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Highest Diagnostic Image Quality at Lowest Dose with AIDR 3D

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Introduction

Traditionally CT images have been reconstructed from the raw data using techniques based on filtered back projection (FBP). Although this has served the CT community well for over 30 years, FBP has its limitations at very low radiation doses when it tends to produce noisy images which may impair diagnosis. Iterative reconstruction on the other hand is a technique whereby the final image is reconstructed from the raw projectional data in multiple steps rather than in a single step with FBP.

All iterative reconstruction solutions start with an assumed image, compute projections from the image, compare the original projection data and update the image based upon the difference between the calculated and the actual projections. Iterative reconstruction techniques are superior to FBP when the projectional data is sparse as occurs in CT when using very low radiation doses. Iterative reconstruction was the original technique used on the first CT scanner developed by Godfrey Hounsfield in 1971. This technique was subsequently abandoned on all commercial scanners due to the increased computational requirements of iterative reconstruction which led to unacceptably long image reconstruction times even with the most powerful mainframe computers of the time. Toshiba has recently implemented its second generation iterative reconstruction system as a commercial product – AIDR 3D (Fig. 1).

AIDR 3D works in both raw data and reconstruction domains in three dimensions. It uses a scanner model and a statistical model considering both photon and electronic noise to eliminate noise and artifacts due to photon starvation in the projection data. A filtered back projection of this processed data is then blended with the final result from the iterative process. This produces images which are visually similar to FBP images but have much higher spatial resolution and suffer from much less image noise and artifacts. Critically, image reconstruction times are almost identical to those of FBP thus enabling AIDR 3D to be used in routine clinical practice. In addition AIDR 3D is totally integrated into the scanning process so that the automatic dose modulation software (SUREExposure 3D) will take account of it when setting the radiation dose required to achieve the desired image quality. This means that all patients are scanned at lower radiation doses automatically with no manual input from the radiology staff.

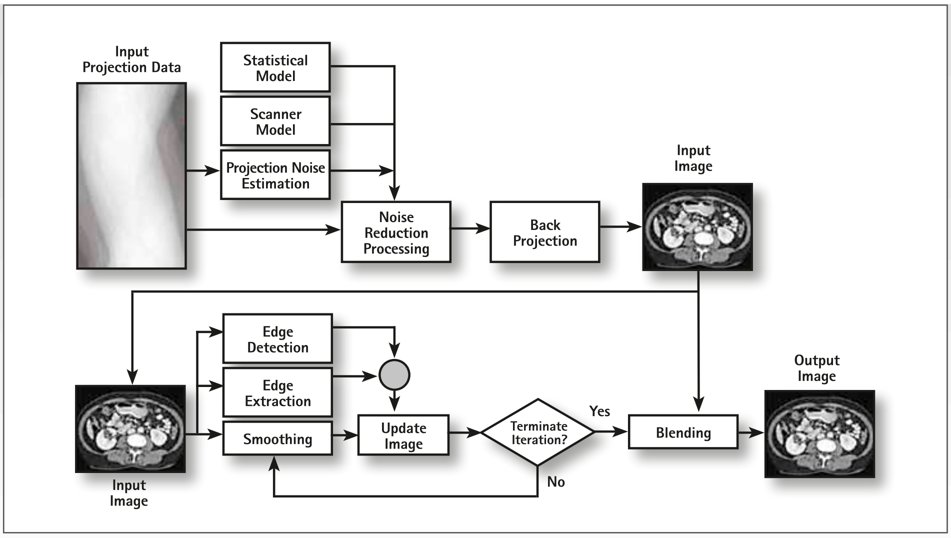


Fig. 1: AIDR 3D is an advanced iterative reconstruction algorithm that reduces noise both in the raw data domain and also in the reconstruction process in three dimensions.

