
Cardiac CT angiography	0.8 - 22 mSv

exposures for imaging and catheter interventions, although it has limitations when used for medical exposures that need to be considered (ref ICRP report 103).

Integration of Pre-acquired 3D Images in 3D Mapping Systems

Many patients that need complex ablation procedures nowadays also undergo 3D imaging to facilitate the procedure itself and to allow adequate planning of access and choice of the necessary tools. This allows to "learn" 3D geometry and identify variants such as additional PVs, left SVC, etc. [10–12]. Correct registration is again key to success [13]. While 3D imaging for image integration in 3D mapping systems (such as CARTO or NAVx) only specifies a DICOM format, many physicians automatically choose CT rather than alternative imaging techniques [14, 15]_ENREF_7.

Alternatives to 3D CT Scans as Roadmaps for Ablation or Follow-up

However, 3D cardiac magnetic resonance imaging can be performed reproducibly and with excellent image quality by either angiography or even by non-contrast whole blood sequences (true fisp imaging) [10, 16]. The so acquired 3D DICOM information can be reconstructed with little extra effort on all available 3D mapping systems and thereby reduce the overall patient exposure significantly.

Equally, 3D imaging after an ablation procedure (eg. to exclude a significant PV stenosis) can be performed by CMR scans or alternative (non-fluoroscopic) studies such as TOE [17, 18]. In an exemplary calculation the avoidance of 2 CT scans before and after AF ablation could avoid an average of 4 to 40 mSv. Given the fact that the patient might need more than one ablation procedure, any additional 3D imaging should be carefully assessed with regard to its contribution to the overall radiation "bill".

Professional Exposure for Health Care Workers

So far attention has been applied to the radiation exposure of patients but only recently the catheter lab staff who expose themselves professionally have come into focus [19•, 20•]. Being close to the patient during an interventional procedure, the first hand operator is exposed to scattered radiation, whilst other health care professionals are better protected by their position at a greater distance to the radiation source and the patient itself. The reduction of radiation exposure with distance is governed by the inverse square law. This means that when distance from the patient doubles, the exposure is quartered. Color-coding of the floor to depict a 2 m radius from the radiation source gives a good marker to where relevant exposure starts for catheter lab staff.

Alarming number of malignancies has been reported for interventional cardiologists and a concerning scary risk of 1: 100 of malignancy has been reported recently [21•]. The effect of more and more complex ablation procedures, with longer exposures, being carried out by more and more electrophysiologists, may lead to a larger future problem for this professional group, if operators do not adopt techniques that could mitigate this risk.

Unlike other professionals with significant exposure during their work such as airline pilots, interventional cardiologists are not that as a matter of course informed about their personal exposure to the same degree and also seem to care less about it [22, 23]. While pilots are required to wear a personal "active" radiation badge with numerical display of their exposure during long distance flights, health care workers generally only wearing "passive" badges that do not give any direct numerical output [24]. Also, pilots have very strict log book documentation of their exposure that allows direct feedback and thereby generating potentially a greater level of awareness of their radiation exposure.

Variability of Radiation Exposure

When comparing different operators and the amount of median exposure for a given procedure, a large variability of results is apparent. This is probably an expression of personal training and experience of the individual operator, but possibly also to some amount of ignorance of the potential dangers for themselves (EPIC abstract ESC).

Five major steps for personal radiation protection could help to reduce personal radiation exposure [9••, 25]:

1. The basic personal protections starts with wearing protection "lead" aprons with emphasis covering the most radiation sensitive body areas (lungs, breasts, red bone marrow colon and stomach). Two piece aprons overlap in this area and are an excellent protection whilst dividing the weight between the hip and the shoulders. It is noticeable

that many interventional cardiologists report on chronic back pain or indeed require surgery [26]. Additional personal shields for other areas such as thyroid shields are used to a lesser extent, however depending on the procedure carried out even shin covers can be useful. An import "organ" is the eye and cataracts have been reported as a consequence of unprotected exposure. As a simple rule a patient's chest should only be seen through lead glass shield (e.g., ceiling suspended). Personal dosimeters should be worn routinely in every single procedure to be able to document exposure. One dosimeter is typically worn under the lead to monitor the exposure to the reproductive organs and one typically outside on an exposed area (e.g., arm closest to the radiation source or at the collar outside the lead apron).

