The clinical benefits of AIR™ Recon DL for MR image reconstruction

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The limitations of conventional MR image reconstruction

The advantages of magnetic resonance imaging (MRI) as a medical imaging modality are well documented, including the lack of ionizing radiation, volumetric capabilities, superior soft tissue contrast and the potential for quantitative imaging. Unfortunately, long imaging times and a lack of high spatial resolution remain as common clinical complaints and represent a major focus of present-day technical development activities. To this end, the MR industry has addressed these needs with innovations such as parallel imaging, compressed sensing and simultaneous multislice for scan-time acceleration.

Artificial intelligence, particularly deep-learning (DL) techniques, have recently been introduced to improve image quality (SNR and sharpness) as well as enable scan time reductions. However, to best understand the opportunity for DL-based reconstruction, we must first understand the inherent limitations of conventional MR image reconstruction.

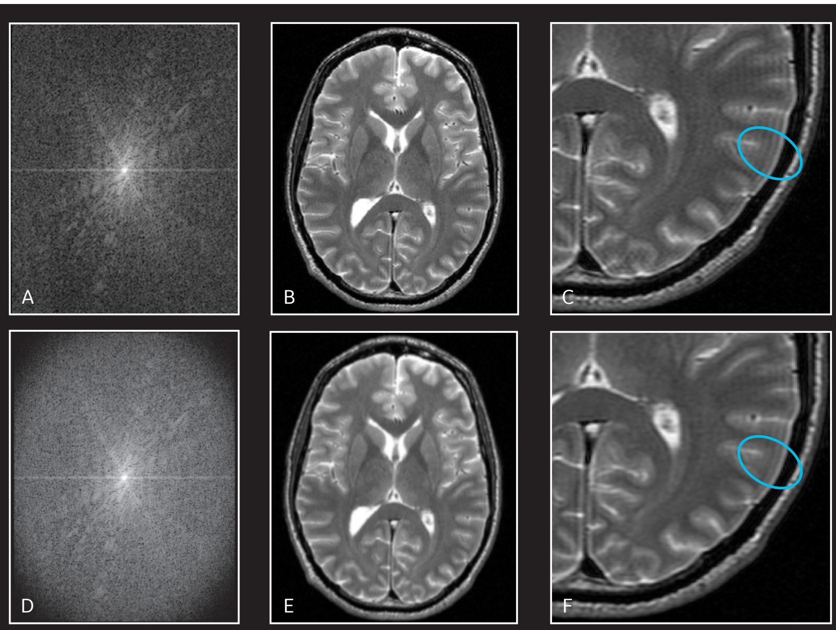


Figure 1. Gibbs ringing artifacts with conventional image reconstruction. Unfiltered raw data (A) reconstructs image (B), resulting in prominent Gibbs ringing artifacts (C) as indicated in the oval. To reduce Gibbs ringing, raw data is filtered or apodized as shown in (D), resulting in images (E) and (F) showing marked reduction in Gibbs ringing artifacts, but at the expense of reduced sharpness.

Gibbs ringing and truncation artifacts

In MR imaging, raw data is collected in the form of so-called k-space, which represents the Fourier transform of the object being imaged. Due to the finite amount of k-space that is collected, certain artifacts result such as Gibbs ringing, which is also known as truncation artifacts, and occur irrespective of the pulse sequence. Gibbs ringing manifests as duplication or ringing of sharp edge structures, like cerebrospinal fluid (CSF). To reduce Gibbs ringing artifacts, raw data is routinely filtered or apodized, effectively suppressing the peripheral regions and consequently attenuating high resolution structures as described in Figure 1.

Reduced spatial resolution

Suppression of Gibbs ringing through raw data filtering comes at a cost in image sharpness or spatial resolution. This is demonstrated in Figure 1C and F. The loss in image sharpness is a natural consequence of the filtering or suppression of the peripheral regions of raw data k-space as these regions represent the high-spatial resolution structures (e.g., sharp edges) of the object. This delicate balance of Gibbs ringing suppression and spatial resolution is a well-known tradeoff in MR imaging.

Presence of noise

One image quality metric that is often used to describe image quality is signal-to-noise ratio (SNR). In MR, there are multiple sources of noise, such as thermal and electrical noise, which impacts the raw data that is collected. Noise in raw data translates into noise in the final image. The typical approach to improving SNR is to perform multiple averaging, which comes at the expense of prolonged scan time, or to increase the voxel volume at the expense of lower spatial resolution. Other hardware-related solutions to improve SNR include using a higher field strength, quality surface coils and low-noise receiver components, which add to overall system cost.

The inherent tradeoffs with SNR, spatial resolution and scan time

Gibbs ringing aside, MR users have become familiar with managing the tradeoff and compromise with respect to spatial resolution, SNR and scan time with conventional MR image reconstruction. Indeed, some imaging facilities or

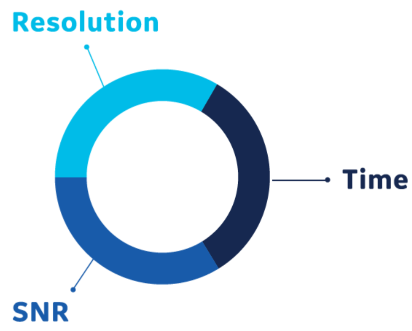


Figure 2. Protocol optimization is a balance of spatial resolution, SNR and scan time.

radiologists may place more weight on one item over another which can result in multiple imaging protocols, each suited to the likes and dislikes of the referring physician. In addition, imaging facilities are under pressure to meet increasingly demanding schedules and need to manage variables such as patient shape, size and level of cooperation. Re-scans and patient call backs are no longer options for managing unexpected results. Fortunately, the field of MR research and development is actively exploring alternatives to conventional MR reconstruction to address these compromises with spatial resolution, SNR and scan time.

Enter AIR™ Recon DL

What if there was an alternative to conventional MR image reconstruction where the user did not have to choose between spatial resolution, SNR or scan time? This motivating question has been the focus of much algorithm development attention with novel MR image reconstruction methods that employ artificial intelligence, specifically DL. In May 2020, GE Healthcare received US FDA clearance of AIR™ Recon DL, a DL-based convolutional neural network for reconstructing MR images on 3.0T systems. Subsequently in September 2020, AIR™ Recon DL became FDA cleared for 1.5T.

AIR™ Recon DL is an algorithm that is embedded in the MR image reconstruction pipeline [1], where the neural network model is applied to remove noise and Gibbs ringing artifacts prior to final image formation. The network employs a cascade of over 100,000 unique pattern recognitions for noise and low resolution to reconstruct only the ideal object image. The network includes a tunable SNR improvement level to suit the user's preference and an innovative ringing suppression technology that recognizes common artifacts like Gibbs ringing and truncation and recasts it into improved image detail. The result is an image with higher SNR and spatial resolution.

