White Paper

Precision Matrix on SOMATOM Force

Ease your workflow in high-resolution CT imaging

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Introduction to high-resolution imaging

In 50 years of technical development, computed tomography (CT) set new standards in diagnostic imaging. Fast visualization of the finest anatomical structures is, for example, one of the strengths of CT. And there are many clinical applications in diagnostic imaging that demand a strong level of high-contrast spatial resolution in the sub-mm range. Typical examples are images of the lung, temporal bone, sinus, wrist, and ankle [1]–[6]. This need is covered by high-resolution CT (HRCT) [7] or nowadays even by ultra-high-resolution CT (UHRCT) [4].

Technological advances in the X-ray tube and X-ray detector, the main pillars of a CT system, increased the level of high-contrast spatial resolution step by step. Focal spot sizes were reduced down to very small sizes of 0.6 x 0.7 (IEC) for HRCT and 0.4 x 0.5 (IEC) for UHRCT [8]–[9]. Various vendors introduced X-ray tubes with focal spot deflection [10]–[11], which can improve the sampling rate in addition to the quarter detector offset. On another front, 3D anti-scatter grids replaced 2D versions. Detector pixel size decreased and channel density increased [12]. An attenuating comb filter can be optionally used in front of the detector to reduce the detector aperture, i.e., the effective detector pixel size [13].

Apart from the excellent high-contrast spatial resolution capabilities achieved through technical progress, today's scanners also have to meet other demanding challenges in high-resolution imaging – challenges like realizing the lowest possible radiation dose level, providing high flexibility, offering high versatility, and ensuring ease of use. In particular, the clinical workflow is increasingly important in the daily routine. This is where Precision Matrix comes into play. But what is Precision Matrix and how does it support clinicians and radiographers in high-resolution imaging with cutting-edge technology?

Role of matrix size in high-resolution imaging

High-contrast spatial resolution depends on various settings in CT imaging. Whereas built-in hardware components predefine the limits, the actual resolution within CT images is controlled via parameters freely selectable by the user. Use-related trade-off between spatial resolution and image noise level is an essential feature because requirements highly depend on the clinical case.

Control is mainly driven by selection of the reconstruction kernel. A huge variety of options to choose from is available: examples include bone kernels for fine high-contrast details, smooth kernels for low-contrast objects, as well as dedicated kernels for certain clinical applications (e.g., quantitative imaging). In addition to kernel selection, the size of the volumetric image pixel (voxel) plays an important role for image resolution. The in-plane size is determined by the displayed field of view (FoV) and the size of the reconstruction matrix. The reconstruction matrix is a two-dimensional matrix with a certain number of rows and columns. Typically, it is a square matrix with an equal number of rows and columns. In most CT scanners and clinical applications, the reconstruction matrix is fixed to 512 x 512 voxels ("512"). Sometimes smaller or larger matrices are available, like 1024 x 1024 voxels ("1024") or 768 x 768 voxels ("768").

What happens when the three identified parameters – reconstruction kernel, FoV, and reconstruction matrix – do not match? Three experiments based on a line pair high-resolution phantom (test module CTP528 of Catphan 600, The Phantom Laboratory, Salem, NY, USA) demonstrate the interaction between parameters and the perceived spatial resolution.

Two CT images are compared to each other in Experiment 1 (see Fig. 1); they differ in matrix size (512 vs. 1024) but share the same choice of reconstruction kernel (Br64) and FoV (300 mm). Why does one image show greater detail than the other? The answer is that the maximum resolution a 512 matrix can depict here is only 8.5 lp/cm. This is not sufficient compared to the 10.1 lp/cm at 50% resolving power (MTF) of the applied kernel. Structural details get lost as a result of the unmatched parameters, details that are supported by the imaging hardware and selected reconstruction kernel.