AIDR 3D was installed on the Aquilion ONE at the Royal Bournemouth Hospital in January 2012. Since then all patients have been scanned using AIDR 3D with dramatic reductions in radiation doses coupled with marked improvements in image quality. The use of routine 100 kVp scanning, even in large patients, has led to reductions in contrast volumes for all types of angiography whilst preserving or even increasing contrast-to-noise (CNR) ratios. This article focuses on CT coronary a ngiography where doses in the microsievert range (< 1 mSv) are now a clinical reality for many patients.

Ultra-low radiation dose

As the Aquilion ONE is able to scan the entire heart in one tube rotation, all patients at our institution are scanned using prospective gating in a single heart beat. Using conventional filtered back projection in conjunction with quantum denoising (QDS) this 'prospective only' approach has led to low radiation doses of < 5 mSV in almost all patients regardless of body mass index, heart rate or rhythm. AIDR 3D is so efficient at removing noise and artifacts at extremely low radiation doses that we have seen further very dramatic reductions in radiation doses. It is now usual for us to scan patients with low to normal body mass indexes (BMI) at doses of < 1 mSv and even in much larger patients up to a BMI of approx. 35, doses of < 2 mSv are now typical (k = 0.014); Figs. 2, 3 and 4a, 4b and Table 1.

Lower kVp with reduced contrast volumes

There is a marked increase in the X-ray absorption of iodine at relatively low photon energies of 33.2 keV. This means that a CT X-ray beam containing numerous photons at or around this energy will be attenuated more strongly by iodinated contrast media compared with higher-energy beams. Consequently for the same total radiation and contrast dose, reducing the peak kilovoltage (kVp) of the X-ray tube will lead to much denser contrast within the heart and coronary vessels with a substantial increase in the contrast-to-noise ratio (CNR) of the image. This increased CNR allows excellent images to be produced at lower radiation doses and also allows use of lower flow rates and

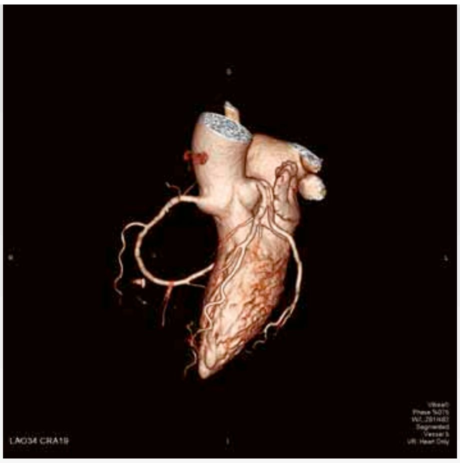


Fig. 2: Normal coronaries. 80 kVp BMI 16, prospective single beat 70 – 80 %, total radiation dose 0.2 mSv (k = 0.014)

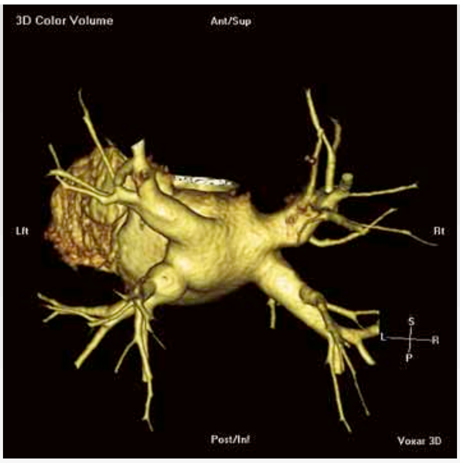


Fig. 3: Left atrial/pulmonary vein assessment prior to pulmonary vein isolation. 80 kVp, BMI 24, prospective single beat 75 %, total radiation dose 0.3 mSv (k = 0.014)