AIR™ Recon DL performs two separate functions within the MR image reconstruction pipeline: ringing suppression and SNR improvement. These provide for clinical benefits such as scan time reduction, sharper images, greater tolerance of protocol variations [2-16] and images that are easier and faster to read.*

Intelligent Ringing Suppression for sharper images

As previously discussed, with conventional MR image reconstruction, suppression of truncation artifacts or Gibbs ringing results in a loss of high-spatial resolution, which leads to images that are less sharp with poorly defined edges. With AIR™ Recon DL's Intelligent Ringing Suppression, which is part of the reconstruction-embedded deep neural network, this tradeoff of ringing suppression for spatial resolution is avoided. The isolated benefits of Intelligent Ringing Suppression are best demonstrated with phantom images as shown in Figures 3 and 4.

AIR™ Recon DL's Intelligent Ringing Suppression makes images sharper and have higher spatial resolution. It is tempting to ask if AIR™ Recon DL images

* Based on an early adopter survey of 21 radiologists from 11 different sites and 6 different countries. 90% of those surveyed indicated that images were easier to read, can be read quicker and lead to reduced eye fatigue.

that are acquired with larger voxel volumes appear equally sharp as conventional images acquired with smaller voxel volumes? Consider the phantom images in Figure 4. In this experiment, a resolution phantom was scanned with different in-plane voxel sizes and reconstructed with both conventional and AIR™ Recon DL. The conventional images get increasingly blurry as the in-plane voxel dimension approaches the diameter of the structures, as expected. However, the AIR™ Recon DL images retain sharpness up to the largest voxel volumes. On closer examination, it is seen that the AIR™ Recon DL 0.78 x 0.78 mm in-plane voxel image (Figure 4L) appears with higher spatial resolution than the conventional 0.78 x 0.78 mm image (Figure 4G) but is slightly less sharp than the conventional 0.52 x 0.52 mm image (Figure 4F). Similarly, the AIR™ Recon DL 0.26 x 0.26 mm in-plane voxel image (Figure 4H) approximately matches the conventional 0.20 x 0.20 mm image (Figure 4A). A more thorough examination leads to Figure 5 where we can relate the conventional (input) voxel dimension with the AIR™ Recon DL (output) voxel dimension. Based on visual matching of the phantom image structures, for equivalent spatial resolution, it is estimated that the AIR™ Recon DL in-plane voxel dimension can be approximately 1.4 times larger than that of the conventional image. This 1.4 factor is consistent with an independent study which found a factor of 1.6, based on edge gradient analysis [1]. Consequently, these phantom findings suggest that a lower in-plane matrix setting can be used with AIR™ Recon DL to obtain equivalent spatial resolution and image sharpness as a conventional image, independent of the SNR improvement.

User-selectable SNR Improvement

The other key component of AIR™ Recon DL is the deep-learning based SNR improvement model [1]. This can also be described as a denoising algorithm that is directly embedded in the MR image reconstruction pipeline, requiring access to raw data. With the commercial release of AIR™ Recon DL, users have the freedom to select their own level of SNR improvement through a user interface that provides a low, medium or high setting, as well as the option to not use AIR™ Recon DL. When a low, medium or high setting is used, there is a system preference setting which can be set to also capture the conventional reconstructed images for comparison. It is anticipated that, once familiar with the product, users will choose to use the AIR™ Recon DL high setting and not have

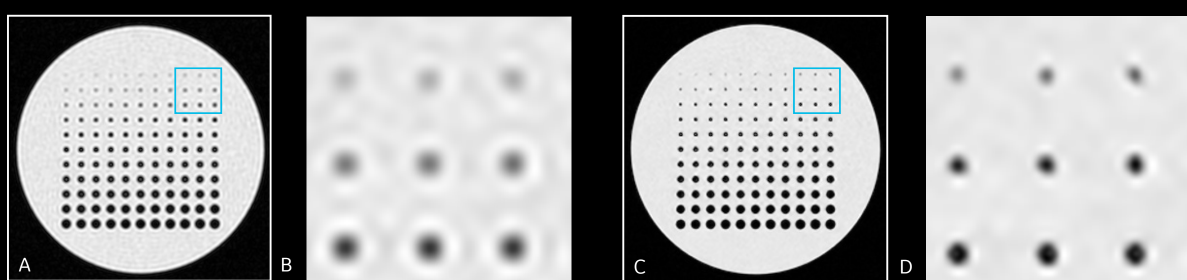
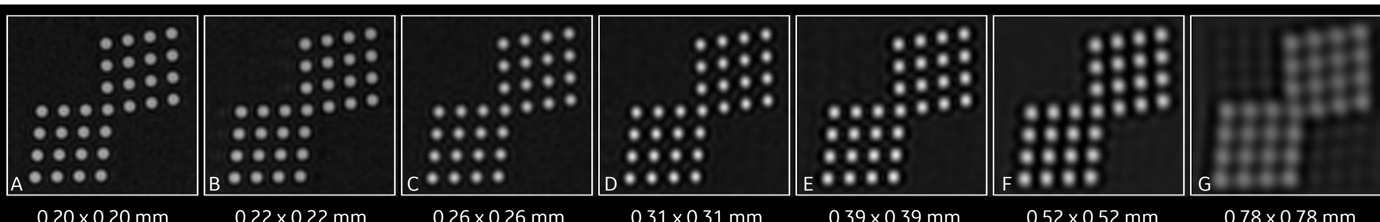


Figure 3. AIR™ Recon DL Intelligent Ringing Suppression for sharper images as demonstrated in an imaging phantom. (A) Conventional image reconstruction with apodization still results in significant Gibbs ringing as indicated at the phantom edge. (B) Magnified A showing ringing and a loss of fine detail in the circular structures. (C) The same raw data as reconstructed using AIR™ Recon DL shows elimination of Gibbs ringing artifacts and (D) considerably sharper images. Note that the AIR™ Recon DL images also show the added benefit of noise reduction, however, this is considered unrelated to the improved sharpness of the images.



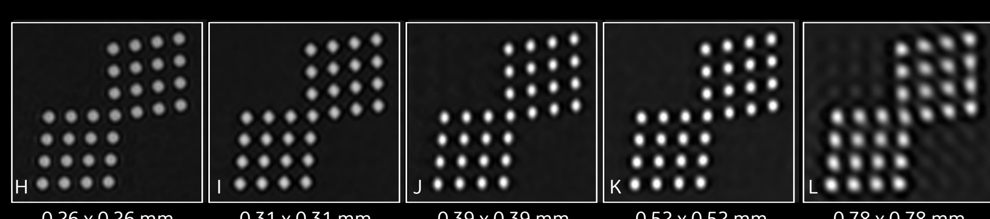


Figure 4. AIR™ Recon DL Intelligent Ringing Suppression preserves image sharpness with larger in-plane voxel dimensions. Shown are resolution phantom images of conventional (A-G) and AIR™ Recon DL (H-L) reconstructions with varying in-plane voxel dimensions. The diameter of the pin holes are approximately 0.9 mm.

