SIEMENS

White Paper

Biograph mCT Flow: PET Technical and Clinical Advances with FlowMotion Technology

Answers for life.

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Introduction

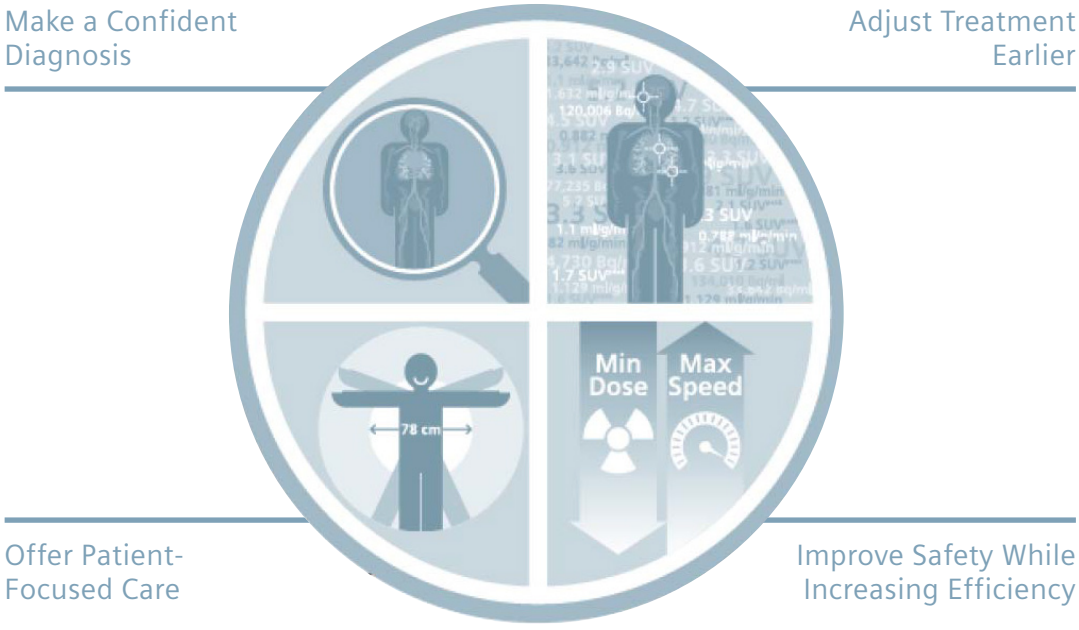
Rapid adoption and growth of PET imaging has been based on its unique ability to image biological processes. Oncology in particular, with applications for staging, radiation therapy planning and therapy monitoring, has benefited from the high sensitivity and quantification that is unique to PET. Several recent advances have further improved PET's ability to both detect and monitor tumors including extended axial field of view (TrueV), respiratory motion management (HD.Chest) and improved quality control and quantification (Quanti.QC). However, until now, PET examinations have been performed in sequential bed positions, alternating between acquisition and patient table motion. As such, planning and scanning have always been restricted by the fixed size of the detector array. Therefore, the inherent complexity of stop and go scanning may have limited the routine use of the above mentioned advanced PET/CT imaging
technology, and often resulted in higher dose, greater patient anxiety, lower efficiency and the potential for patient motion and related image degradation. This paper introduces yet another advancement from Siemens towards overcoming the limitations of stop and go and enabling further improvements: FlowMotion™.
PET/CT oncology studies typically require a long patient axial range to be scanned (e.g., eyes to thighs). Since conventional PET cameras have less than 22 cm axial field of view (FOV), combining multiple bed acquisitions (called "stop and go") has become the standard for whole body acquisitions. While the stop and go acquisition has incrementally improved over the years, challenges still remain such as optimizing the bed overlap, improving the corrections applied to the data and developing an efficient and patient-centric scan planning interface.

FlowMotion technology is a major revolutionary step for PET acquisition. FlowMotion works by continuously moving the patient through the PET FOV – similar to the motion patients experience during a CT scan – and has the following major benefits over stop and go:

- **Finest Detail in Every Organ***
  Easy, patient-centric planning of the acquisitions enables precise organ imaging based on a patient's unique anatomy and clinical indications supporting improved image quality
- **Accurate Quantification in All Dimensions**
  Decreased axial noise variance positively impacts SUV_{max} quantification
- **Minimum Dose and Maximum Speed**
  CT-like organ-based planning and scanning may result in lower dose to patient and faster workflow
- **Open Comfort for All Patients****
  The continuous sense of scan progress enables increased patient comfort during the acquisition

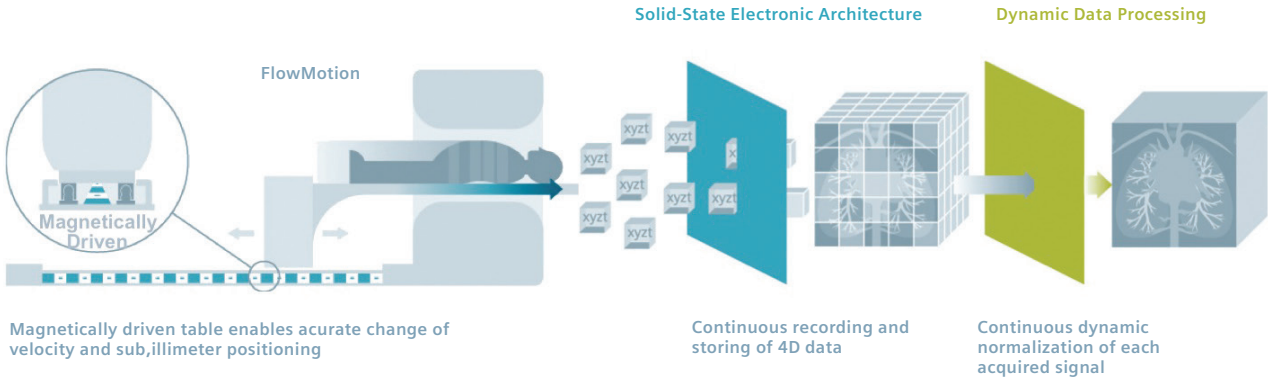
Therefore, the FlowMotion benefits offer PET/CT imaging sites an efficient and patient-centric way to plan the scan, improve image quality, lower the CT dose and improve the patient experience during the PET scan. All these benefits contribute to the best exploitation of the finite scan time such that tumor detectability is further optimized based on a specific patient's needs.

This paper explains the technologies behind FlowMotion on the Biograph™ mCT Flow and shows phantom and clinical studies illustrating the advantages of using it in routine clinical practice.



* Based on volumetric resolution of 87 mm^3. Based on competitive literature available at time of publication. Data on file.
** Patients up to 227 kg (500 lb).

Figure 1. *An overview of the FlowMotion technology: from the patented patient bed to the development of specialized dynamic data processing, all innovations were necessary to make FlowMotion a reality.*



FlowMotion Technology

Different from conventional stop and go bed motion, FlowMotion offers a continuous movement of the patient bed, eliminating the need for overlapping bed positions and interval bed travel between static acquisitions of discrete bed positions.

From creating novel acquisition mechanics that feature a precise, magnetically driven patient table to modernizing the acquisition electronics and new data processing algorithms, every aspect of the Biograph mCT Flow was designed to realize the benefits that only FlowMotion scanning can provide (see Figure 1).

Patient Bed

Traditionally, PET/CT has relied on belt-driven CT tables to move the patient through the axial FOV, resulting in delayed velocity response and imprecise, multi-axis deflection. The multi-axis deflection of the bed can affect both the registration between the PET and CT images and the resolution of the PET image itself if the deflection is not corrected during data processing. Therefore, traditional tables may not be able to provide the high level of accuracy required for continuous scanning achieved with FlowMotion.

FlowMotion in the Biograph mCT Flow scanner builds on the Siemens patented SMART Patient Handling System (PHS) technology. The SMART PHS contains a horizontal magnetic drive system that enables an accurate change of table velocity, as well as continuous motion with a positioning accuracy of <0.25 mm. The velocity range of the Biograph mCT Flow bed is 0.1 to 200 mm/s–sufficient to cover both the PET and CT needs. Utilizing the magnetic drive system, the bed can be accelerated smoothly at rates as high as 200 mm/s^2. Also, due to the magnetic drive, the bed is "clutchless" – which further makes for a smoother patient experience and easier manual positioning for technicians when needed.

The bed's unique cantilever design eliminates differential deflection as the table travels through the gantry, as compared to traditional beds that have multiple vertical support systems as the bed moves into the scanner. The vertical and horizontal bed movements are completely independent–making patient positioning more efficient. Similar to CT acquisitions, FlowMotion now tracks the bed position in real time and stores this information in the listmode data file–the same file that contains the raw PET data (e.g., prompts, singles, randoms, etc.). The extra bed position information is then utilized during the data processing, assuring that the final reconstructed image contains the correct position information.

