images as a result of patient and equipment movement, whereas pulsed fluoroscopy reduces blurring by counter-acting movements, with the additional benefit of reducing radiation exposure.[150]

Pulsed fluoroscopy is the default mode in modern C-arms[111,145,160] with pulse rates typically available at 30, 15, 7.5, 4, and 2 pulses per second. As early analogue fluoroscopy was initially developed at 30 frames per second (fps), continuous fluoroscopy was produced at 30 pulses per second. The human eye and the brain's visual reception system can only analyse up to 12 images per second, any more than this are interpreted as an illusion of visual continuity,[161] therefore reducing pulse rates from 30 to 15 or 7.5 pulses/second decreases the fluoroscopy dose by 47% and 72%, respectively[150,162] without major impact on image quality. The lowest pulse rate that produces an adequate image should be chosen, with studies demonstrating that complex FEVAR can be performed adequately at as low as 3 pulses/sec.[111,112,138,150,152,162,163]

Recommendation 13

The use of pulsed rather than continuous fluoroscopy at the lowest pulse rate possible (7.5 pulses per second or less) that produces an adequate diagnostic image is recommended for endovascular procedures.

Class	Level	References
I	C	Rolls *et al.* (2016),[163] Panuccio *et al.* (2011),[112] Pitton *et al.* (2012),[152] Ketteler *et al.* (2011),[150] Hertault *et al.* (2015),[138] Monastiriotis *et al.* (2015),[111] Miller *et al.* (2002)[162]

5.3.4. Digital subtraction angiography and frame rate. DSA describes the acquisition of multiple images in succession within one field of view, with the subsequent digital subtraction of non-vascular structures, such as bone, leaving a contrast enhanced image of the vessels. The cost of these multiple high quality images is a substantial increase in radiation dose compared with fluoroscopy,[138,164] a fact that seems to be generally underappreciated.[165] The contribution of DSA to total radiation dose during peripheral arterial and cardiac interventions has been shown to range between 70% and 90%,[152,166] and accounts for 50% – 80% of the radiation dose during TEVAR and EVAR, even when low frame rates of 2/sec were selected.[165,167] DSA frame rate describes the number of images recorded per second, distinct to fluoroscopy pulse rate which describes the number of bursts of radiation the fluoroscope emits per second. Compared with fluoroscopy, DSA is associated with at least 10 fold higher dose rate per frame,[164] contributing to 66% of the radiation dose while only accounting for 23% of total exposure time.[168] The patient entrance dose for one fluoroscopy image may be 10 – 30 μGy, 100 – 300 μGy for one fluoroscopy loop and 1 000 – 3 000 μGy (or more) for one DSA image. For operators, DSA leads to an eight fold higher radiation dose than fluoroscopy.[152]

If DSA runs are essential, the associated dose can be minimised by (1) reducing the number of pictures acquired per second (frame rate); (2) minimising time per run; and (3) limiting the number of acquisitions.[147] Reducing the frame rate will reduce dose in the same way as reducing pulse rate during fluoroscopy,[112,147,152,165] with number of frames correlating highly with total radiation dose.[152] Reducing frame rates to 7.5 fps from a continuous mode, for example, results in a 90% reduction in image numbers, with an equivalent reduction in radiation dose.[138] Adequate images can be obtained even with frame rates of 2 fps for pelvic and upper leg interventions and 1 fps for lower leg and foot interventions.[152] It should be noted that CO_2 angiography often needs higher frame rates (4–6 fps) to obtain adequate images and may be associated with higher radiation doses.[169,170] Some systems allow a variable frame rate setting, which reduces the frame rate once adequate vessel opacification has occurred and this may help further reduce radiation usage.

One of the most effective techniques for reducing radiation dose during endovascular procedures is to limit DSA acquisitions to key scenes and critical steps during the procedure.[152] If high quality imaging is not essential, then fluoroscopy loops can often replace DSA.[111,138,151,152,160,165,171,172] The endovascular operator needs to determine the lowest quality image that still maintains safety by allowing effective diagnosis, and treatment at all times during the procedure.[150] Modern C-arms reduce the need for repeated DSA by allowing overlay roadmap of a DSA for target cannulation and the ability to return the table to the exact position and overlay a fade of a previous DSA.[152] Some C-arms also allow this to be done using fluoroscopy, avoiding the extra radiation required for DSA to perform this function.

Recommendation 14

It is recommended that use of digital subtraction angiography (DSA) be limited to critical steps during endovascular procedures, and that it is carried out with the shortest time per run, lowest frame rate and least number of acquisitions possible to acquire an adequate image.

Class	Level	References*
I	B	Pitton *et al.* (2012),[152] Ketteler *et al.* (2011),[150] Hertault *et al.* (2015),[138] Haqqani *et al.* (2013)[171]

*Physics principle

5.4. Collimation

Collimation uses metallic apertures within the Xray source to modify the beam and minimise the radiation field size to the required area of interest.[172] By shaping the beam and absorbing photons, collimation not only produces sharper images by hardening the beam, but also reduces radiation exposure (Fig. 8) to the patient and medical personnel in