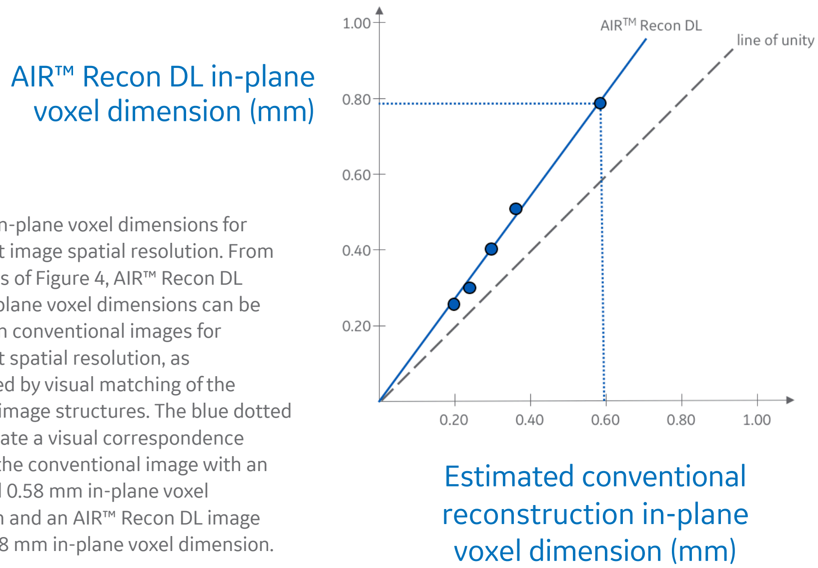


Figure 5. In-plane voxel dimensions for equivalent image spatial resolution. From the images of Figure 4, AIR™ Recon DL image in-plane voxel dimensions can be larger than conventional images for equivalent spatial resolution, as determined by visual matching of the phantom image structures. The blue dotted lines indicate a visual correspondence between the conventional image with an estimated 0.58 mm in-plane voxel dimension and an AIR™ Recon DL image with a 0.78 mm in-plane voxel dimension.

a need to compare with conventional reconstructed images. Figure 6 shows representative examples of the low, medium and high setting, relative to conventional reconstruction.

Putting it all together

The Intelligent Ringing Suppression algorithm is completely independent of the SNR improvement algorithm. As such, the image sharpening benefits will be the same for all SNR improvement levels. However, some structures may become more conspicuous with a higher SNR improvement level. Figure 7 demonstrates the clinical impact of both Intelligent Ringing Suppression and SNR improvement.

Clinical benefits and early adopter feedback

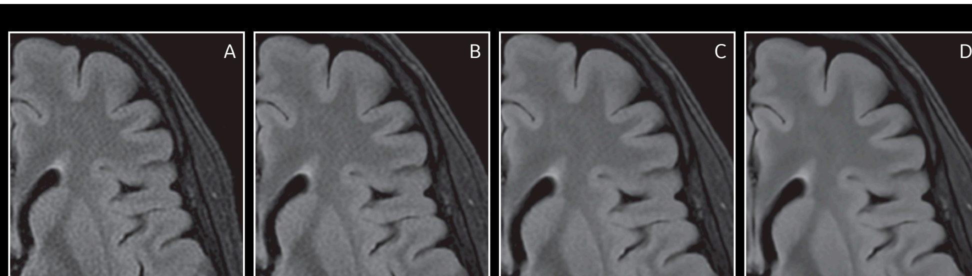
There are many benefits to AIR™ Recon DL which extend to clinical, operational and financial aspects of MR imaging. Clinical benefits are best demonstrated with images that span multiple anatomies†, which compare AIR™ Recon DL to conventional image reconstruction and are described in Figures 8 - 13.

Operationally, it is expected that AIR™ Recon DL will lead to more predictable patient scheduling as a result of fewer repeat scans and shorter scan times. This may also allow for disinfection time between patients during the COVID-19 pandemic. The scan time savings and more consistent image quality may help reduce stress among the MR technologists and radiographers. Finally, AIR™ Recon DL images will be easier to read, resulting in faster interpretation and less eye fatigue which was experienced by some early adopters of the technology.‡‡

Early adopter feedback

Many of the clinical image examples were obtained from early adopter clinical sites with access to research prototype versions of AIR™ Recon DL, used within institution review board guidelines. Feedback from the 11 sites was overwhelmingly positive, which consisted of 21 radiologists (average experience of over 15 years) from six different countries. The following feedback was obtained on

Figure 6. User-selectable SNR improvement levels with AIR™ Recon DL. Shown are (A) conventional (apodized) reconstruction, along with AIR™ Recon DL, (B) low, (C) medium and (D) high SNR improvement levels. All images were reconstructed from the same raw data.



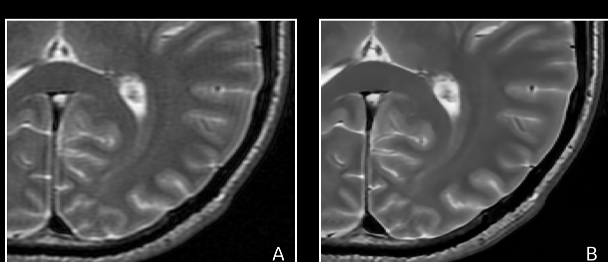


Figure 7. Intelligent Ringing Suppression and SNR improvement with AIR™ Recon DL. Shown are representative images of (A) conventional MR image reconstruction (same image as Figure 1F) compared to (B) AIR™ Recon DL using a high SNR improvement level, which demonstrates Gibbs ringing artifact elimination, sharper structures and noise removal.

† The US FDA clearance of AIR™ Recon DL does not have any anatomy restrictions.

‡‡ Based on an early adopter survey of 21 radiologists from 11 different sites and 6 different countries. 90% of those surveyed indicated that images were easier to read, can be read quicker and lead to reduced eye fatigue.