Finally, FlowMotion can take advantage of all of the integrated patient bed features. The optional radiation therapy pallet, the integrated physiological cable management and the patient I.V. pole features all work seamlessly with FlowMotion.

Redesigned Acquisition Electronics

Acquiring a continuous stream of counts required Siemens to design a new electronic architecture built on ultra-fast, solid-state components capable of continuously recording and storing detector addresses, as well as sub-second timing information. The acquisition electronics were re-architected to improve performance, reliability and serviceability. A new PETLINK™ Stream Buffer (PSB)[1] was designed to support higher rates of data acquisition. The PSB directly connects via SATA2 interfaces with new and very fast solid state drives (SSDs)–storing up to a total of 30 billion coincidence events.[2]

The solid-state technology forms an embedded RAID data storage system. A key aspect of this architecture is that this SSD RAID is isolated from the operating system environment running on the acquisition computer. With this isolation comes a critical functionality gain: the real-time storage of the raw PET detector-pair coincidence-event data is given the highest priority. This means that the detector-pair coincidence-event data are safely acquired at high rates and are never at risk of loss because of too many operations running on the acquisition computer.

In addition, this embedded RAID approach provides sufficient extra bandwidth for rapid output of the just-stored data–even while the acquisition is proceeding. This output is critical in that it enables the generation of projection data (sinograms) simultaneously with the data acquisition. Therefore, the reconstruction time of the final whole body image is not compromised.[3]

Finally, the horizontal bed position reporting is automatically incorporated within the stream of detector-pair coincidence-event data stored onto the SSD RAID. This bed position reporting ensures correct and proper generation of projection data in real time.

The SSDs use the latest monitoring protocol S.M.A.R.T. (Self-Monitoring Analysis and Reporting Technology) to report their status and send alerts when issues are encountered. The new acquisition control system (ACS) is a state-of-the-art computer with more memory (64 GByte) and faster CPUs (two 3.3 GHz CPUs with 4 cores each) which allows more tasks to be done quicker and more reliably. Finally, all of the components individually report their status to Siemens Service enabling a proactive service for reduced downtime of the scanner.

New Dynamic Data Processing Algorithms

Two major innovations were required to process FlowMotion data due to the continuous patient movement during acquisition[4]:
- virtual LOR-based normalization
- new randoms smoothing algorithm

Scan-Specific Normalization

Normalization of the data is performed to account for efficiency differences of the PET detectors. While FlowMotion uses the same daily quality control/normalization procedures to calculate the detector efficiency coefficients, the normalization algorithm was modified for the special case of FlowMotion to be scan-specific. During a stop and go acquisition, a line of response (LOR) is defined to be a physical LOR–which is the line between two crystals that detect coincidence events. During a FlowMotion acquisition, the concept of a virtual LOR is needed, which is the summation of the physical LORs as the activity moves through the scanner (see Figure 2 and Figure 3).

The first academic prototype of a continuously moving bed during a PET acquisition assumed that the normalization coefficients were uniform across all of the projection data segments[5], and the geometrical and detection efficiencies were averaged over the axial length of the scanner. FlowMotion accounts for the dynamic nature of the normalization coefficients including:
- the decaying activity as it moves across the detectors
- the fact that a given patient region can spend a different amount of time in the various physical LORs
- the dead-time correction is a function of time since the detector singles rate is constantly changing

All of the above factors mean that each FlowMotion virtual LOR will have a unique normalization coefficient which must be calculated from knowledge of the table position in the axial FOV.

These events will accumulate in the virtual LORs as the patient moves through the scanner. The Poisson variable summation law can be used to determine the efficiency of the accumulated counts in the virtual LORs. Therefore, the final efficiency (normalization coefficient) is the summation of the single event efficiencies.

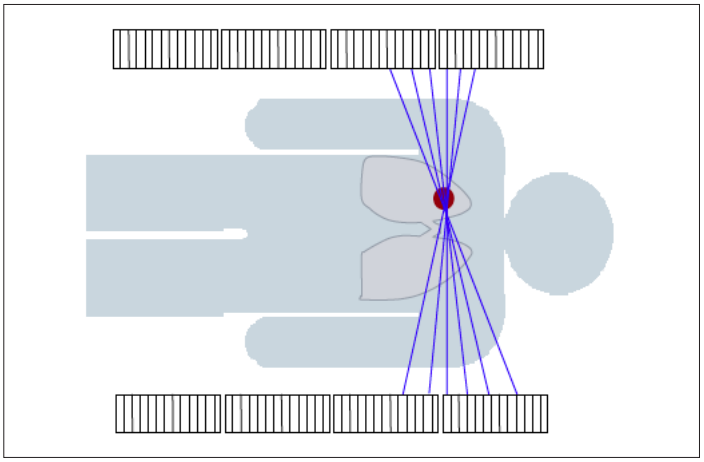


Figure 2. *In a conventional stop and go scan, a tumor (shown in red in figure above) is detected by a limited number of detectors (blue lines represent physical LORs).*

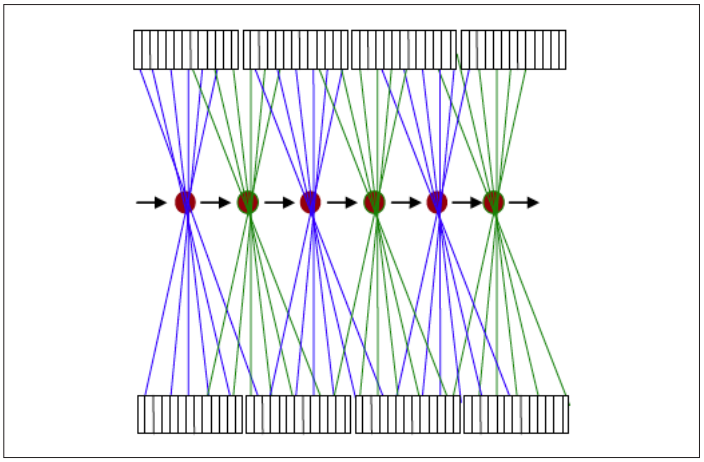


Figure 3. *FlowMotion technology enables the tumor activity to be detected by significantly more detectors (i.e., physical LORs, blue and green lines), leading to improved axial noise uniformity. Only the tumor movement is shown in this figure for simplicity reasons. Note that the number of counts acquired with FlowMotion would not be greater than with stop and go, but the counts are spread across more physical LORs. Knowing the bed position, the physical LORs are combined into virtual LORs such that they can be reconstructed into the final image.*

New Randoms Smoothing Algorithm

The PET acquisition data are corrupted by random events which need to be estimated and smoothed during reconstruction. The scanner acquires separate randoms data which can have a significant noise level depending on the amount of activity inside of the scanner. The expected randoms data is typically modeled by estimating the crystal singles rate.[6] The FlowMotion acquisition significantly complicated the relationship between the mean randoms data rate and the detector singles rate for two reasons. First, summation over all detectors in the axial direction is performed, and second, the singles rate is not constant and is a function of time due to the various activity levels of the patient as it passes through the scanner. Therefore, direct estimation of the singles from the measured randoms data is a complicated task.

To overcome the above complications, the assumption was made that a randoms data de-noising effect can be achieved by decomposing each data plane's randoms into transverse efficiencies. Such efficiencies model the detector efficiencies (detector edge efficiency is lower as compared to the central part) and geometrical effect, when the singles distribution is varying due to differences in attenuation. Randoms decomposition is performed plane by plane in the sinogram domain, based on an algorithm by Panin.[6] Due to the nature of FlowMotion, one can assume that randoms data should be smooth in the axial direction in the sinogram segment. This provides an additional opportunity to smooth the mean randoms estimation in the axial direction, leading once again to decreased noise variance in the axial direction of the reconstructed image.

Converting Static Bed Acquisition Times to Bed Velocity

Due to the revolutionary step of going from stop and go to FlowMotion, a transition period is expected until the user gains experience and confidence in this new technology.

Table 1 may serve as an aid in converting static bed acquisition times into velocities. Using the theory behind FlowMotion technology,[4] and validating experimentally, Table 1 and Table 2 were generated to match stop and go minutes per bed acquisition times to FlowMotion bed velocity, for equivalent counts per plane at the axial center of the scans.