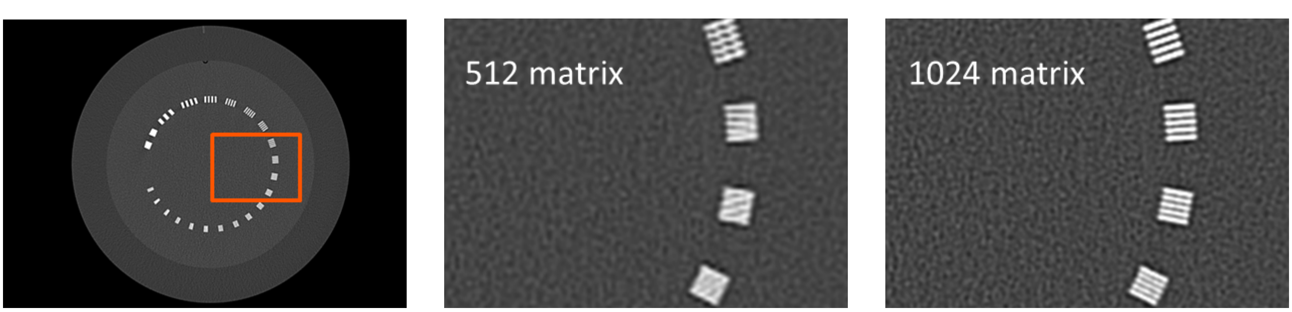


Fig. 1: Section from line pair high-contrast resolution phantom for kernel Br64 (50% MTF: 10.1 lp/cm), FoV of 300 mm, and different matrix sizes. Voxel size for 512 matrix is d = 300 mm / 512 = 0.59 mm and maximum spatial resolution that can be displayed is f_{max} = 10 mm/cm / (2/lp * d) = 8.5 lp/cm. For the 1024 matrix, f_{max} is 17 lp/cm.

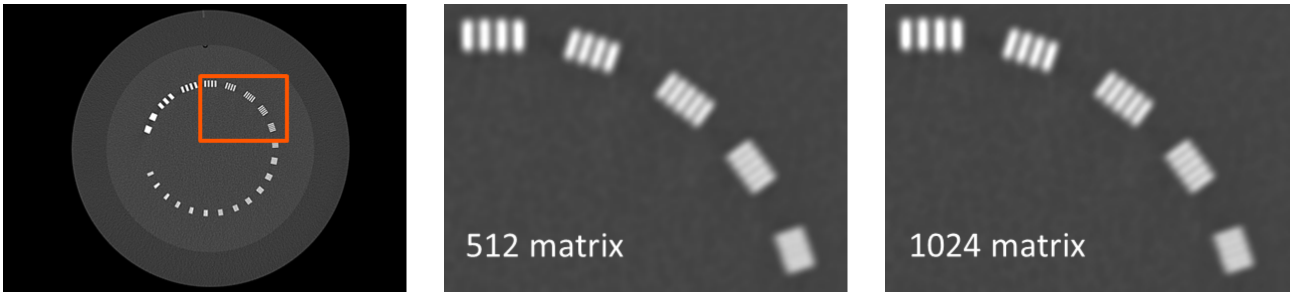


Fig. 2: Section from line pair high-contrast resolution phantom for kernel Br40 (50% MTF: 4.0 lp/cm), FoV of 300 mm, and different matrix sizes.

A similar setup is used in Experiment 2 (see Fig. 2), where both CT images are again based on joint kernel selection, however a smoother version (Br40) is chosen. Here, the two reconstructions do not show any noticeable difference. The reason is the limited resolution of the kernel with only 4.0 lp/cm at 50% MTF. This can already be properly represented by a 512 matrix.

In Experiment 3, two image reconstructions are compared to each other that again share the same sharp reconstruction kernel (Br64) but now also have the same voxel size. Therefore individual FoVs are used: 300 mm @ 1024 and 150 mm @ 512. No differences are evident between both images within the overlapping region (see Fig. 3). But here the 1024 matrix covers an area four times larger than the 512 matrix.

What are the lessons learned from these three experiments? An unmatched parameter selection can result in a loss of spatial resolution. In return, a larger matrix size may improve the resolution of CT images, but not in every case. One can alternatively adjust the FoV in order to achieve the same result, but larger matrix sizes enable coverage of larger FoVs at the same image quality. The respective workaround in high-resolution imaging is thus no longer needed, i.e., adding further image reconstructions with dedicated smaller FoVs. But at the same time one has to understand that system hardware remains the limiting factor of maximum resolution in CT imaging and this cannot be improved by introducing larger matrix sizes.

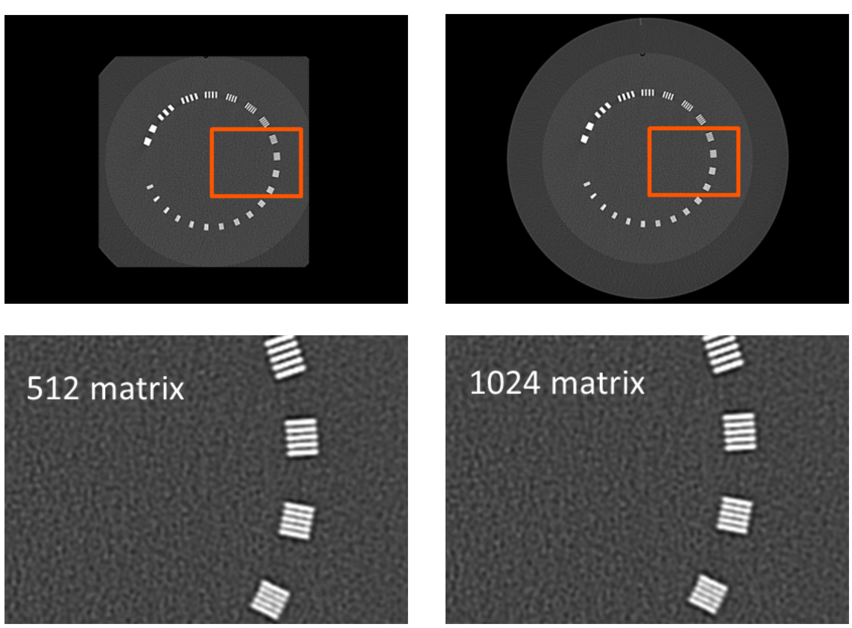


Fig. 3: Section from line pair high-contrast resolution phantom for kernel Br64 (50% MTF: 10.1 lp/cm), and same voxel size based on different pairs of FoV and matrix size (150 mm @ 512 vs. 300 mm @ 1024).