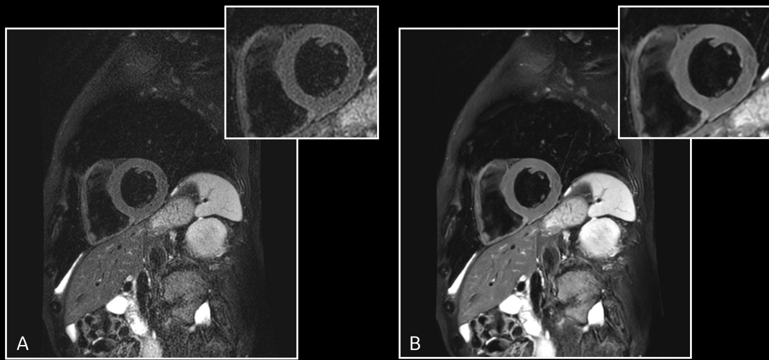


Figure 8. SNR improvement with AIR™ Recon DL. Shown is a short axis T2 Double IR black blood FatSat breath hold scan, 1.3 x 1.4 x 6 mm, 2:13min scan time with 11sec breath hold. (A) Conventional image reconstruction and (B) AIR™ Recon DL high setting of the same raw data showing considerable SNR improvement.

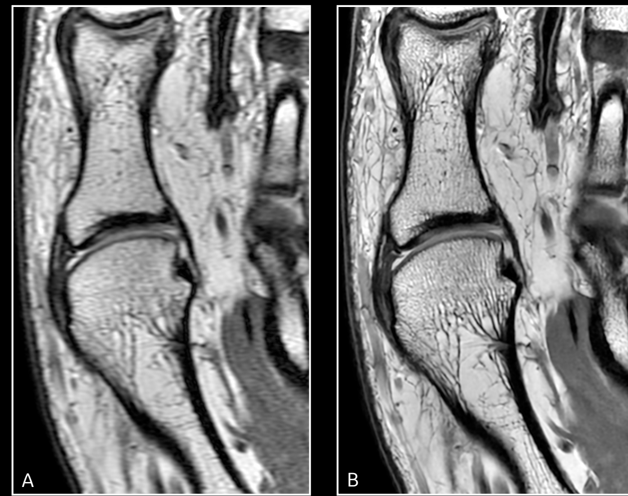


Figure 9. Sharper images with AIR™ Recon DL. Shown is a coronal FSE PDw, 0.3 x 0.3 x 1.0 mm of the first metatarsal. (A) Conventional image reconstruction and (B) AIR™ Recon DL high setting of the same raw data (same matrix and scan time) showing sharper trabecular structure.

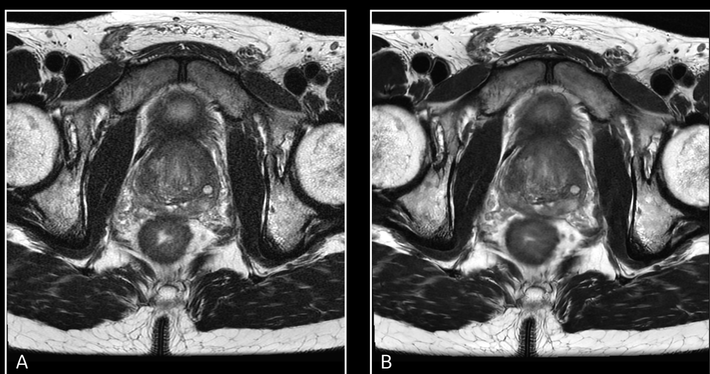


Figure 10. Higher resolution and shorter scan time with AIR™ Recon DL. Shown is an axial FSE T2w of a prostate. (A) Conventional image reconstruction with a 448 x 288 matrix, 3:29 min scan time. (B) AIR™ Recon DL with a 512 x 320 matrix, 2:17 min scan time showing higher resolution with a shorter scan time.

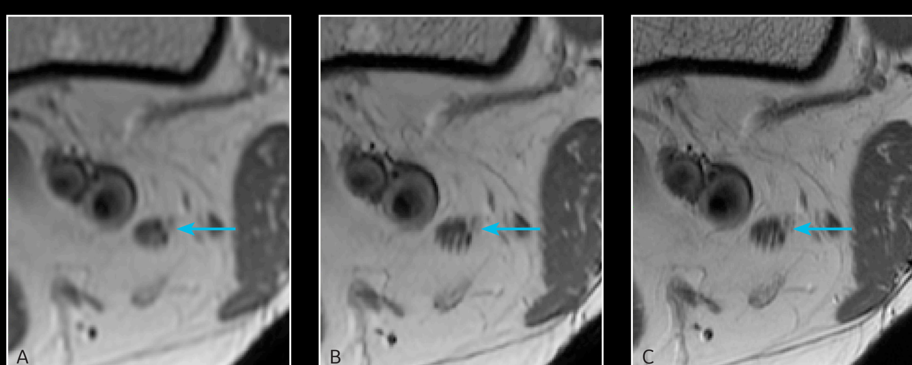


Figure 11. Scan time reduction with AIR™ Recon DL. Shown is an axial FSE PDw showing a tibial nerve (arrow). (A) Conventional image reconstruction with a 256 x 180, 1:10 min scan time. (B) AIR™ Recon DL image reconstruction of the same data in A showing fascicular structure in the tibial nerve. (C) Conventional image reconstruction of a higher matrix and longer scan time (512 x 352, 4:09 min scan time) confirms the same fascicular structure as in B.

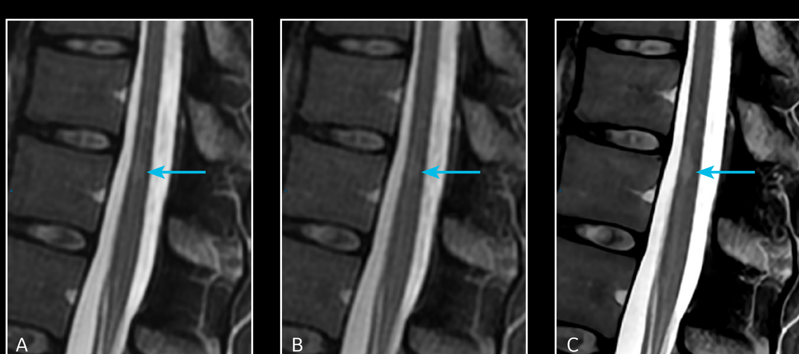


Figure 12. Improved lesion contrast with AIR™ Recon DL. Shown is a sagittal FSE T2w of the spine. (A) Conventional image reconstruction with a 4 NEX, 2:50 min scan time. (B) Conventional image reconstruction with 2 NEX, 1:28 min scan time, showing less contrast-to-noise ratio as in A. (C) AIR™ Recon DL image reconstruction of the same raw data as in B showing improved lesion conspicuity of the lesion (arrow).