Resolution Recovery Comparison – NEMA IQ Phantom

A ^{68}Ge-filled NEMA IQ phantom[7] with 2.1 mCi of activity and a hot sphere to background ratio between 1.0 and 3.87 was imaged using both stop and go and FlowMotion acquisition protocols. The two largest sphere inserts were filled with air. Both acquisitions covered a 254 mm axial FOV, which meant two bed positions were used for the stop and go protocol. The stop and go data were acquired using 108 s/bed position and the FlowMotion data with a bed velocity of 0.8 mm/s. Figure 4 shows a comparison of the images, and Table 3 shows the comparison of the calculated recovery coefficients. No statistically significant differences were found between the recovery coefficients, which was expected since the phantom was placed in the center of the FOV of the PET camera (i.e., there was no activity near the end planes).

Stop and Go Acquisition Time (min/bed)	Flow Bed Velocity (mm/s)
1:00	1.5
1:48	0.8
2:00	0.7
2:30	0.6
3:00	0.5
4:00	0.4
5:00	0.3
6:00	0.2
10:00	0.1

Table 1. *Stop and go min/bed acquisition times mapped to FlowMotion bed velocity to achieve equivalent image quality for the Biograph mCT Flow*

Stop and Go Acquisition Time (min/bed)	Flow Bed Velocity (mm/s)
1:00	2.1
1:48	1.2
2:00	1.1
2:48	0.8
3:00	0.7
4:00	0.5
5:00	0.4
8:00	0.3
10:00	0.2

Table 2. *Stop and go min/bed acquisition times mapped to FlowMotion bed velocity to achieve equivalent image quality for the Biograph mCT Flow with TrueV option*

Figure 4. *Transverse images through the sphere inserts of the NEMA IQ phantom. The image on the left was reconstructed from data acquired using the stop and go acquisition, and the image on the right using FlowMotion acquisition. See Table 3 for the list of calculated recovery coefficients.*

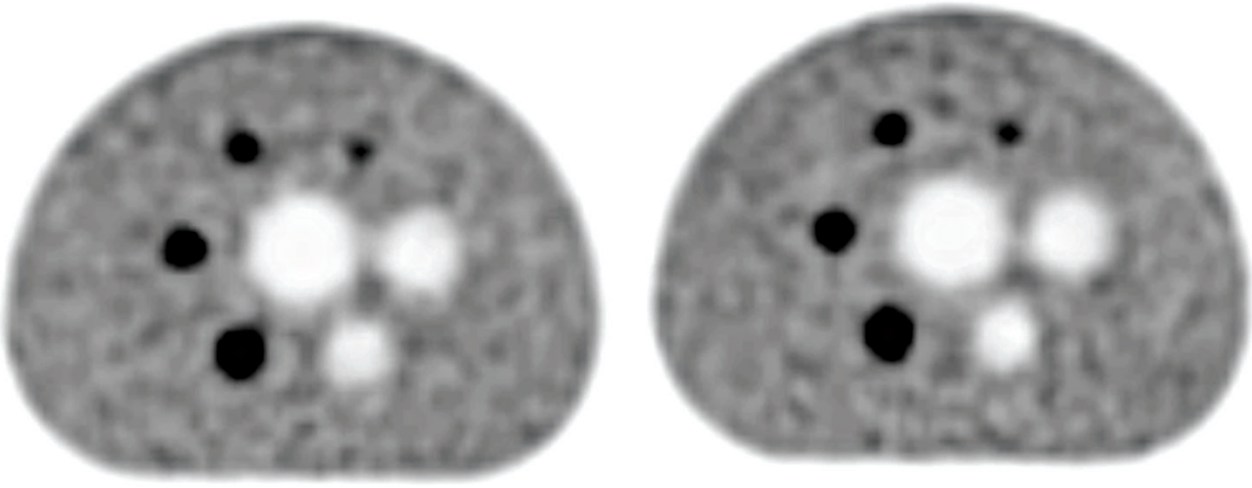
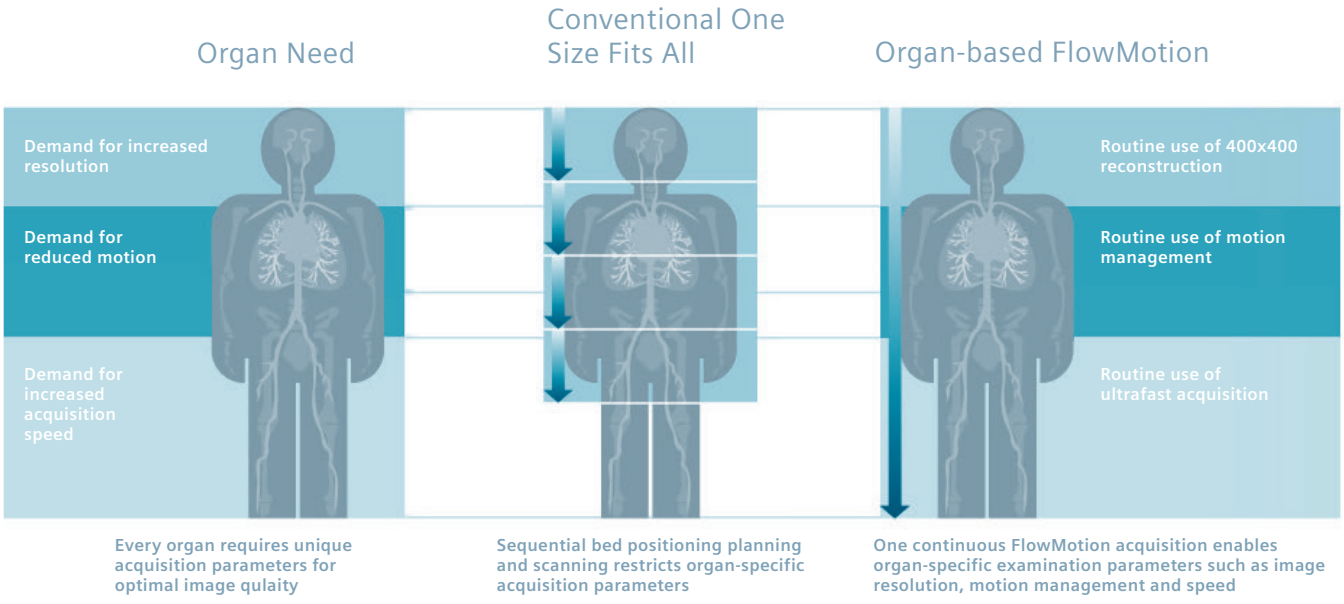


Table 3. *Comparison of the recovery coefficients of stop and go and FlowMotion acquisitions for the NEMA IQ phantom for the data shown in Figure 4. Note that the FlowMotion acquisition gave very similar and, in general, slightly better recovery coefficients than stop and go.*

Sphere Size (mm)	Stop and go	FlowMotion	Delta (%)
10 (hot)	18.0	20.3	12.8
13 (hot)	35.9	38.5	7.2
17 (hot)	59.6	57.1	-4.2
22 (hot)	65.7	66.1	0.6
28 (cold)	62.8	66.1	5.3
37 (cold)	68.2	69.2	1.5

Figure 5. *FlowMotion incorporates flexible yet easy to set up acquisition protocols in any range with the ability to define smaller acquisition ranges with slower continuous table speed for higher count statistics. This enables higher image matrix resolution reconstructions as well as longer acquisitions with the standard image matrix resolution and optimum acquisition speed for the rest of the body.*



Easy Patient-centric Acquisition Enables Precise Organ Image Quality

PET/CT imaging has traditionally used the protocol of planning the CT range and PET bed positions for stop and go with a CT topogram followed by a whole-body spiral CT study and finishing with the PET acquisition.

In stop and go acquisitions, although acquisition times for single bed positions on some more advanced PET/CT scanners can be varied according to the clinical need, there is limited flexibility due to the discrete nature of bed positioning. Dynamic or gated list mode acquisitions have extra technical limitations and are often required to be performed separately. As a result, the best image quality and efficiency that could be obtained for each region of interest is often not achieved due to settings dictated by discrete bed positions rather than patient and disease requirements. Please see Figure 5 for a visual illustration as to why the FlowMotion planning is a more natural and efficient way to plan a PET scan as compared to stop and go.

For example, in patients with head and neck cancer, FlowMotion enables high image matrix (400x400) resolution imaging in the head and neck, followed by normal image matrix (200x200) resolution imaging in the rest of the body, with faster acquisition in the pelvis and extremities which are of limited importance as compared to soft tissue metastatic sites in head and neck cancer.