2. The position of the patient at the unit's center of rotation, with the detector (image intensifier or flat panel imager) as close as possible to them, is crucial to obtaining good quality images. There are in fact two sources of radiation: the greater being the scatter emitted from the patient and the lesser leakage radiation from the x-ray tube itself. Importantly, scattered radiation levels are highest under the patient's table for the AP projection such that the under table apron is of crucial importance to the exposure of the operator. When using angulated projections and especially in the left anterior oblique position, the operator stands within 50 cm of the second radiation source, the x-ray tube, which emits low levels of leakage radiation radially in all directions. Positioning of additional lead protection and the use of a ceiling mounted protection screen does reduce the operator's exposure significantly [9••].
3. Choosing the best program to image the electrode catheters with appropriate exposure parameters such as higher tube voltages and additional copper filtration, reduced frame rates and as low as possible input dose per frame to the detector. Much lesser detail is necessary in electrophysiology (EP) procedures as compared to coronary interventions where discrete lesions in small vessels are imaged. This amount of contrast resolution is mostly unnecessary in EP procedures where the metal tip catheters are easily identified on the image. All efforts should be made to remove all other items that may show on a given image. One example is a trans-oesophageal echocardiography (TOE) probe that is visible during an atrial fibrillation case (after a left atrial appendage clot has already been ruled out). If the TOE is required to guide a transseptal puncture, it is unavoidable that it will obstruct the view, however during the mapping and ablation part it can be removed. If in doubt about pericardial collection it can easily be advanced again. Of note is that current fluoroscopy systems can automatically respond to the presence of metal objects by increasing the exposure parameters in order to penetrate through the object, and in doing so increasing the exposure to the patient and the operator.
4. Operators should always try to employ the "as low as reasonably achievable" ALARA concept [25]. Rather than reviewing the same location of a given catheter position over several cardiac cycles, a single cycle should be enough to ascertain this information. Using the "last image hold" LIH feature, the relationship between the catheter position and the electrical signals can be assessed and corrected if necessary. Choosing the optimal radiation projection for a given task requires detailed knowledge of the cardiac anatomy and its correlation in the fluoroscopy image. Storage of catheter positions for archiving should be performed using the "store fluoroscopy" feature rather than cine acquisitions (that are carried out at 5 to 10 times the dose rate of fluoroscopy). Using reference images in various projections can allow the operator to visually remind him- or herself to previously visited locations or could mark important areas like the His bundle recording site. Making use of freeze framing of angiographies such as contrast injections into pulmonary veins or the coronary sinus in various projections can be toggled to allow best orientation of the operator when navigating in these delicate areas.
5. Optimization of the image by using all available means of collimation and shielding of lung fields should be readily applied and adjusted whenever possible. Where applicable the removal of the antiscatter grid can be considered. A recent innovation is the use of asymmetric collimation which allows keeping the table in the iso center position whilst "homing in" on the specific region of interest [27].

Use of 3D Mapping Systems to Reduce Radiation Exposure in Complex Procedures

Orientating the operator to the exact location of the catheters is paramount in any given invasive procedure. The information provided by fluoroscopy is limited since it is a 2D display of a complex 3D situation. The transparency of the cardiac tissue only allows visualization of the contours exactly, but fails to identify inner structures like AV valves or vessel openings. Using 3D mapping systems, a virtual 3D map is created of any given cardiac chamber and ideally the catheters can be navigated without the need of fluoroscopy [28, 29]. An important caveat using these virtual geometries is to assure its accuracy and to realize that an area not reached in a given chamber will not be displayed on these systems and thereby might be overlooked. Similarly, if a shift of the patients position relatively to the mapping system occurs than accuracy might be lost and positioning needs to be re-established in reference to the "real" fluoroscopy image. Using 3D mapping systems like

CARTO allows one to actively navigate with the help of the real time depiction of the catheter tip. The color coding does facilitate the catheter manipulation. This is especially helpful when using bidirectional catheters and transition from uni- to bidirectional can be facilitated. Choosing to deflect using the “D” curve (equalling toward red) or “F” curve (toward blue) makes the catheter navigation more intuitive and helps reduce the radiation exposure during the mapping and ablation process itself.