Figure 13. Ultra-thin slice imaging using 2D sequences with AIR™ Recon DL. Shown is a coronal FSE PDw FatSat of the shoulder, 0.6 x 0.6 x 0.7 mm slice thickness. (A) Conventional image reconstruction showing clinically unacceptable noise level. (B) AIR™ Recon DL of the same raw data. (C) Reformat of the AIR™ Recon DL data set in B showing near-seamless 3D image quality.

AIR™ Recon DL:

- 100% of users said that images were sharper, more detailed and displayed less noise, which could enable prescription changes to shorten scan time
- 95% of users indicated improved lesion conspicuity and improved diagnostic confidence that may help reduce the number of repeat series
- 90% of users confirmed that AIR™ Recon DL may allow for prescription changes to increase spatial resolution and that images were easier to read and could be read more quickly, leading to reduced eye fatigue
- 81% of users indicated that AIR™ Recon DL may achieve greater consistency between patients and technologists

As of April 2020, more than 6000 exams were obtained with AIR™ Recon DL at these 11 clinical sites. Many of these early adopters published their AIR™ Recon DL clinical findings in GE's SIGNA Pulse of MR [2,3], proceedings for RSNA 2019 [4-7] and proceedings for ISMRM 2020 [8-16].

How AIR™ Recon DL addresses the tradeoff with SNR, spatial resolution and scan time

AIR™ Recon DL provides a solution to the tradeoff with SNR, spatial resolution and scan time. To begin, SNR is usually thought of as an output metric of the image, which depends on various input protocol settings of the MR scan such as voxel volume (e.g., spatial resolution) and number of averages (e.g., scan time). There generally is no direct SNR parameter; SNR simply results from the selected MR parameters.

We will look at the impact of AIR™ Recon DL on the SNR vs. voxel volume and SNR vs. scan time dependencies separately. Then we will examine how AIR™ Recon DL can expand the protocol space, utilizing the benefits of both spatial resolution and scan time simultaneously.

SNR and voxel volume

SNR is directly dependent on voxel volume, which is the product of the in-plane pixel dimensions with slice thickness. Voxel volume is typically used to characterize the prescribed spatial resolution. It is generally intuitive to most MR users that the larger the signal-bearing voxel volume, the greater the SNR and that this dependence is linear, i.e., if the voxel volume doubles then the SNR doubles.

If we model AIR™ Recon DL as a simple multiplication of conventional image reconstruction SNR, then we have a scenario as pictured in Figure 14 where the SNR of both conventional reconstruction and AIR™ Recon DL images vary linearly with voxel volume, with AIR™ Recon DL having a greater SNR slope.

In this scenario, we also have clinical acceptance thresholds for spatial resolution and SNR as indicated by the vertical and horizontal dotted lines, respectively, which would likely be dependent on the imaging facility and the reading radiologists. As previously demonstrated, AIR™ Recon DL can provide equivalent spatial resolution with a larger voxel volume compared to conventional reconstructed images, due to the image sharpening benefit of Intelligent Ringing Suppression. As such, the clinically acceptable spatial resolution (dotted vertical line) for AIR™ Recon DL would be larger than for conventional reconstructed images. Recall, the prior discussion on spatial resolution in a phantom suggested an in-plane voxel dimension improvement factor of 1.4.

Consider point A on Figure 14 as an unacceptable clinical protocol. It has sufficient SNR, however its voxel volume is too large and lacks for high spatial resolution. AIR™ Recon DL can be used to reduce the voxel volume, increasing the spatial resolution to acceptable clinical levels while keeping the SNR preserved, as indicated at point B. If a protocol were to start at point C, having sufficient clinical spatial resolution but inadequate SNR, AIR™ Recon DL could be used to improve the SNR to acceptable levels (point B). To complete this example, Figure 15 shows representative knee images at points A, B and C from Figure 14.

With the clinical acceptance thresholds as shown in the Figure 14 example, there is a very narrow range of voxel volumes with conventional reconstruction that will meet both SNR and spatial resolution needs, as indicated by the red arrows. With AIR™ Recon DL, there is a much wider range of voxel volumes indicated with the double-sided blue arrow, signifying more freedom and flexibility with the imaging protocol.

SNR and scan time

In MR imaging, the most common way to increase SNR is to acquire additional signal averages or excitations, effectively collecting more raw data. Unfortunately, due to the nature of MR noise statistics, a doubling of the number of excitations (NEX) only results in a square root 2

Figure 14. SNR as a function of voxel volume. The SNR of both conventional and AIR™ Recon DL varies linearly with voxel volume. AIR™ Recon DL allows smaller voxel volumes while maintaining sufficient clinical SNR. The vertical and horizontal dotted lines represent the clinically acceptable spatial resolution and SNR, respectively.

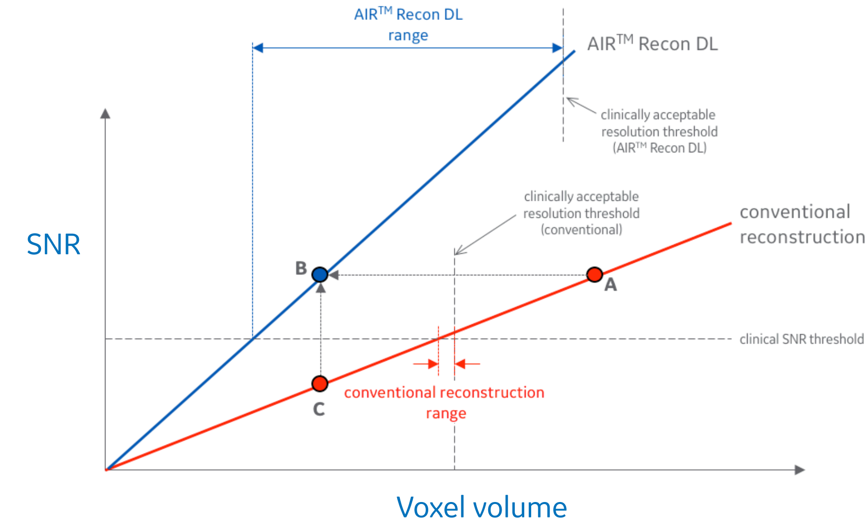
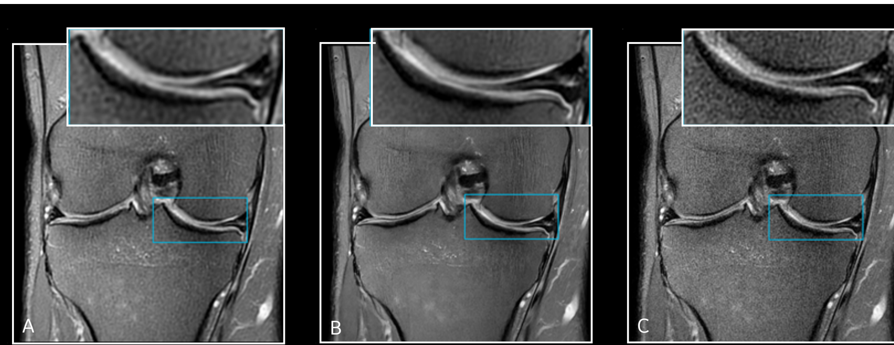


Figure 15. Representative knee images to correspond to points A, B and C in Figure 14. Shown are (A) conventional 0.6 x 0.6 mm (in plane), (B) AIR™ Recon DL 0.4 x 0.4 mm and (C) conventional 0.4 x 0.4 mm reconstructed images. Image A has sufficient SNR but lacks clinical spatial resolution. Image C has sufficient clinical spatial resolution but lacks in SNR. AIR™ Recon DL delivers high SNR with clinical spatial resolution as demonstrated in image B.