Similarly, in lung carcinoma with significant respiratory motion and the possibility of brain metastases, a gated acquisition incorporating a longer acquisition time for higher count statistics can be performed in a specific range including the lungs and the diaphragm as an integral part of the whole-body FlowMotion acquisition, as well as a high resolution brain image with 400x400 matrix size reconstruction. The optimal gated (HD•Chest) image can be interpreted along with conventional static reconstructions for optimized evaluation of tumor size and intensity of uptake and Standard Uptake Value (SUV), while the 400x400 brain image can be analyzed for the possibility of metastatic lesions in the brain which may impact the treatment strategy for the patient.

User Interface

The user interface (UI) for planning the scan is simple with clean graphics (Figure 6). A single bed speed (one region) can be defined, or up to four distinct regions, each with a different bed speed, can also be configured easily and quickly by entering the desired bed speed in the color-matched table (Figure 7).

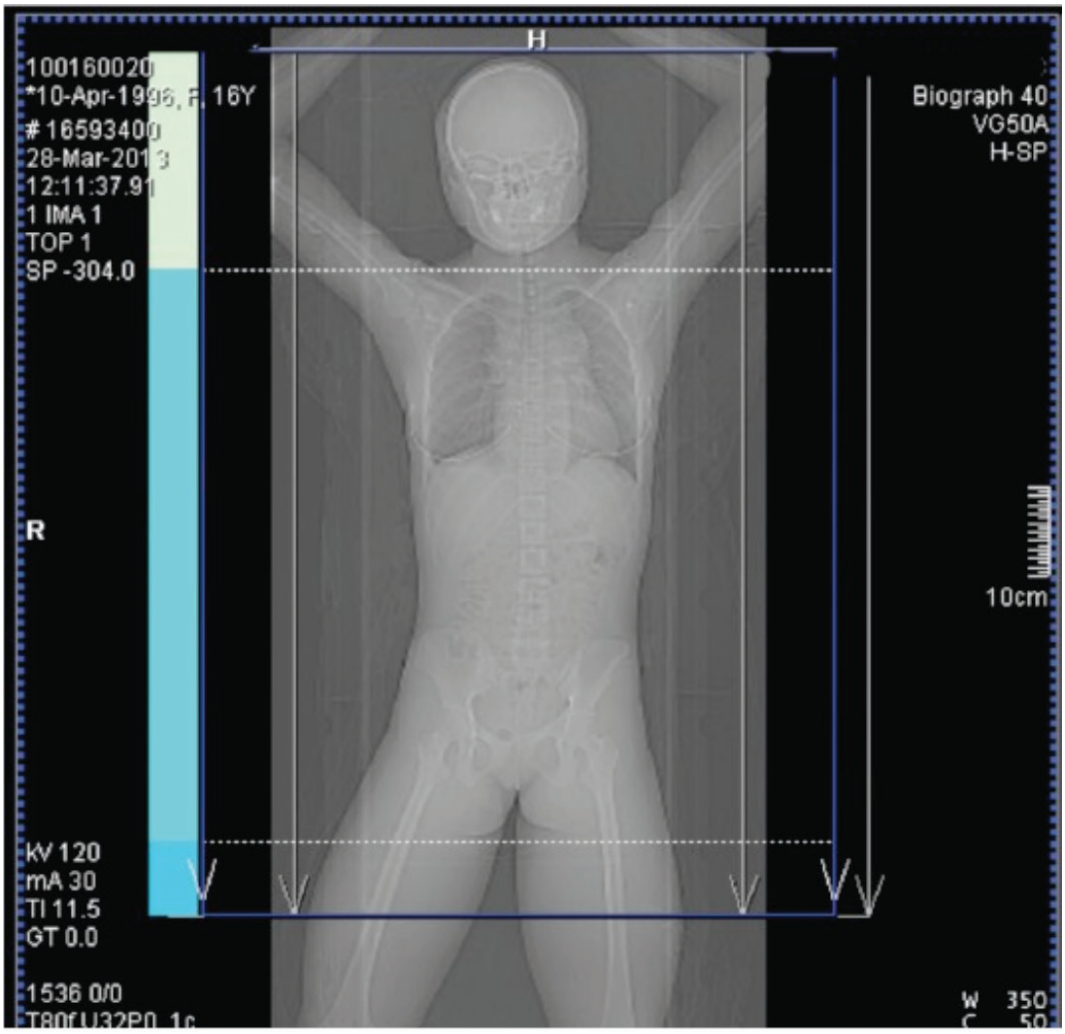


Figure 6. *FlowMotion acquisition planning user interface. The blue rectangle can be exactly repositioned to change scan start region (near top of head) and end region (scan direction is craniocaudal in this case). The rectangle will not "snap" to the next bed position as is the case for step and shoot.*

Data courtesy of University of Tennessee Medical Center, Knoxville, Tennessee, USA.

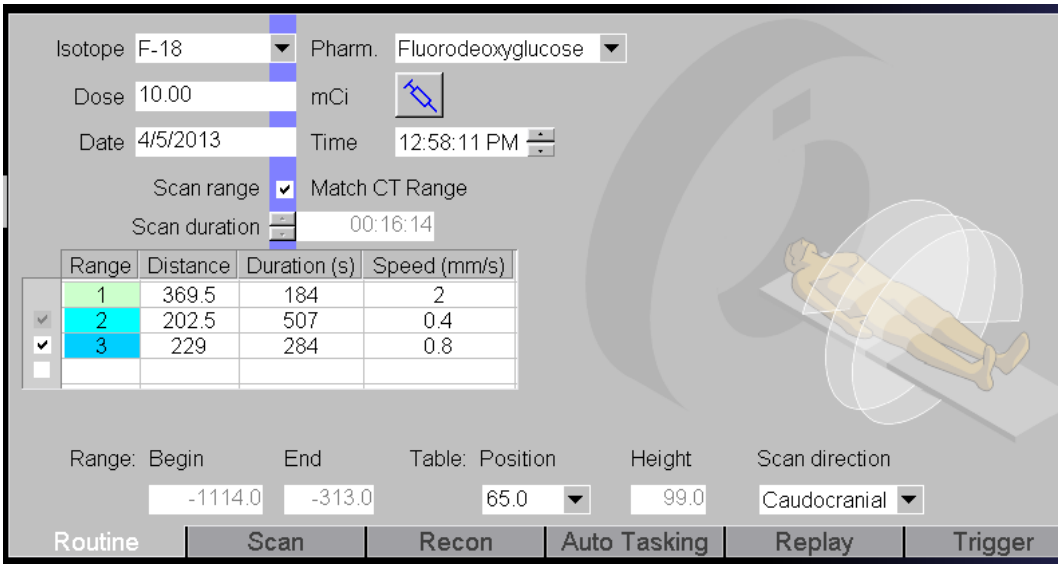
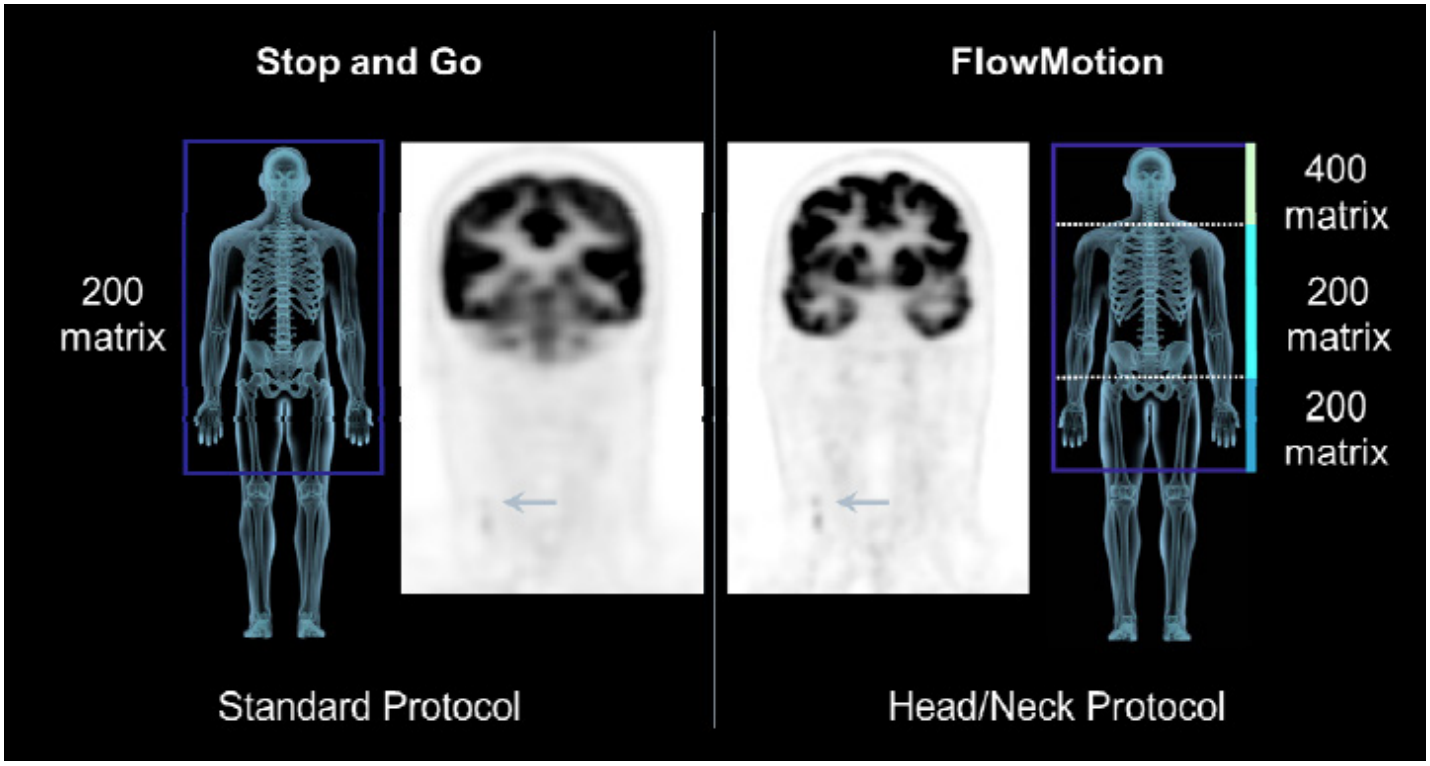