Transfer of Location Information from Fluoroscopy to 3D Mapping Systems

Contrast-enhanced imaging may be of assistance, e.g., when PV ostia are displayed but due to the fleeting nature of the contrast and the need for imaging in two (ideally orthogonal) projections it is sometimes a tedious endeavor. When using 3D mapping systems in addition, common practice is to mark ostial sites with colored tags to transfer the angio 2D information to the 3D mapping system, respectively [30, 31]. This also allows navigating more precisely on the 3D mapping system without using fluoroscopy to navigate the catheters eg along the ablation line. If unsure about the “real” rather than “virtual” position, fluoroscopy can be used for a single cardiac cycle rather than for seconds or even minutes in one go.

Picture in Picture Display and Real Time Depiction of Catheters

When using an image in image display with real time depiction of the catheter tip, need for “real” fluoroscopy is automatically reduced since the catheter is displayed on the familiar “background”. After spot checks on the accuracy of the systems, most operators rely on the electrical signal information and the 3D location. Seeing the 3D map evolving on the fluoroscopy background pictures allows transferring the 3D mapping information directly to the 2D fluoroscopy information, however this requires consequent and exact registration. The same is true for the use of pre-acquired 3D images (see above). The most important step in using these volumes is the accurate registration, which should not rely on single or three point landmark registration but require stepwise adjustment to the virtually created 3D map and or registration on the fluoroscopic contour of the patient’s heart (Fig. 1). Recently, a new localization system (MEDI GUIDE) was introduced to the EP lab which is mounted on the image intensifier/ flat panel detector and picture in picture display of all catheters is enabled, similarly to the already available system on the navigation platform of the remote magnetic navigation system [32]. Whilst the reported reduction of radiation exposure for various procedures are significant, the overall exposure in comparison to previous reports of experienced operators employing the ALARA technique or using other 3D mapping systems like Navx or CARTO have not been met yet [33, 34].

Radiation Exposure in Young Patients or Patients with many Exposures to Radiation During Their Life Time

A special effort should be made to avoid unnecessary exposures to radiation of children and adolescents whenever possible. Employing all available technologies such as image integration, remote magnetic navigation should be considered when planning procedures in this cohort [35–37]. Reports on larger single center experience have demonstrated a substantial reduction of radiation exposure as compared to the

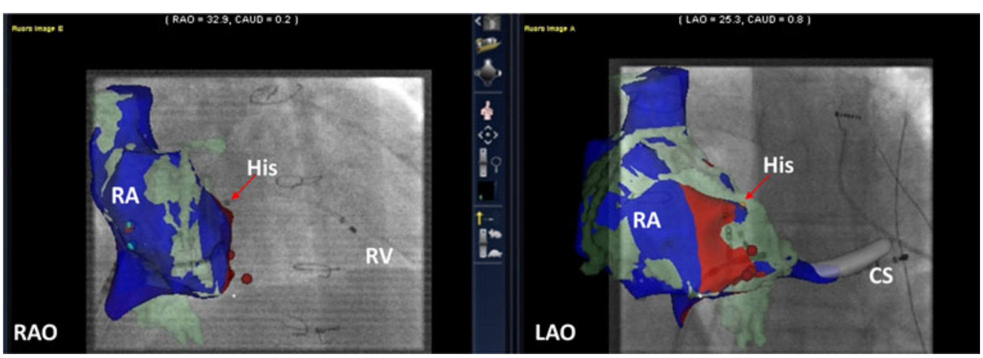

Fig. 1 Example of a real time “picture- in-picture” display of a right atrial 3D reconstruction using CARTO RMT (Biosense Webster) on the background of corresponding RAO and LAO (both about 30 degrees) using the Odyssey system (Stereotaxis Inc, St. Louis MS). Depicted is a frame during “propagation” of the cardiac activation (in red) on the 3D virtual map in blue to demonstrate the information transfer from the CARTO system onto the background fluoroscopic images. Also depicted is the 3D reconstruction of a non-contrast cardiac magnetic resonance imaging study (light green). The overall fluoroscopy exposure time of this patient with re-inserted pulmonary vein and ASD closure who underwent catheter ablation for recurrent supraventricular tachycardias was 90 sec. Abbreviations: His His bundle recording catheter (see also yellow tag, red arrow), CS coronary sinus electrode, RV right ventricular catheter

reported results from larger registries. Using all available tools is key in performing procedures in these more vulnerable patients and the ultimate choice lies with the operator.