Conventional 0.6 x 0.6 x 3 mm | AIR™ Recon DL 0.4 x 0.4 x 3 mm | Conventional 0.4 x 0.4 x 3 mm

Figure 16. SNR as a function of scan time. The SNR of both conventional and AIR™ Recon DL varies as the square root of scan time. AIR™ Recon DL allows reduced scan times while maintaining sufficient clinical SNR.

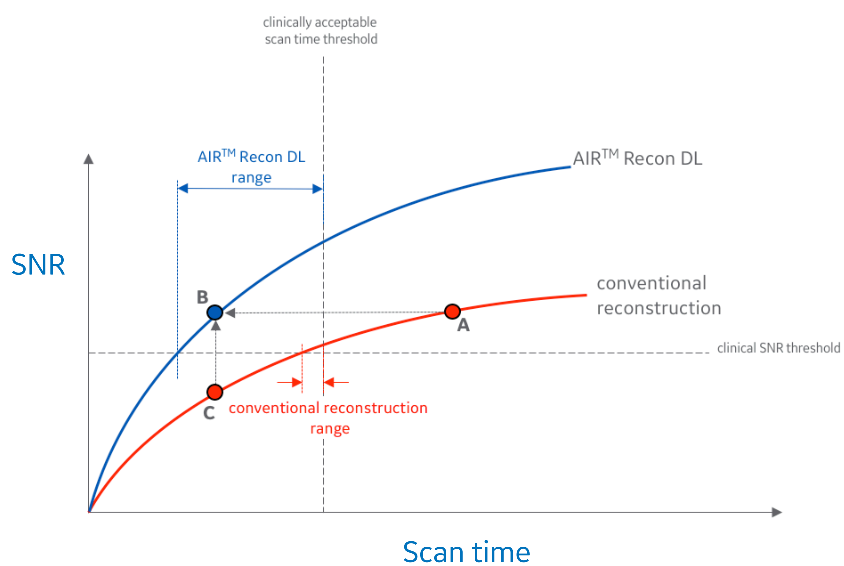
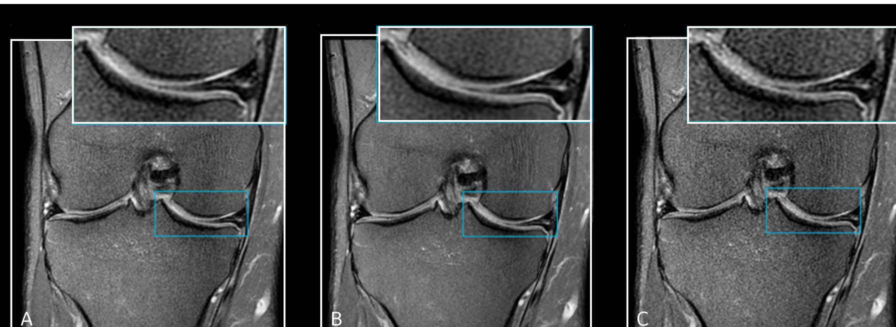


Figure 17. Representative knee images to correspond to points A, B and C in Figure 16. Shown are (A) conventional with 3:24 min scan time, (B) AIR™ Recon DL with 1:56 min scan time and (C) conventional with 1:56 min scan time reconstructed images. Image A has sufficient SNR but is considered too long a scan time. Image C has acceptable scan time but lacks SNR. AIR™ Recon DL delivers high SNR with clinically acceptable scan time in image B.



Conventional 3:24 min. | AIR™ Recon DL 1:56 min. | Conventional 1:56 min.

increase in the resultant SNR. The well-known relationship is that SNR varies as the square root of the total scan time.

As with the prior discussion on spatial resolution, if we assume that the SNR in AIR™ Recon DL images is a multiplication of the conventional SNR, then we have an SNR dependence on scan time as pictured in Figure 16. Similar to the previous discussion, we consider clinical acceptable thresholds for both scan time and SNR.

If point A on Figure 16 represents a protocol with an unacceptably long scan time but with sufficient SNR, then AIR™ Recon DL can allow for shorter scan times while keeping SNR constant, as indicated by point B. If a protocol has clinically acceptable scan time but insufficient SNR, as in point C, AIR™ Recon DL could improve the SNR to acceptable levels, (point B). Note the broadened range of scan times with AIR™ Recon DL as indicated with the double-sided blue arrow. Representative images for points A, B and C are shown in Figure 17.

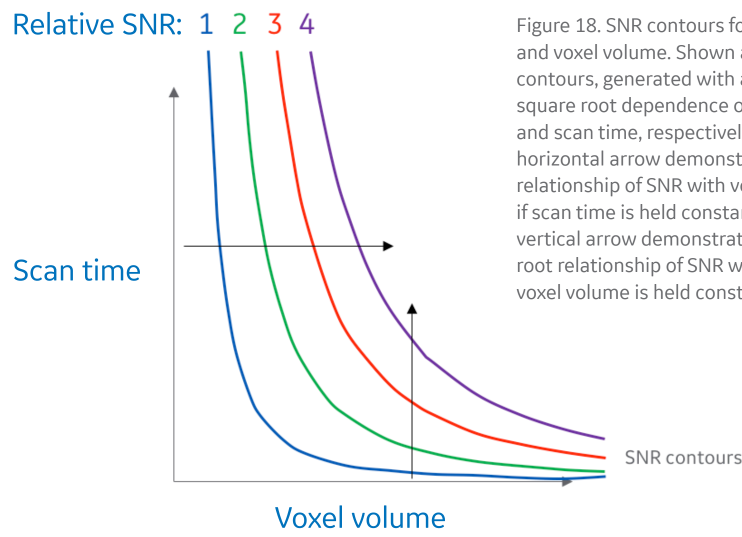


Figure 18. SNR contours for scan time and voxel volume. Shown are four SNR contours, generated with a linear and square root dependence on voxel volume and scan time, respectively. The black horizontal arrow demonstrates the linear relationship of SNR with voxel volume, if scan time is held constant. The black vertical arrow demonstrates the square root relationship of SNR with scan time, if voxel volume is held constant.