Figure 7. *The operator simply types in the desired bed speed for the three regions (up to four can be specified). Note the color coding on the left of the table which matches the regions on the topogram above.*

Figure 8. *Coronal whole body images were reconstructed at 200x200 matrix with separately reconstructed head and neck region (400x400 matrix) using the same FlowMotion data. Small hypermetabolic neck node metastases are visualized with improved clarity and lower partial volume effect with the 400x400 versus 200x200 matrix reconstruction (arrows).*
Data courtesy University of Michigan, Ann Arbor, Michigan, USA.

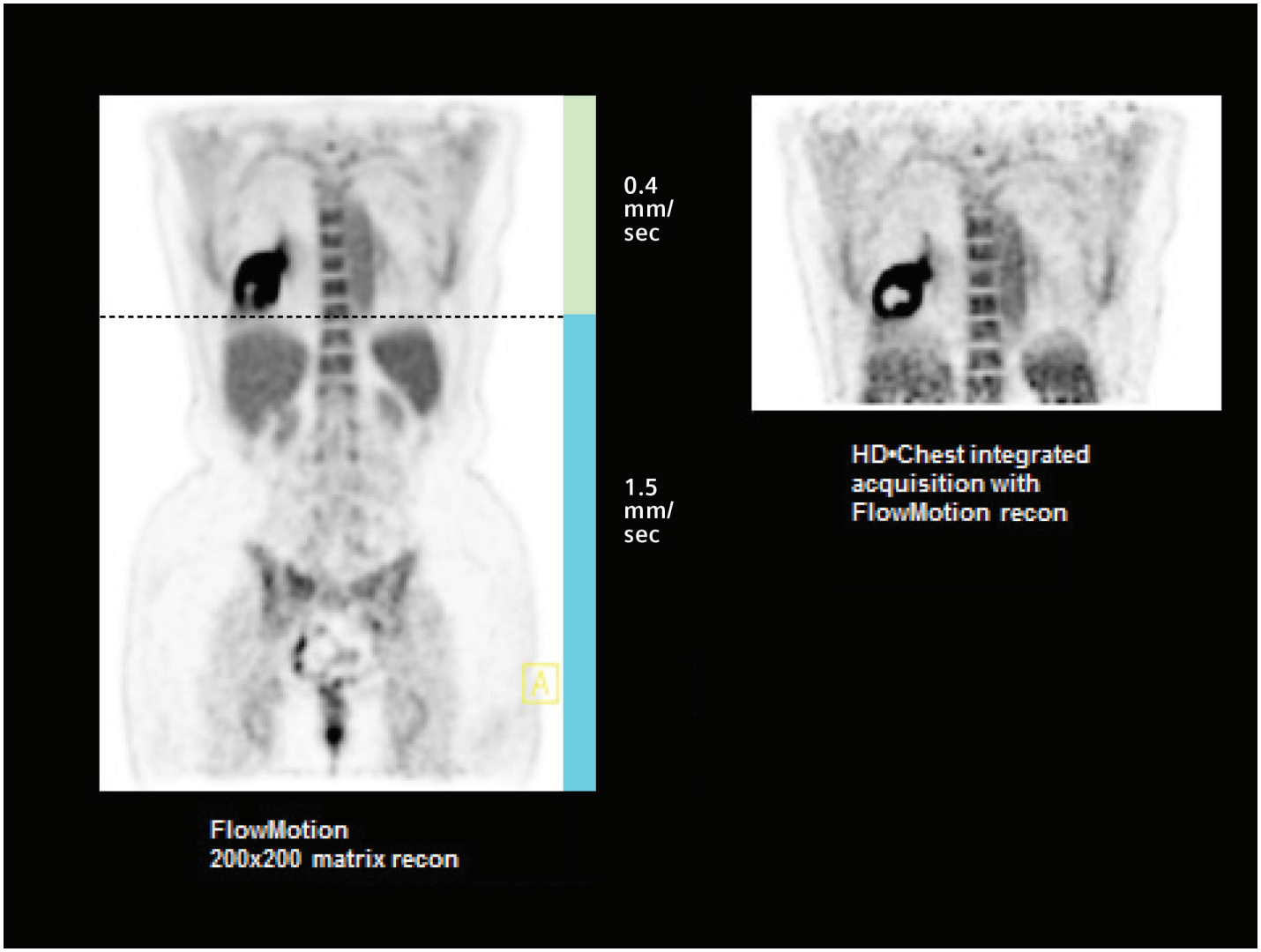


Clinical Case Studies

Figure 8 shows a clinically optimized scan of a patient with operated thyroid carcinoma with neck nodal metastases. The higher matrix reconstruction is performed over part of the extended FlowMotion scan range with slower table travel speed (0.4 mm/s) as compared to the other anatomical regions (1.0 mm/s in chest and abdomen and 2.0 mm/s in legs). This enables higher count statistics for higher matrix reconstruction where clinicians need it the most for optimized tumor detectability.

Integrated respiratory gated acquisition as a part of the whole-body FlowMotion acquisition–without the need for a separate single bed position gated acquisition–is another key workflow advantage of FlowMotion. In the clinical example shown in Figure 9, the gated acquisition performed in the thorax as a part of the integrated FlowMotion acquisition is displayed separately as an optimal gated HD•Chest image which shows the data with the least respiratory motion for sharper definition of liver margins and moving lesions. In this particular case, the hypointense central necrotic region of the tumor was much more sharply defined in the HD•Chest image (see right side of Figure 9).

Figure 9. *Whole-body FlowMotion acquisition with integrated respiratory gated motion management acquisition of the thorax in a 72-year-old 150 lb. female patient. The separately reconstructed HD•Chest image of the thorax (right) is displayed along with the standard wholebody reconstruction (left). Note the sharper definition of the margins of the necrotic center of the lung mass in the HD•Chest image.*
Data courtesy of University of Tennessee, Knoxville, Tennessee, USA.



More Uniform and Decreased Axial Noise Variance Positively Impacts SUV_{max} Quantification

FlowMotion inherently benefits from a more uniform axial noise variance due to the fact that almost all of the LORs in the PET scanner see all of the activity of the object as it moves through the scanner (see Figure 2 and Figure 3). Consequently, there are additional signal averaging effects as compared to stop and go. It is important to note that the variance or noise level also depends on the bed velocity as well as the variable attenuation from the differences in anatomy.

The clinical examples shown in Figure 8 and Figure 9 are – from a statistical point of view–trying to make the axial noise variance more uniform by scanning longer in more attenuated regions (i.e., thorax) and shorter in less attenuated regions (i.e., legs). Decreasing the variance can lead to increased detectability of tumors.[8] Hence, the clinical need to scan longer in the thorax region; every possible advantage should be applied to not miss small tumors.

In addition, FlowMotion has automatic end plane compensation at the beginning and the end of the acquisition. This improves the end plane sensitivity with the final result being improved end plane image quality which may impact significantly the SUV_{max} values in these planes. It is important to note that this feature is built into the FlowMotion acquisition protocol with no need for the operator to enable or adjust it. The automated nature of this feature enables reproducibility from scan to scan limiting inter-user variability.