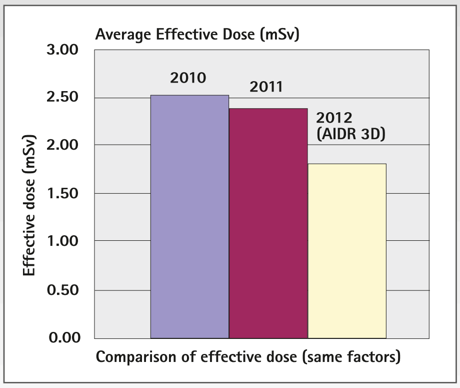
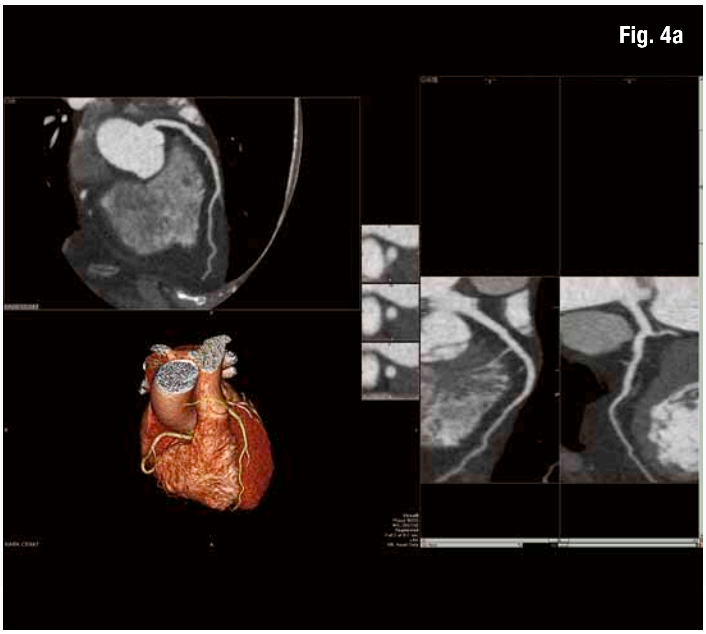


Table 1: Mean total radiation dose for cardiac CTCA 2010 – 2012 (prospective single beat 70 – 80 %), BMI range 18 – 65 (k = 0.014)



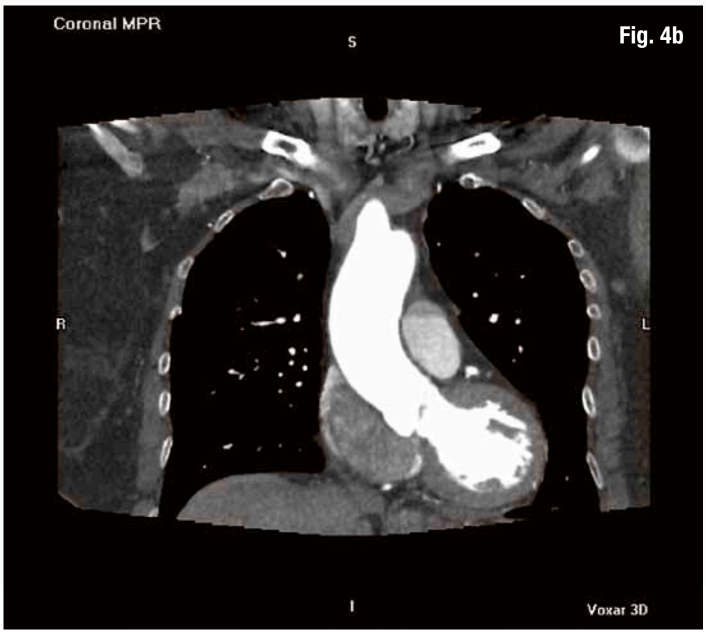


Fig. 4a and 4b: Normal chest and coronaries. 100 kVp BMI 25, 2-step whole chest coverage, prospective single beat 70 – 80 %, total dose 1.7 mSv (k = 0.014) total volumes of contrast media. This leads to potential benefits in terms of cost savings and reduced risk of contrast-induced nephropathy (CIN). The introduction of AIDR 3D with its dramatic ability to reduce noise whilst increasing spatial resolution now allows us to scan slim to average patients (BMI < 23) at 80 KVp and much larger patients (up to a BMI of approx. 35) at 100 kVp whilst maintaining tube current (mA) at low levels (Figs. 5, 6). This ability to scan almost all patients at a kVp of 100 or lower has enabled us to use 60 ml Niopam 370 IV at 4.5 ml/s as our standard protocol for medium to large patients (BMI < 35), with slim patients (BMI < 23) now routinely scanned using 50 ml or less of contrast at flow rates of 4 ml/sec or less. This represents a reduction in IV contrast volumes of up to 33 % compared with our former protocols.