In special circumstances such as pregnant or very young patients, EP procedures can be carried out with zero exposure or very low exposure to radiation seems safe to apply [38].

Another special group of patients are those requiring multiple cardiac procedures over their lifetime and start being exposed at an early age: patients with congenital heart disease frequently present several decades after their operation(s) with sustained arrhythmias that can be treated successfully by catheter ablation. Using all available tools (such as 3D mapping and image integration) a major improvement in outcome of these procedures can be achieved. Recently, several centers have independently demonstrated that the use of remote magnetic navigation in these patient cohort results in even better outcome and reduction of fluoroscopy exposure to levels equal or lower than reported for "normal" anatomy patients [35, 39]. Since these patients also may still need hemodynamic interventions in the future, any reduction of radiation is of major benefit for these young patients.

Conclusion

Radiation exposure is not only an important issue for patients but is of even greater relevance for the invasive electrophysiologist. By protecting him- or herself against the professional health risk of radiation induced malignancy by applying five simple steps of personal and structural protection measures, the patient is automatically benefitting as well. Using all available technical options and tailoring non-fluoroscopic imaging options to the individual patient and procedure, radiation exposure can be minimized. Further simplification by arriving at a single measure to make exposure data easily comparable and the use of "active" dosimeters for physicians with help to increase awareness and change current practice patterns.

Compliance with Ethics Guidelines

Conflict of Interest Sabine Ernst has been a consultant for Biosense Webster and Stereotaxis; has received grant support from CardioInsight; has received payment for development of educational presentations including service on speakers' bureaus from Biosense, St. Jude Medical, Stereotaxis, Biotronik; and has received travel/accommodations expenses covered or reimbursed from Biosense, St. Jude Medical, Stereotaxis, Biotronik.

Isabel Castellano declares that she has no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:
- • Of importance
- •• Of major importance

1. [Munchener Medizinische Wochenschrift/20 March 1931 Contrast representation of the cavities of the living right half of the heart by Werner Forssmann, Eberswalde]. MMW, Munchener medizinische Wochenschrift 1978; 120(14): 489.
2. Einstein AJ, Knuuti J. Cardiac imaging: does radiation matter? Eur Heart J. 2012;33(5):573–8.
3. Berrington de Gonzalez A, Mahesh M, Kim KP, et al. Projected cancer risks from computed tomographic scans performed in the United States in 2007. Archives of Intern Med. 2009;169(22):2071–7.
4. Mettler Jr FA, Bhargavan M, Faulkner K, et al. Radiologic and nuclear medicine studies in the United States and worldwide: frequency, radiation dose, and comparison with other radiation sources–1950–2007. Radiology. 2009;253(2):520–31.
5. Berrington de Gonzalez A, Darby S. Risk of cancer from diagnostic X-rays: estimates for the UK and 14 other countries. Lancet. 2004;363(9406):345–51.
6. Calkins H, Reynolds MR, Spector P, et al. Treatment of atrial fibrillation with antiarrhythmic drugs or radiofrequency ablation: two systematic literature reviews and meta-analyses. Circ Arrhythm Electrophysiol. 2009;2(4):349–61.
7. Commission. E. European Guidance on Estimating Population Doses from Medical X-Ray Procedures. Radiation Protection Report 154. 2008. p. http://ec.europa.eu/energy/nuclear/radiation_protection/doc/publication/154.zip.
8. Kotre CJ, Reay J, Chapple CL. The influence of patient size on patient doses in cardiology. Radiation protection dosimetry. 2005;117(1–3):222–4.
9. •• Cousins C, Miller DL, Bernardi G, et al. ICRP PUBLICATION 120: Radiological protection in cardiology. Ann ICRP. 2013;42(1):1–125. *This report summarises current knowledge on radiation-induced cancer and tissue injuries relevant to cardiology, and provides guidance to assist the cardiologist in optimising clinical procedures and minimising staff doses.*
10. Schmidt B, Ernst S, Ouyang F, et al. External and endoluminal analysis of left atrial anatomy and the pulmonary veins in three-dimensional reconstructions of magnetic resonance angiography: the full insight from inside. J Cardiovasc Electrophysiol. 2006;17(9):957–64.
11. Lemola K, Sneider M, Desjardins B, et al. Computed tomographic analysis of the anatomy of the left atrium and the esophagus: implications for left atrial catheter ablation. Circulation. 2004;110(24):3655–60.
12. Hunter RJ, Ginks M, Ang R, et al. Impact of variant pulmonary vein anatomy and image integration on long-term outcome after catheter ablation for atrial fibrillation. Europace : European pacing, arrhythmias, and cardiac electrophysiology : journal of the working groups on cardiac pacing, arrhythmias, and cardiac cellular electrophysiology of the European Society of Cardiology. 2010;12(12):1691–7.
13. Reddy VY, Malchano ZJ, Holmvang G, et al. Integration of cardiac magnetic resonance imaging with three-dimensional electroanatomic mapping to guide left ventricular catheter manipulation: feasibility in a porcine model of healed myocardial infarction. J Am Coll Cardiol. 2004;44(11):2202–13.
14. de Chillou C, Andronache M, Abdelaal A, et al. Evaluation of 3D guided electroanatomic mapping for ablation of atrial fibrillation in reference to CT-Scan image integration. J Interv Card Electrophysiol. 2008;23(3):175–81.