Automatic End Plane Compensation

The stop and go approach makes an overlap in bed positions necessary to compensate for the decline in count sensitivity towards the ends of the detector ring. However, the first and last bed positions lack this compensation. This may result in lower count sensitivity and, ultimately, higher noise, compromising quantitative accuracy and reproducibility.

With FlowMotion, the scan automatically starts before the specified start point and ends after the defined scan range to intelligently ensure near-uniform sensitivity throughout the scan range. The built-in PET scan range extension (the CT scan range is not extended in order to limit radiation dose) is the innovation behind the reduced axial noise resulting in the "edge-to-edge" image quality (IQ) improvements of FlowMotion. To illustrate this, an ^{18}F homogenous cylinder was scanned and reconstructed using both stop and go and FlowMotion acquisitions (see Figures 10 and 11). Also note that there is no significant difference in the mean and standard deviation near the center of the phantom between FlowMotion and stop and go, verifying Table 1 and Table 2.

The results of Figure 11 emphasize that FlowMotion and stop and go will have equivalent image quality at the center of the reconstructed FOV, which means that the amount of counts in the center portion of both scans are essentially equivalent. FlowMotion–due to intelligent range extension and decreased axial noise–does demonstrate reproducible and improved image quality in the end planes which may significantly impact the SUV_{max} values for these planes (see Figure 12).

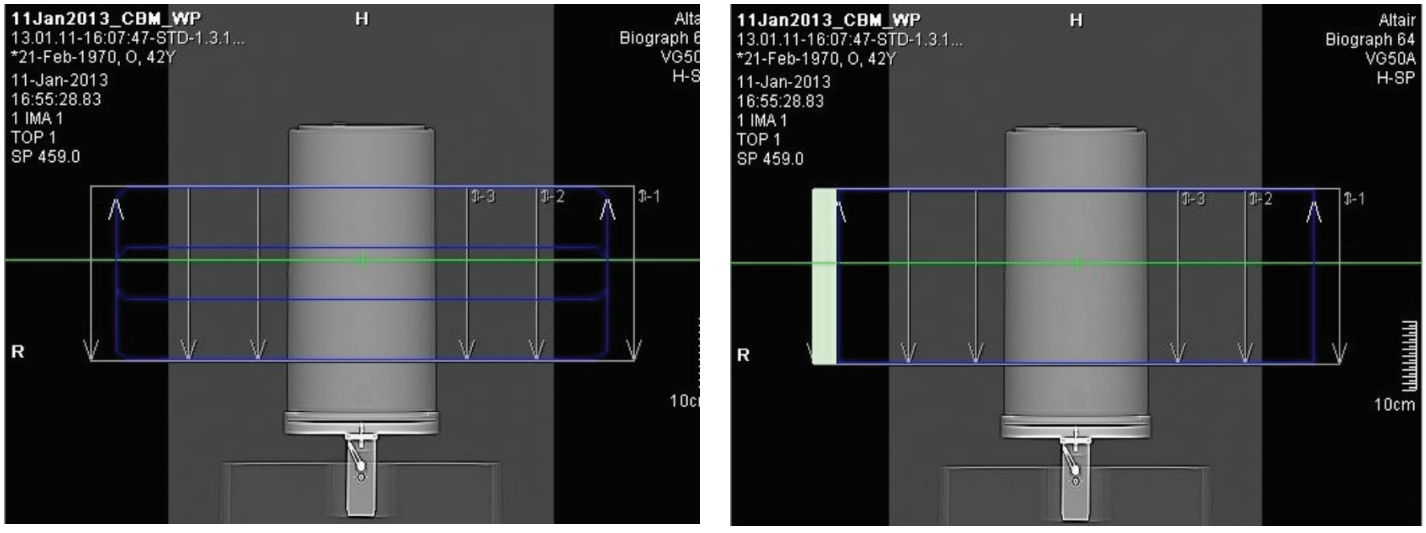
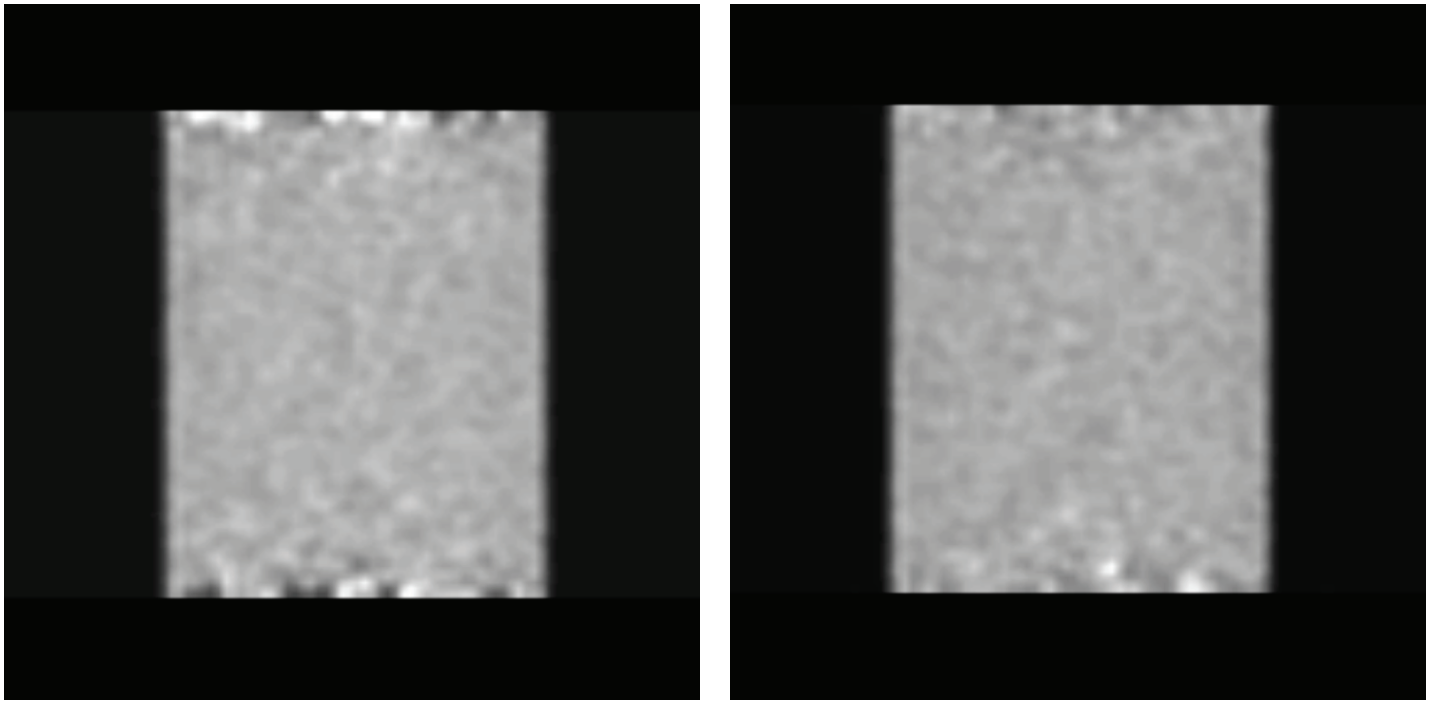


Figure 10. *Acquisition planning of an ^{18}F homogenous cylinder: 254 mm or 2 bed positions for stop and go. The stop and go planning is on the left and the FlowMotion is on the right. Note the cleaner planning interface for FlowMotion planning.*

Figure 11. *Coronal plane of the truncated cylinder shown in Figure 10. Left is the stop and go acquisition and right is the FlowMotion acquisition. Note that visually, the end planes of the stop and go data seem noisier.*