Why a larger matrix size is not always the best choice

Three experiments demonstrated that larger matrix sizes either outperform the standard 512 matrix in resolution and coverage or at least maintain its level of quality. Given the potential benefits, why not replace the standard matrix size in every case and perform all image reconstructions with the largest matrix size available?

Where there is light, there is shadow, and the advantages mentioned are countered by certain potential drawbacks. As an example, CT images increase in size by a factor of 4 when using a 1024 matrix instead of the standard 512. Still, assuming a use of 1024 matrix in only 10% of cases, 786 in 40% of cases, and the standard 512 otherwise, the storage capacity requirements on PACS and acquisition workplaces increase by 76% and double the image storage capacity required.

Another related problem is the fact that the reconstruction effort increases up to a factor of 4 when using a 1024 matrix. The actual factor will however be lower because operations in the projection space are not affected by the matrix size. Nevertheless, a noticeable increase in reconstruction effort has to be expected and needs to be offset with commensurate computational power in order to limit the impact on clinical workflow.

When a parameter selection induces a mismatch between FoV size and reconstruction kernel, a larger matrix size will increase the spatial resolution. But image noise level will increase simultaneously. In this case, the previous configuration should be checked. Was it intentional and, in fact, limited by standard matrix size? If not, it is obvious the reconstruction kernel can be adapted and does not need a larger matrix size with its previously mentioned drawbacks.

Last but not least, all applications that are applied for postprocessing and viewing of reconstructed images have to support larger matrix sizes. One needs to doublecheck the compatibility of the affected applications in advance, before applying a 1024 matrix.

In a nutshell: Whereas the reconstruction kernel and FoV have to be chosen based on clinical needs, the matrix size needs to be large enough to cover the spatial resolution of the kernel and simultaneously be as small as possible to limit demands on computational and storage resources. In addition, the matrix size has to be supported by the respective postprocessing and viewing applications.

Which matrix sizes are available with Precision Matrix and how to select them?

With the introduction of Precision Matrix, the user can now modify the matrix size to values beyond the standard 512. Possible choices are: 1024, 768, 512, and 256*. A respective combo box becomes part of the reconstruction tab via "Advanced reconstruction options" (see Fig. 4), next to the previously available iBHC and iMAR options. Matrix sizes can be independently chosen for each single image reconstruction. This applies to axial as well as 3D reconstructions using the same configuration option.

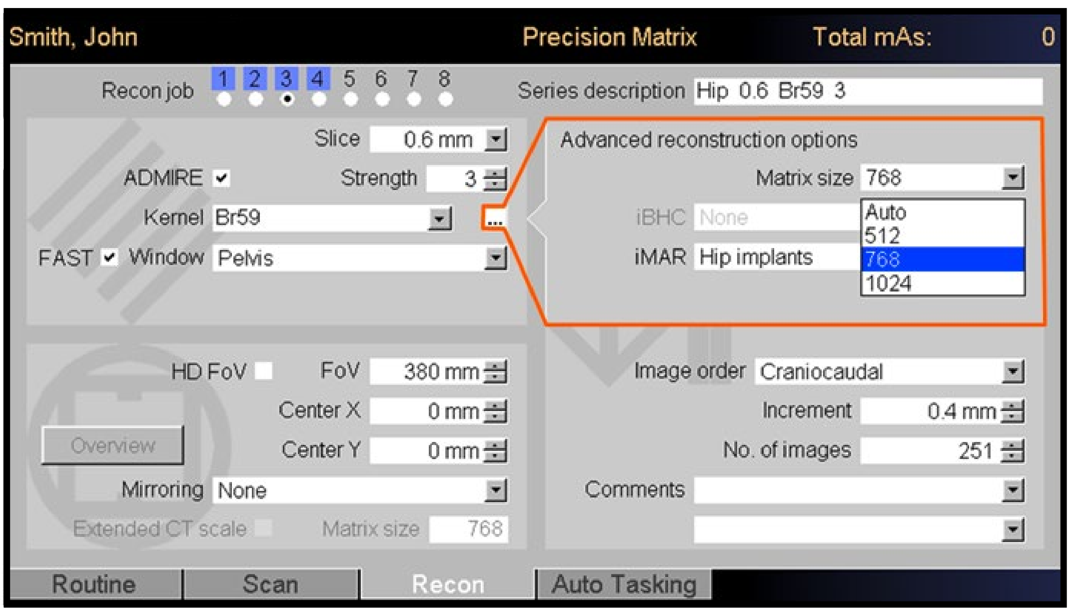


Fig. 4: Matrix size accessible via advanced reconstruction options of reconstruction tab.