15. Kistler PM, Rajappan K, Jahngir M, et al. The impact of CT image integration into an electroanatomic mapping system on clinical outcomes of catheter ablation of atrial fibrillation. J Cardiovasc Electrophysiol. 2006;17(10):1093–101.
16. Yamaji H, Hina K, Kawamura H, et al. Sufficient pulmonary vein image quality of non-enhanced multi-detector row computed tomography for pulmonary vein isolation by catheter ablation. Europace : European pacing, arrhythmias, and cardiac electrophysiology : journal of the working groups on cardiac pacing, arrhythmias, and cardiac cellular electrophysiology of the European Society of Cardiology. 2012;14(1):52–9.
17. Schneider C, Ernst S, Bahlmann E, et al. Transesophageal echocardiography: a screening method for pulmonary vein stenosis after catheter ablation of atrial fibrillation. European journal of echocardiography : the journal of the Working Group on Echocardiography of the European Society of Cardiology. 2006;7(6):447–56.
18. Stavrakis S, Madden GW, Stoner JA, Sivaram CA. Transesophageal echocardiography for the diagnosis of pulmonary vein stenosis after catheter ablation of atrial fibrillation: a systematic review. Echocardiography. 2010;27(9):1141–6.
19. • Picano E, Vano E. Radiation exposure as an occupational hazard. EuroIntervention : journal of EuroPCR in collaboration with the Working Group on Interventional Cardiology of the European Society of Cardiology. 2012;8(6):649–53. *This paper gives a good overview about exposure and protection measures.*
20. • Russo GL, Picano E. The effects of radiation exposure on interventional cardiologists. Eur Heart J. 2012;33(4):423–4. *Article highlighting the importance of maintaining good radiation protection practices whilst greater insight is gained into the damaging, or beneficial, biochemical and cellular changes associated with exposure to low levels of radiation.*
21. • Roguin A, Goldstein J, Bar O. Brain tumours among interventional cardiologists: a cause for alarm? Report of four new cases from two cities and a review of the literature. EuroIntervention : journal of EuroPCR in collaboration with the Working Group on Interventional Cardiology of the European Society of Cardiology. 2012;7(9):1081–6. *Concerning report on brain tumours as a consequence of extented radiation exposure.*
22. Hammer GP, Blettner M, Langner I, Zeeb H. Cosmic radiation and mortality from cancer among male German airline pilots: extended cohort follow-up. Eur J Epidemiol. 2012;27(6):419–29. Report on another professional group with relevant radiaiton exposure but also better monitoring.
23. Yong LC, Sigurdson AJ, Ward EM, et al. Increased frequency of chromosome translocations in airline pilots with long-term flying experience. Occup Environ Med. 2009;66(1):56–62.
24. Bottollier-Depois JF, Trompier F, Clairand I, et al. Exposure of aircraft crew to cosmic radiation: on-board intercomparison of various dosemeters. Radiation protection dosimetry. 2004;110(1–4):411–5.
25. Limacher MC, Douglas PS, Germano G, et al. ACC expert consensus document. Radiation safety in the practice of cardiology. J Am Coll Cardiol. 1998;31(4):892–913.
26. Fadl YY, Ellenbogen KA, Grubb Jr RL, Khoo-Summers L, Lindsay BD. A review of spinal injuries in the invasive cardiologist II: prevention and treatment. Pacing Clin Electrophysiol. 2007;30(9):1149–57.