How AIR™ Recon DL expands the useable clinical protocol space

In the previous sections, we have examined how SNR varies with voxel volume and how SNR varies with scan time separately, and how AIR™ Recon DL can provide tangible clinical advantages regarding voxel volume and scan time choices, separately. Here we look at a more complete picture of the protocol space and consider SNR, voxel volume and scan time all together.

Consider Figure 18 showing SNR contours for different scan time and voxel volume combinations. Each curved contour line represents a constant SNR for different scan times and voxel volumes. Four evenly spaced SNR levels are shown in blue, green, red and purple. The SNR contour lines were generated using the linear and square root relationship for SNR with voxel volume and scan time, respectively. Intuitively, the SNR increases as either the voxel volume or scan time increases.

Acceptable clinical protocols are those that simultaneously meet three criteria: SNR, spatial resolution and scan time. Figure 19A is an example of conventional

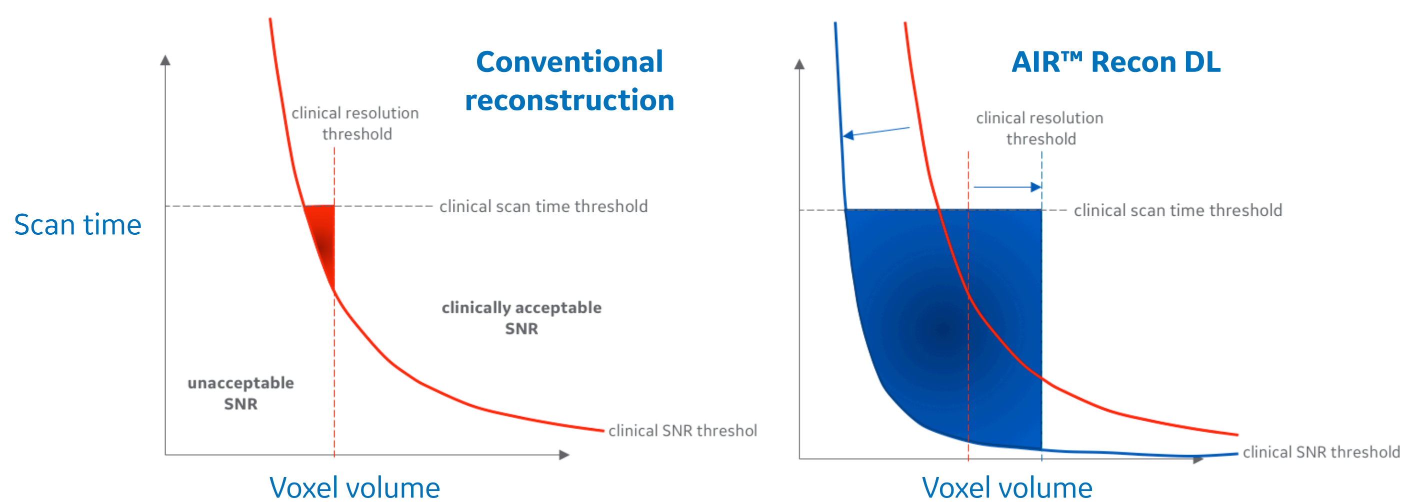


Figure 19. Expanded clinical protocol space with AIR™ Recon DL. (A) Conventional reconstruction with the clinically acceptable SNR contour, as indicated in red, the only protocol combinations of voxel volume and scan time that are simultaneously clinically acceptable for SNR, scan time and spatial resolution is the triangular area in red. (B) An expanded protocol space with AIR™ Recon DL reconstruction showing the clinically acceptable SNR contour to be shifted lower (dependent on a low, medium or high SNR improvement setting) and the clinically acceptable resolution threshold is further to the right, compared to conventional reconstruction in A (red solid and dotted lines). The area in blue represents more protocol combinations of voxel volumes and scan times that are clinically acceptable for SNR, scan time and spatial resolution with AIR™ Recon DL.

reconstruction. Given a clinically acceptable SNR level, as indicated by the red contour line, any protocol with a larger voxel volume or longer scan time will result in higher SNR. However, the acceptable clinical protocol is also bounded by the clinical spatial resolution threshold (vertical dotted line) and clinical scan time threshold (horizontal dotted line), leaving the only clinical acceptable protocols as being those in the red triangular shaped region in Figure 19A.

We can redraw the protocol space for AIR™ Recon DL to see how the SNR gain and improved image sharpness manifest in the protocol space. As pictured in Figure 19B, the SNR contour with AIR™ Recon DL is shifted lower for scan time and voxel volume due to the SNR advantage over conventional reconstruction. To clarify, the red contour in Figure 19A and the blue contour in Figure 19B represent the same clinically acceptable SNR, however, AIR™ Recon DL delivers this with shorter scan times and smaller voxel volumes. Also note the positioning of the clinical resolution threshold (vertical dotted line) as being further to the right on Figure 19B compared to Figure 19A. This reflects AIR™ Recon DL's Intelligent Ringing Suppression that can deliver equivalently sharp images with larger voxel volumes.

As demonstrated with this analysis, the SNR and image sharpening benefits of AIR™ Recon DL can dramatically increase the clinically acceptable protocol space and allow more freedom with clinical scanning.