For oblique reconstructions via 3D Recon, there is a second opportunity to alter matrix size: the 3D Graphical Reconstruction Planning (GRP) controls bar (see Fig. 5). Here, all sizes are available as square as well as non-square options. The largest aspect ratio of non-square matrixes is 1:8 for 256 and 1:4 for all other matrix sizes. Thus, CT reconstructions with a matrix up to 1024 x 4096 are now possible.

It is possible to limit the selection by setting an upper limit for matrix size within the Examination Configuration "Workflow" subtask card. The matrix size can also be pre-configured within the Scan Protocol Assistant, just as users are accustomed to from all the other scan and reconstruction parameters.

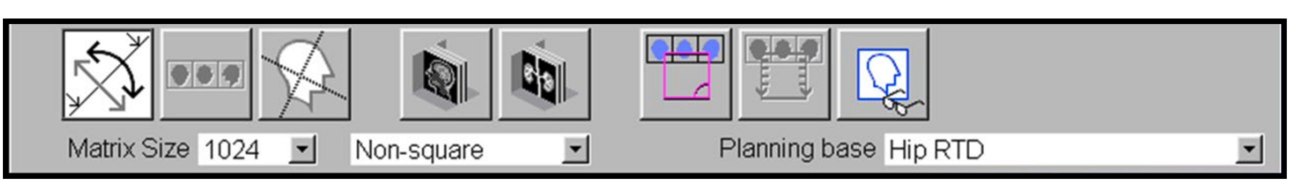


Fig. 5: Matrix size accessible via 3D GRP as a square as well as non-square option.

**Available in cardio protocols only* — *Available in cardio protocols only

And what if I need support to select the right matrix size?

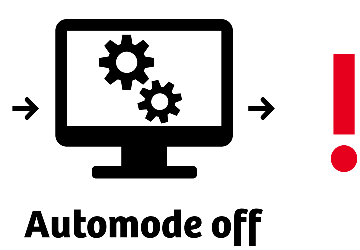
In addition to the manual selection of matrix sizes up to 1024, Precision Matrix also offers “Automode”. In order to activate this mode, the radiographer just has to select “Auto”. But why does Precision Matrix include Automode and how does it work?

There are so many degrees of freedom when it comes to reconstruction parameters. A large number of reconstruction kernels are provided to cover the huge variety of clinical tasks; the FoV can be automatically adapted to patient size in every single case, e.g., via FAST 3D, and different organ characteristics include optimized settings for imaging different body parts, to name just a few examples. Almost each individual clinical case has its own setting. And the matrix size depends on the above-mentioned parameters and more. The optimal choice may require verification for every patient. It will be difficult for radiographers to choose the right matrix size for every clinical question and patient as well as to establish consistency among all staff members (see Fig 6).

Parameters to be considered

- Scan protocol
- Field of view
- Reconstruction kernel
- Reconstruction method
- Matrix size

- Image size
- Reconstruction effort



Manual entry
Correlated parameters

Potential pitfalls without Automode

Scenario 1:
matrix size too large

- No additional image visualization improvement
- Reconstruction effort too great
- Image size too big

Scenario 2:
matrix size not large enough

- Potential image visualization improvement missed
- Potential additional reconstruction needed (e.g., with a different FoV)

Fig. 6: Parameters to be taken into account and potential pitfalls when matrix size is entered manually.

For this reason, Precision Matrix offers Automode, which takes the burden from the radiographer. This mode considers different variables like sharpness of reconstruction kernel, FoV size, reconstruction effort, amount of image data, and a list of available matrix sizes (see Fig. 7). Automode provides as output the best matrix size that maintains the sharpness of the reconstruction kernel within the final CT image while minimizing reconstruction effort and image data size. In other words, it selects the proper matrix size in order to allow for the requested spatial resolution at the lowest costs. By default, the list of available matrix sizes includes the values 512, 768, and 1024. It is possible to limit the selection by setting an upper limit for matrix size within the Examination Configuration “Workflow” subtask card. This setting will be valid for both Automode and manual selection.

The spatial properties of the reconstruction kernel, chosen by the user, are converted into a minimum required voxel size, potentially taking further parameters into account like organ characteristics or reconstruction method. Depending on the requested minimum voxel size, one gets several thresholds. FoV sizes below such a threshold include voxel sizes smaller than or equal to the requested one. For sizes above the threshold, a larger matrix size is needed. The FoV size, selected by the user, is then compared with those thresholds in order to get the optimal matrix size. Two examples are shown in Fig. 8, which shows the threshold's dependency on requested voxel size and the optimal matrix size for respective FoV ranges.