Scanning obese patients at very low radiation doses with AIDR 3D

Scanning of obese patients at acceptable radiation doses has always been a challenge using conventional systems. Increased X-ray attenuation and scatter is seen in obese patients which results in noisy images with substantial artifact when using conventional filtered back projection (FBP). In addition, higher tube voltages (up to 135 kVp) often have to be used in these patients to obtain sufficient X-ray penetration which leads to reduced contrast-to-noise ratios. This is further exacerbated by the fact that intravenous access is often poor in these patients meaning that it is not possible to deliver high contrast flow rates through sufficiently large bore cannulae. Due to the above factors relatively high radiation doses are required, while the quality of CT angiographic images in obese patients is still poor when using traditional FBP techniques.

AIDR 3D now allows us to scan obese patient up to a BMI of approx. 35 using 100 kVp (compared with a maximum BMI of approximately 28 prior to AIDR 3D) with much better contrast opacification (and therefore increased CNR), less artifacts,

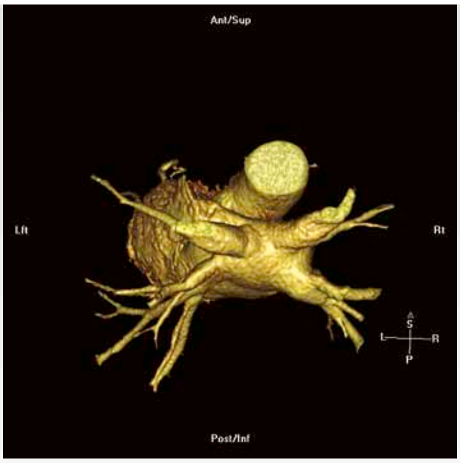


Fig. 5: Left atrial planning, 80 KVp, 40 ml Niopam 370 IV @ 3.5 ml/s

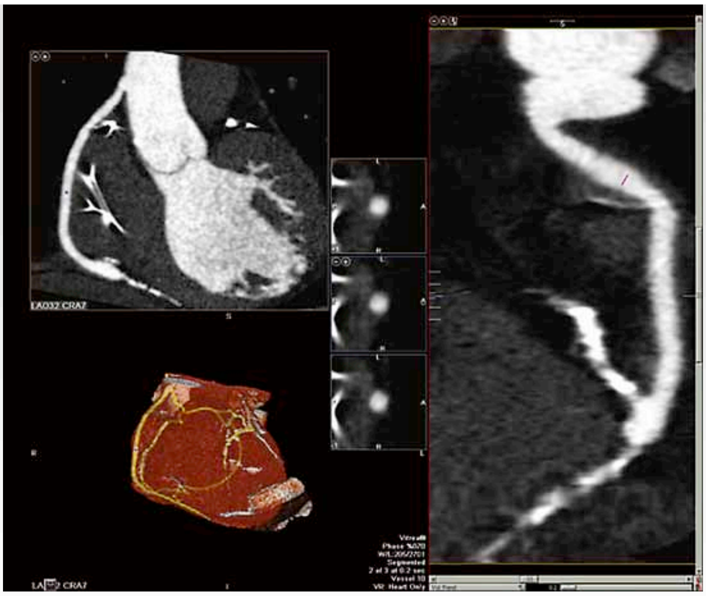


Fig. 6: RCA graft, HR 79 AF, eGFR 29, 80 kVp, 45 ml Niopam 370 IV @ 3.5 ml/s

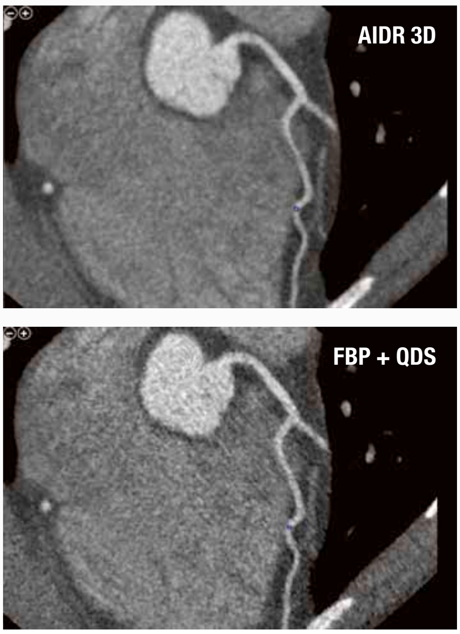


Fig. 7: Normal LAD with segment of intramyocardial bridging, AIDR 3D vs. FBP with QDS (BMI33, dose 2 mSV)

Fig. 8: Normal RCA, BMI 34, 100 kVp, 2 mSv total radiation dose (k = 0.014)

better spatial resolution and dramatically reduced radiation doses (Figs. 7, 8, 9). Image quality (using 120 kVp) is also dramatically improved in very obese patients (BMI >35) leading to reliably diagnostic images at very acceptable radiation doses (typically < 3 mSv) even in this very challenging patient group.