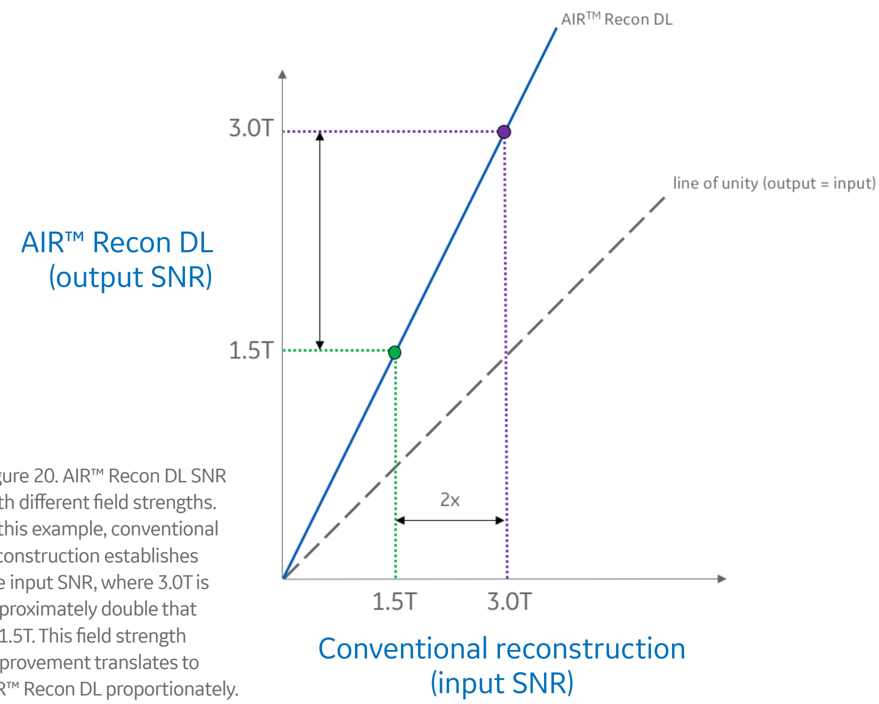


Figure 20. AIR™ Recon DL SNR with different field strengths. In this example, conventional reconstruction establishes the input SNR, where 3.0T is approximately double that of 1.5T. This field strength improvement translates to AIR™ Recon DL proportionately.

The continued importance of field strength, surface coils and gradient performance

AIR™ Recon DL represents a significant breakthrough for improving SNR and image sharpness, along with numerous other clinical benefits. However, it is important to realize that other hardware-related improvements remain important such as field strength, surface coils and gradient performance.

Take field strength for example. It is well understood that a doubling in field strength, such as from 1.5T to 3.0T, translates into an approximate doubling in the image SNR. AIR™ Recon DL can be modeled as a multiplication of the conventional image SNR, so it's benefit would also translate to higher field strength proportionately. Consider the diagram in Figure 20. We can regard the conventional reconstruction as providing the input SNR, where AIR™ Recon DL results in a multiplied output SNR. A doubling of the input conventional image SNR, in going from 1.5T to 3.0T, should also result in a doubling of the AIR™ Recon DL output SNR. In short, AIR™ Recon DL is effective at both field strengths and should not be only reserved for 1.5T. Although 3.0T scanning has SNR advantages, routine clinical protocols still rely on signal averaging and remain constrained with scan times and spatial resolution.

This argument can also extend to other hardware-related MR system components that impact image quality and SNR. Quality and high-channel count surface coils will continue to be important and clinically relevant, as the higher the input SNR, the higher the output AIR™ Recon DL SNR will be. This also holds true for high-performance gradients, which may result in reduced TEs and shorter TRs which can lead to higher input SNR, making AIR™ Recon DL reconstructed images even better.

Considerations for deep-learning MR image reconstruction solutions

AIR™ Recon DL represents a pioneering new development in the use of DL-trained convolutional neural networks for MR image reconstruction, providing clinical benefits as described in this article. While a detailed performance study of AIR™ Recon DL's neural network can be found elsewhere [1], it is instructive to discuss some considerations when it comes to the adoption of neural networks for MR image reconstruction, given that this is an intense focus of interest for many MR vendors and researchers.

To begin, one of the most pressing concerns with any new form of DL-based algorithm is the prospect of missing pathology or of "hallucinating" structure. With AIR™ Recon DL, extensive clinical evaluation was performed involving 21 radiologists from 11 clinical sites from six different countries. Of the thousands of cases collected with both conventional and AIR™ Recon DL reconstructions, no pathologies were reported to have been missed compared to the conventional reconstructed images[§]. In addition, no instances were identified where structures were hallucinated with AIR™ Recon DL. Such hallucinations are a known consequence of the use of generative adversarial networks (GANs), which are not used in the convolutional neural network of AIR™ Recon DL. When considering new DL-based reconstruction techniques, these questions remain at the forefront of clinical concern.

As with any new medical device algorithm, regulatory approval must be attained, to demonstrate safety and efficacy. AIR™ Recon DL has been cleared by the US FDA, which involved an extensive reader study. GE Healthcare will be seeking regulatory approval in other countries for AIR™ Recon DL to bring its benefit to users worldwide.

Anatomical coverage is also a key consideration and can sometimes be dependent on the construction of the DL algorithm. For example, some algorithms may be trained (and regulatory cleared) on specific anatomies such as neuro, knee or spine. This presents clinical use limitations to clinicians if the method is used on anatomies that are untested and without regulatory clearance. Transparency with respect to the approved anatomies is important, as are software limits in place to restrict unintended usage. AIR™ Recon DL is compatible with all anatomies, as evidenced by the US FDA clearance.

When considering novel image reconstruction techniques, the method should deliver more than just SNR improvement to address the tradeoff of spatial resolution, SNR and scan time. As discussed previously, AIR™ Recon DL delivers not just SNR improvement but also Intelligent Ringing Suppression, which can significantly increase the image sharpness and spatial resolution of the resultant image.

Radiologists and MR technologists have preferences when it comes to image quality and appearance. For this reason, it is important that any new MR image reconstruction technique allow a user preference selection. With AIR™ Recon DL, the ability to determine the level of SNR improvement (low, medium or high) is offered, as well as the ability to turn it off entirely. In addition, GE Healthcare provides users the capability to generate the conventional reconstruction images for comparison with AIR™ Recon DL images, which can be useful for establishing clinical confidence during the initial phase of familiarity.

Finally, a key differentiation among MR DL-based techniques is whether they require raw data or operate solely on DICOM images. As discussed previously, use of raw data leads to the most effective result and is necessary to perform procedures such as image sharpening with Intelligent Ringing Suppression. Any algorithm that only functions on DICOM images will be only partially effective, as steps such as raw data apodization make irreversible impacts to the image quality. Related to this topic is whether the images appear at the MR console in real time. As AIR™ Recon DL makes use of raw data and is integrated in the reconstruction pipeline, it delivers images to the MR console in real time allowing the MR technologist to assess the image quality while the patient is still on the table. Some approaches may only send the processed images to PACS, thus unable to provide benefit during the actual patient scanning.

Summary

AIR™ Recon DL offers many clinical benefits over conventional image reconstruction, including increased SNR and sharper images due to the Intelligent Ringing Suppression, as demonstrated on both phantom and in vivo. Functioning on raw data, AIR™ Recon DL can help users manage the delicate balance between spatial resolution, SNR and scan time. With an understanding of the relationship between SNR, voxel volume and scan time, AIR™ Recon DL can significantly expand the clinically useable protocol space, allowing users more freedom and flexibility in prescribing MR scans to suit their needs.

If you would like to learn more about GE Healthcare's AIR™ Recon DL, or any other MR technology, please contact us at GEHealthcare.com.

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[§] These cases were not part of the US FDA submission for AIR™ Recon DL.

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