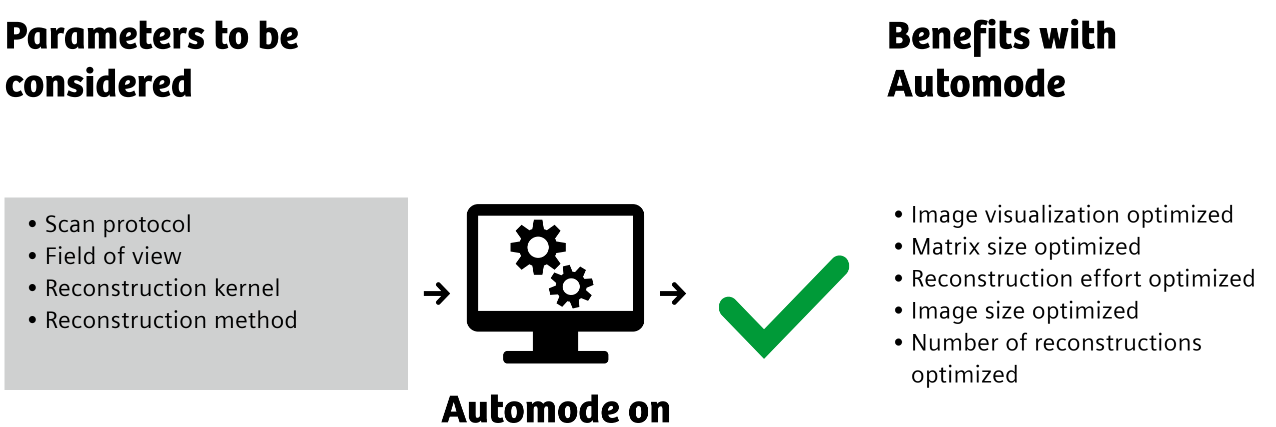


Fig. 7: Automode considers several variables to select the proper configuration.

Let's take another look at the experiments from the previous section. The standard 512 matrix was not sufficient for the first experiment and image details that were visible with 1024 matrix were lost. What happens when we apply Automode? The mode recognizes that the standard matrix size is insufficient but selects 768 and not 1024. The reason: 768 matrix is sufficient to cover the same level of detail as 1024 matrix, but with a lower computational and storage burden (see Fig. 9). In Experiment 2, Automode selects the standard 512 matrix because it is already sufficient for smooth kernels. Different FoV sizes can lead to different matrix sizes, as shown in Experiment 3. There, Automode selects 512 for 150 mm FoV and 768 for 300 mm FoV.