Increased spatial resolution

The use of 'sharper' higher spatial frequency reconstruction algorithms increases spatial resolution and allows better visualization of the lumens of structures such as coronary stents and heavily calcified vessels due to reduced blooming. The use of these algorithms is however limited using traditional FBP techniques as at low radiation doses, image noise often becomes unacceptably high. AIDR 3D now allows us to generate images with minimal noise using the highest spatial reconstruction frequency coronary algorithm (FC05) whilst reducing radiation dose. In addition, AIDR 3D approximately doubles spatial resolution (lp/mm), compared with FBP for any given dataset. Thus we are now able to take full advantage of the unmatched inherent spatial resolution provided by the 0.5 mm wide Aquilion ONE detectors. Owing to the above changes all our patients are effectively scanned in high definition mode but without the penalty of increased radiation dose inherent in some other systems designed to improve spatial resolution.

Conclusion

In our clinical setting of a busy general CT department providing a high volume cardiac CT service, AIDR 3D had transformed our service. In addition to the robustness already provided by the Aquilion ONE, we are now able to scan all patients with even better image quality using even lower doses of both radiation and IV contrast. The combination of excellent image quality and extremely low radiation doses is likely to increase the trend for cardiac CT to replace conventional catheter angiography in many patient groups.

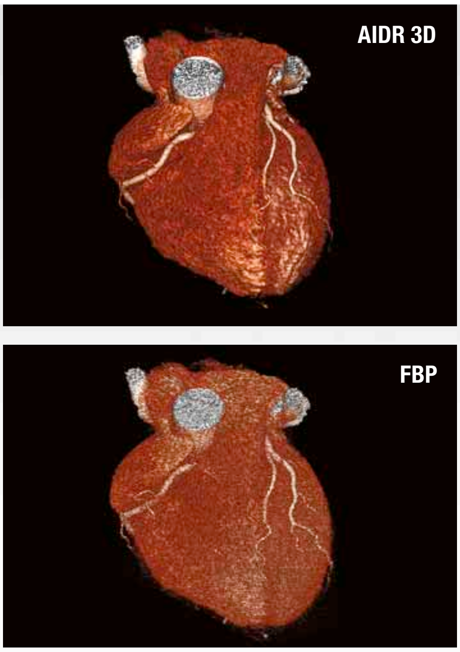


Fig. 9: 3D heart, BMI 34, dramatic reduction in image noise using AIDR 3D compared with conventional FBP

Fig. 10: 100 kVp, BMI 25, FC05, excellent visualization of critical proximal LAD stenosis (prospective single-beat 70–80% protocol), total radiation dose 0.7 mSv (k = 0.014)

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