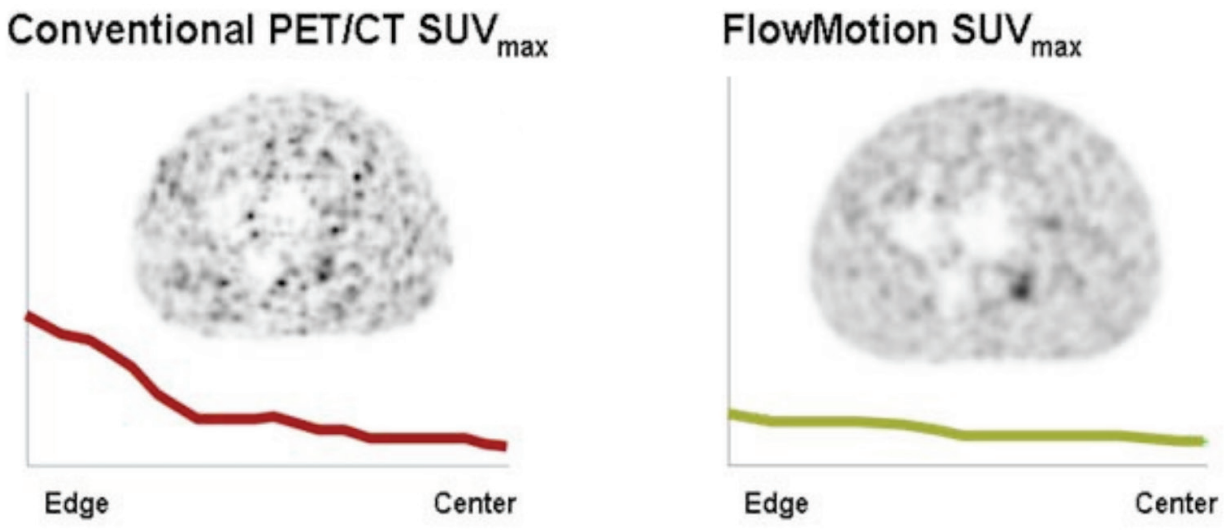
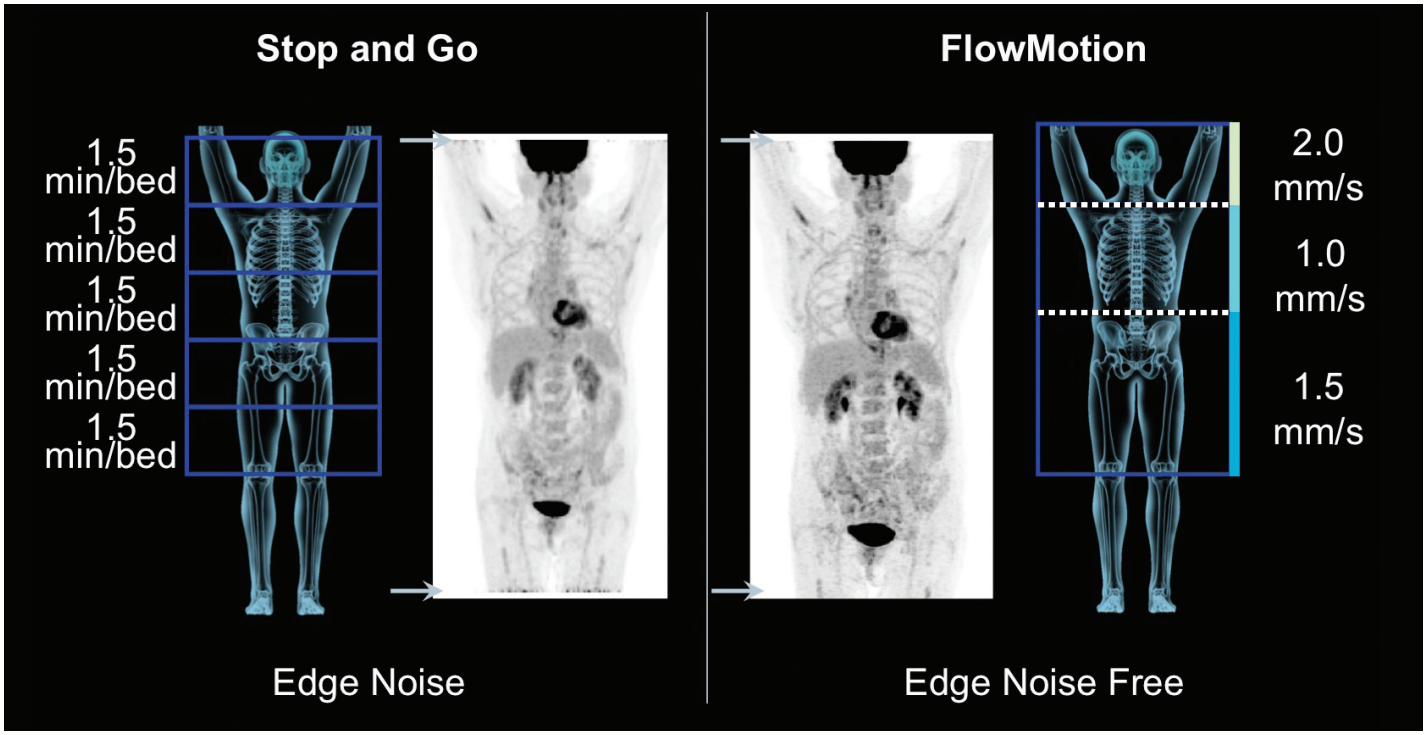


Figure 12. *The NEMA IQ phantom described above was placed near the edge of the axial FOV of the scanner and data were acquired using both protocols such that the image quality at the center of the axial FOV was equivalent. The graph on the left depicts the SUV_{max} plotted from the end plane to the center plane for a homogenous region of the phantom for the stop and go acquisition, and the graph on the right depicits the same data for the FlowMotion acquisition. Note the consistency of the FlowMotion SUV_{max} curve, especially near the end planes. The end slice for each acquisition is shown in the upper right of the respective graph. Note the striking difference in image quality.*

Figure 13. *MIP images a post-therapy follow-up ^{18}F FDG PET/CT study acquired with stop and go (left) and FlowMotion (right) of a patient with lung carcinoma treated with chemoradiation. Increased noise is visualized at the edge of the acquisition at the level of the extended arm and mid-thigh seen on the stop and go image (arrows on both images) and is not visualized on the FlowMotion image.*
Data courtesy of University of Tennessee, Knoxville, Tennessee, USA.



Clinical Images

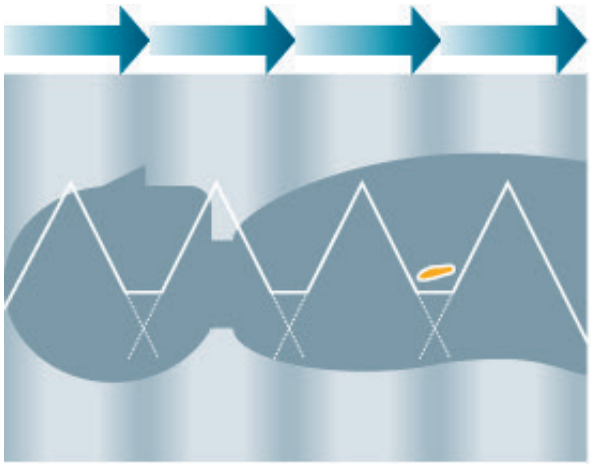
Figure 13 above shows the difference in end plane image quality from a patient study.

No Bed Overlap Optimization Needed

Since discrete bed positions are no longer needed, the question of what is the optimal bed overlap that some vendors require the operator to select is no longer an issue with FlowMotion. The left side of Figure 14 illustrates a case where minimal bed overlap was chosen in a stop and go scan, which could potentially decrease the detectability of small tumors if they happen to fall in one of these low sensitivity regions. FlowMotion eliminates this variable and it works automatically for all patient sizes (right side of Figure 14).

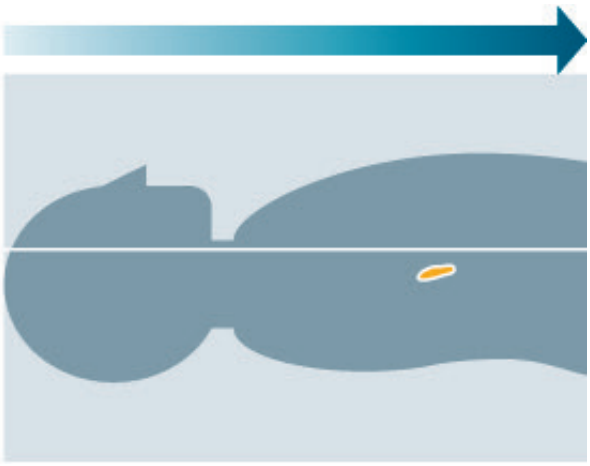
Figure 14. *Noise sensitivity profile exhibited by the white line in the illustration of stop and go versus FlowMotion. Automated scan range optimization for uniform noise sensitivity enables quantitative accuracy in all dimensions.*

Conventional Stop and go



Insufficient overlap of sequential bed acquisitions may cause varying noise sensitivity, resulting in viability and quantitative measurements

FlowMotion



Uniform noise sensitivity enables quantitative accuracy in all dimensions

Precise CT-like Organ-based Planning and Scanning Enables Lower CT Dose to Patients

Because CT is used for attenuation correction, the scan length must exactly match the length of the PET range. As well as for accurate PET quantification, technologists must cover the same range with CT as with PET. This may force the technologist to extend the CT acquisition by an entire PET axial bed length to match the PET scan range. In some situations, such additional CT range scanning may lead to unnecessary radiation exposure. FlowMotion has the ability to define the precise scan range requirement without it being determined by individual bed positions (Figure 15).