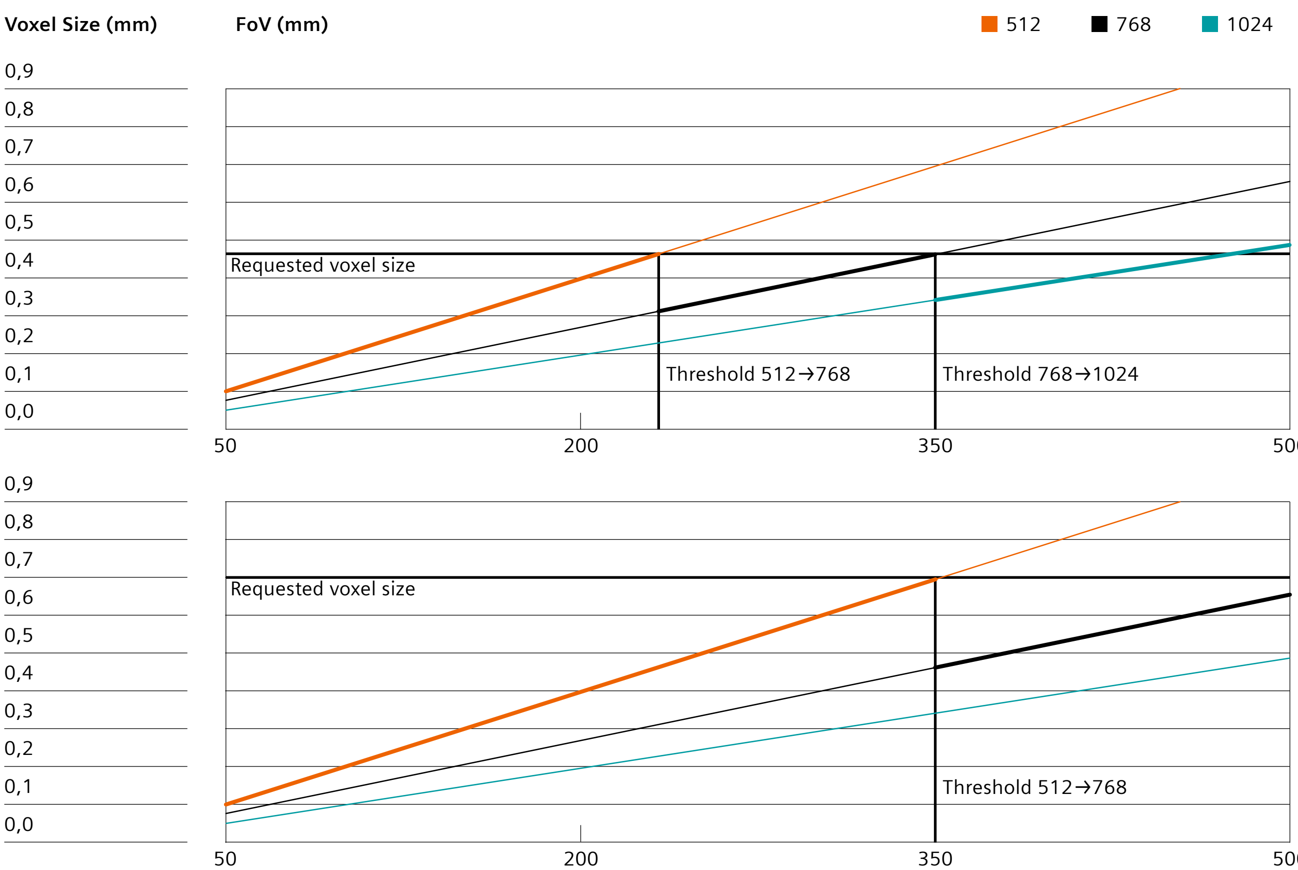


Fig. 8: Optimal matrix size for each requested voxel size.

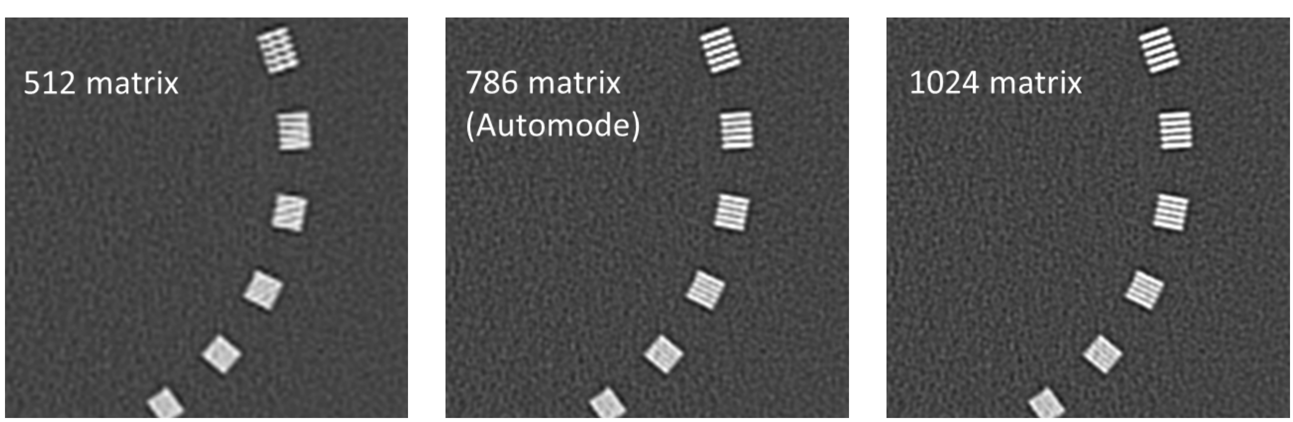


Fig. 9: Matrix size of 786 is the right choice, which Automode made as well.

Additional factors to be considered in high-resolution imaging

Maximum resolution can only be achieved when everything fits together, with or without Precision Matrix. Therefore, it is necessary to pay particular attention to acquisition settings for high-resolution imaging. Besides spatial resolution, temporal resolution is one of the main contributors particularly in chest imaging. Limitations in temporal resolution can deteriorate image quality by artifacts induced through breathing or cardiac motion. Ultra-fast data acquisition is an essential technique to reduce motion artifacts especially when patients are not able to hold their breath. Turbo Flash mode on Dual Source CT scanners, for example, increases diagnostic confidence and improves assessability of vascular and bronchial structures compared to standard pitch breath-hold acquisition for detection of pulmonary embolism [14].

High spatial resolution is always accompanied by a high level of image noise that nonetheless should not affect diagnostic confidence. In addition to iterative reconstruction methods to reduce noise, one should always exploit the full potential on the acquisition side. This includes patient size-dependent tube voltage selection such as provided by CARE kV and 10 kV Steps, or spectra dedicated to high-contrast imaging such as those available on SOMATOM® CT scanners with Tin Filter.