27. De Buck S, La Gerche A, Ector J, et al. Asymmetric collimation can significantly reduce patient radiation dose during pulmonary vein isolation. Europace : European pacing, arrhythmias, and cardiac electrophysiology : journal of the working groups on cardiac pacing, arrhythmias, and cardiac cellular electrophysiology of the European Society of Cardiology. 2012;14(3):437–44. Interesting technical solution to collimation which reduces overall exposure significantly.
28. Shpun S, Gepstein L, Hayam G, Ben-Haim SA. Guidance of radiofrequency endocardial ablation with real-time three-dimensional magnetic navigation system. Circulation. 1997;96(6):2016–21.
29. Schilling RJ, Peters NS, Davies DW. Feasibility of a noncontact catheter for endocardial mapping of human ventricular tachycardia. Circulation. 1999;99(19):2543–52.
30. Ouyang F, Bansch D, Ernst S, et al. Complete isolation of left atrium surrounding the pulmonary veins: new insights from the double-Lasso technique in paroxysmal atrial fibrillation. Circulation. 2004;110(15):2090–6.
31. Ouyang F, Ernst S, Chun J, et al. Electrophysiological findings during ablation of persistent atrial fibrillation with electroanatomic mapping and double Lasso catheter technique. Circulation. 2005;112(20):3038–48.
32. Rolf S, Sommer P, Gaspar T, et al. Ablation of atrial fibrillation using novel 4-dimensional catheter tracking within autoregistered left atrial angiograms. Circ Arrhythm Electrophysiol. 2012;5(4):684–90.
33. Kerst G, Weig HJ, Weretka S, et al. Contact force-controlled zero-fluoroscopy catheter ablation of right-sided and left atrial arrhythmia substrates. Heart Rhythm. 2012;9(5):709–14. ZERO exposure is important for "vulnerable" patients and can be achieved with modern technologiy without increasing the risk for complications.
34. Casella M, Pelargonio G, Dello Russo A, et al. "Near-zero" fluoroscopic exposure in supraventricular arrhythmia ablation using the EnSite NavX mapping system: personal experience and review of the literature. J Interv Card Electrophysiol. 2011;31(2):109–18.
35. Ernst S, Babu-Narayan SV, Keegan J, et al. Remote-controlled magnetic navigation and ablation with 3D image integration as an alternative approach in patients with intra-atrial baffle anatomy. Circ Arrhythm Electrophysiol. 2012;5(1):131–9. Demonstration of effect of remote navigation and 3D image integration in the most complex patient cohort of adult congenital heart disease.
36. Mantziari L, Rigby M, Till J, Ernst S. Accessory Pathway Ablation in a 6-Year-Old Girl Using Remote Magnetic Navigation as an Alternative to Cryoablation. Pediatric Cardiol. 2012.
37. Schwagten B, Witsenburg M, De Groot NM, Jordaens L, Szili-Torok T. Effect of magnetic navigation system on procedure times and radiation risk in children undergoing catheter ablation. Am J Cardiol. 2010;106(1):69–72.
38. Casella M, Dello Russo A, Pelargonio G, et al. Rationale and design of the NO-PARTY trial: near-zero fluoroscopic exposure during catheter ablation of supraventricular arrhythmias in young patients. Cardiol Young. 2012;22(5):539–46.
39. Wu J, Deisenhofer I, Ammar S, et al. Acute and long-term outcome after catheter ablation of supraventricular tachycardia in patients after the Mustard or Senning operation for D-transposition of the great arteries. Europace : European pacing, arrhythmias, and cardiac electrophysiology : journal of the working groups on cardiac pacing, arrhythmias, and cardiac cellular electrophysiology of the European Society of Cardiology. 2013.
40. Rogers DP, England F, Lozhkin K, Lowe MD, Lambiase PD, Chow AW. Improving safety in the electrophysiology laboratory using a simple radiation dose reduction strategy: a study of 1007 radiofrequency ablation procedures. Heart. 2011;97(5):366–70.