Clinical cases

Precision Matrix with matrix sizes up to 1024 can improve clinical workflow where sharp kernels are required and a large FoV has to be covered. What are clinical questions and examples that combine these two requirements of high spatial resolution in a large region of interest? For bilateral hip replacements, it is important to cover the entire pelvis and to apply bone kernels, e.g., to measure acetabular cup placement or assess osteolysis when the possibility of revision arthroplasty needs to be evaluated. The same applies for acute care where whole-body bone CT scans are conducted to detect missed bone injuries in polytrauma patients. Sharp kernels and a large FoV including the entire rib cage are used in high-resolution chest imaging. These are just some examples, and they become even more challenging in obese patients.

A clinical example from chest imaging is shown in Fig. 10: a 42-year-old female with pulmonary fibrosis and emphysema in the lower lobes. Here, Turbo Flash mode acquisition was conducted with a total scan time of 616 ms to avoid any motion artifacts. In addition, Tin Filter was applied to achieve the low radiation dose level of 2.02 mGy. For this case, axial views that share all reconstruction parameters except the matrix size are compared to each other (see Fig. 11). The section covering the entire chest (top row) does not reveal any difference. But the details in the zoomed version from the same image (bottom row) reveal clear differences visible in resolution. With the standard 512 matrix, an additional reconstruction and dataset may be required with a dedicated smaller FoV to reacquire the level of detail that the 1024 matrix already provides.

SOMATOM Force

Scan time: 616 ms
Scan length: 315 mm

Sn150 kV

CTDI$_{vol}$: 2.02 mGy
DLP: 76.63 mGy cm

Fig. 10: Acquisition parameters and coronal MPR in a sample chest imaging case.
Courtesy of Hôpital Albert Calmette, Lille, France.

Another example is shown in (Fig. 12). An 81-year-old with bilateral hip replacement; taken from a chest-abdominal-pelvic scan (120 kV, scan time 4.9 s, scan range 579 mm, CTDI$_{vol}$ 10.84 mGy, DLP 678.21 mGy cm). Here two kinds of artifacts are present in the default reconstruction. Metal artifacts emerging from the hip implants deteriorate image quality and have to be addressed by a metal artifact reduction technique like iMAR [15]. In addition, stair-step artifacts are clearly visible at the edges of bony and metal structures due to the limited resolving power of the standard 512 matrix for such a large FoV including both hip implants. The larger matrix size provided by Precision Matrix plus metal artifact reduction by iMAR can substantially improve image quality and allow evaluations on just a single reconstruction. Without Precision Matrix, dedicated FoVs are needed, e.g., one for each implant to get the same image quality.

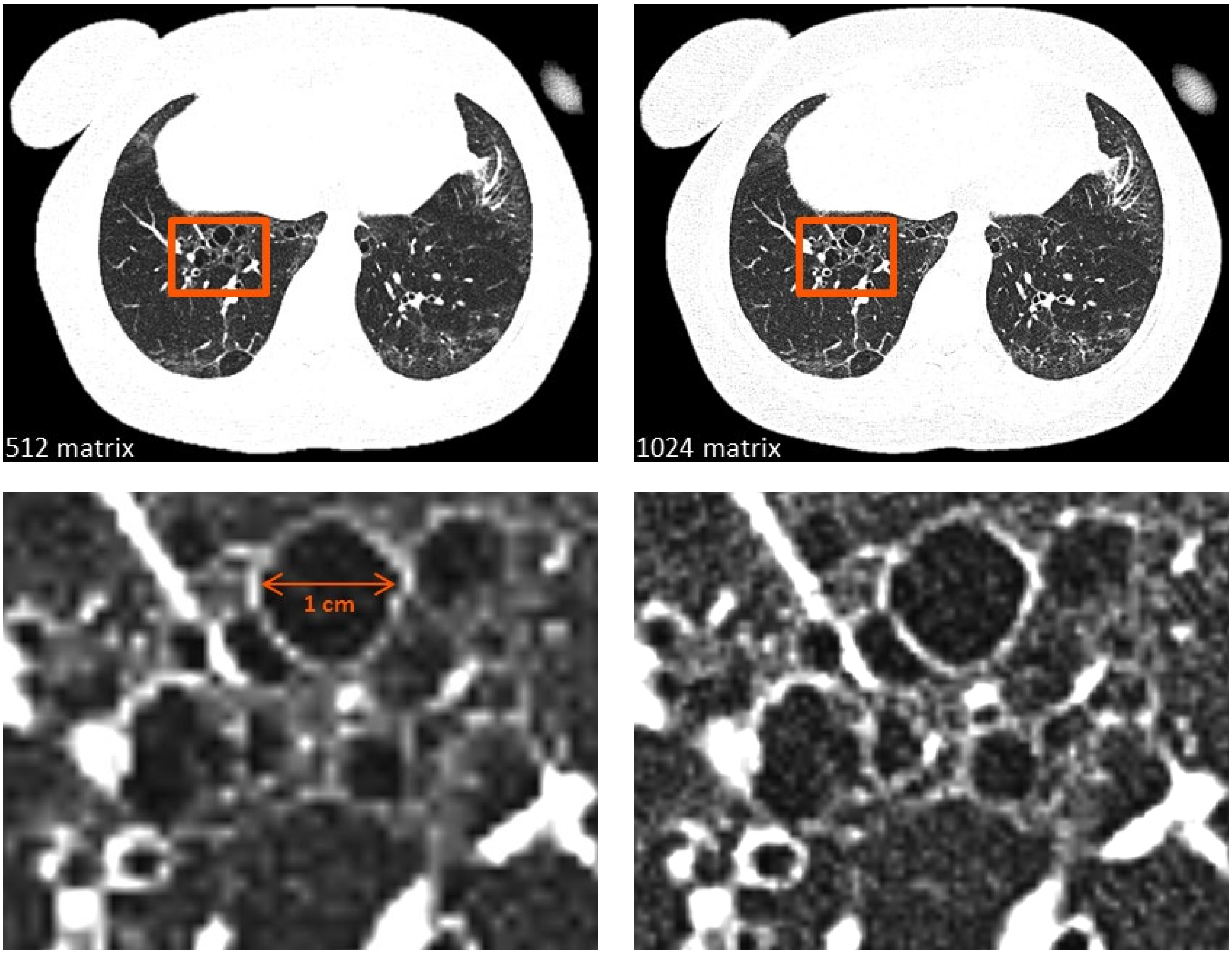


Fig. 11: Axial views for 512 matrix (left) and 1024 matrix (right). Reconstruction parameters: Bl64, ADMIRE level 3, and max. FoV. Courtesy of Hôpital Albert Calmette, Lille, France.

Large matrix sizes provided by Precision Matrix can ease clinical workflow and allow creating just a single dataset that covers the entire region of interest with the level of detail needed independent of patient size and resulting FoV size. Also of interest are details that do not change the diagnosis but increase confidence through the clear presentation of the finest structures in every patient.

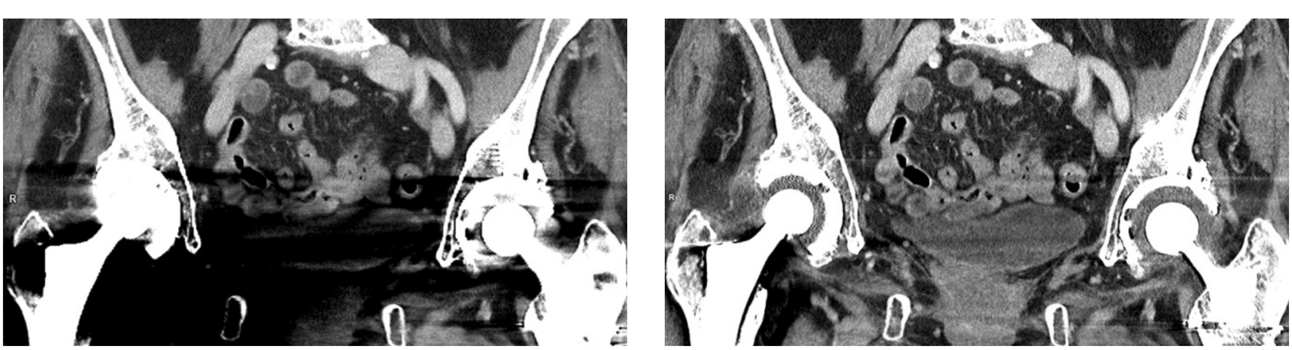


Fig. 12: Coronal views for 512 matrix without iMAR (left) and 1024 matrix with iMAR (right). Reconstruction parameters: Br59, ADMIRE level 5, and 460 mm FoV. Courtesy of Hôpital Albert Calmette, Lille, France.

Combine forces

When it comes to high-resolution imaging, SOMATOM® Force offers the latest technologies and thus prominent characteristics: outstanding spatial resolution provided by Vectron™ X-ray tubes with the smallest available focal spot size of 0.4 x 0.5 (IEC), 3D anti-scatter grid, Stellar^Infinity detectors, unparalleled and unbeaten native temporal resolution driven by Dual Source technology and a rotation time of 250 ms, the fastest acquisition speed of up to 737 mm/s available with Turbo Flash mode, exceptionally fast reconstruction with up to 70 images/s for iterative reconstruction at standard matrix size, and personalized radiation dose reduction via Tin Filter or 10 kV Steps. This unique imaging chain enables sharp and contrast-rich images for every patient at high speed and low dose. The variety of advanced technological features is now complemented by Precision Matrix to improve workflow performance and unlock the full power of SOMATOM® Force.

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