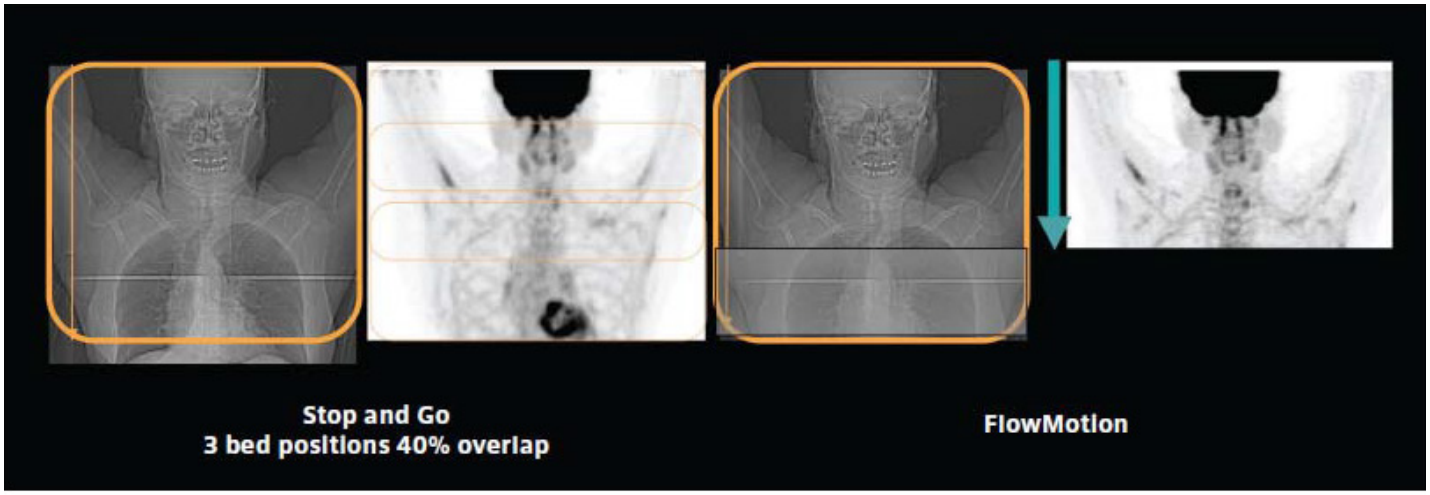
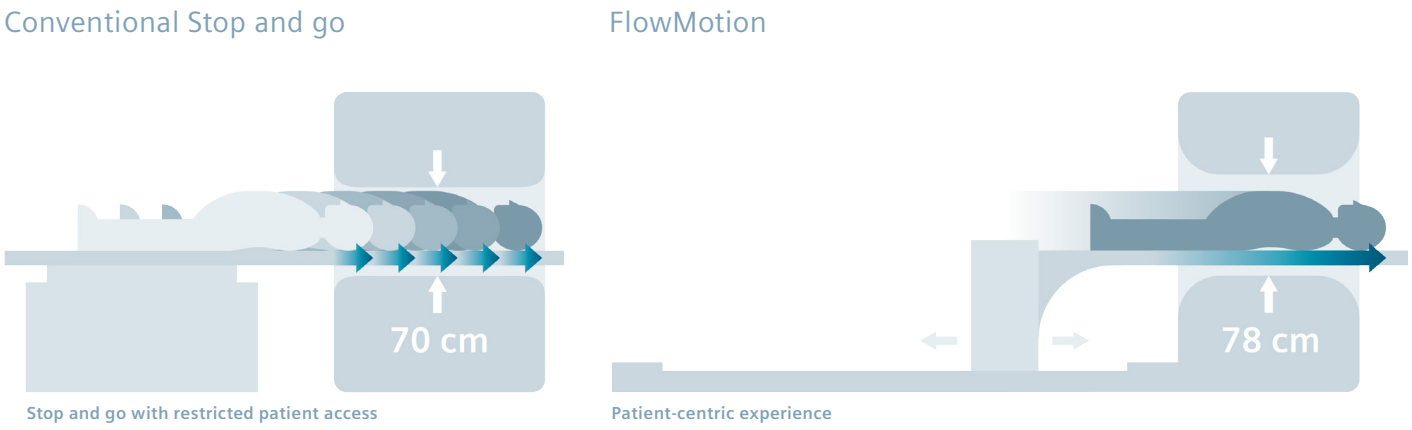


Figure 15. *On the left side, planning and scanning in sequential bed positions requires the PETand CT acquisition to expose an area beyond what is needed. With precise CT-like organ-based planning and scanning as shown on the right side, FlowMotion targets only the desired range.*
Data courtesy of University of Tennessee, Knoxville, Tennessee, USA.

Figure 16. *Positive patient perceptions induced by magnetically driven table and open bore gantry design versus conventional designs.*



The Continuous Sense of Scan Progress Enables Increased Patient Comfort During Acquisition

Another key concern in PET imaging is patient anxiety and cooperation. Conventional stop and go acquisitions have limitations in this area since they require a combination of static acquisition with sudden table motion from one bed position to another (see Figure 16). This pattern of table motion creates two undesired patient perceptions: the lack of motion may be interpreted as lack of scan progress with resulting anxiety, and the sudden table motion may be seen as an indication of the end of the scan. Both can result in patient motion, causing either artifacts or, if severe enough, a rescan which adds to scan time and patient radiation dose since the CT may also need to be reacquired.

FlowMotion addresses these aspects with a continuous bed motion similar to that of the CT scan, although at a slower pace. FlowMotion may also eliminate the need for continuous patient instruction to prevent surprise associated with table movement.

Patient comfort is an aspect of the exam that is sometimes overlooked. However, research in this area has found that patient experience and memories of unpleasant medical procedures influence their decisions about future treatment choices.[9] This effect has been studied in the fields of mammography[10], dentistry[11], cardiology[12] and colonoscopy[13], with comparable findings. The number of patients refusing to return for subsequent treatments based on a painful first experience ranges from 10% in dentistry to 20% in mammography, 40% in cardiology and 50% in colonoscopy.

As a consequence, the patient experience may impact patient volume, depending on the ratio of follow-up exams to first time exams. In PET oncology, follow-up scans typically account for 60% of exams and patient satisfaction should, therefore, not be neglected. The patient perception of the examination can be positively influenced by taking into account that the formation of memories is imperfect and susceptible to bias. Studies found that the objective duration of an experience has less influence on how pleasant an experience is rated (duration neglect) compared to noticeable events during and at the conclusion of the experience (peak and end effect).[14] The dominating aspect to focus on in PET/CT examinations should, therefore, be the perception of exam duration and sense of progress.

Table 4. *Perceived scan duration and patient preferences for FlowMotion vs. stop and go*

n=11 patients	Percieved duration			FlowMotion comfort level					Patient preference		
	FlowMotion percieved duration	Stop and go perceived duration	Perceieved difference	Very anxious	Somewhat anxious	Neutral	Somewhat relaxed	Very relaxed	FlowMotion	Stop and go	Indifferent
1	5	5	0				X			X	
2	5	10	-5				X		X		
3	10	10	0				X				X
4	10	5	5					X		X	
5	10	25	-15					X	X		
6	10	15	-5				X		X		
7	15	15	0		X				X		
8	10	15	-5				X		X		
9	15	10	5					X		X	
10	5	10	-5				X				X
11	5	5	0					X	X		
	Average: 9.1 min	Average: 11.4 min	Average: -2.3 min	0 (0%)	1 (9%)	0 (0%)	6 (55%)	4 (36%)	6 (55%)	3 (27%)	2 (18%)

The effects guiding cognitive processing and the perception of time have been investigated with similar conclusions in the fields of medicine, economics, advertising, and human computer interaction. The passage of time is usually not perceived linearly. Conn introduced the concept of the 'time tolerance window', which is the maximum length of time a person is willing to wait before deciding a task is not making adequate progress.[15] Chris, et al have investigated the influence of acceleration, deceleration and pauses on the human perception of progress with the aim to design user feedback that makes progress appear faster while the objective duration remains unchanged. The study investigated multiple progress functions, ranging from decelerating to linear and accelerating both with and without pauses at various stages. The study found that participants consistently rated progress functions with pauses as taking longer to complete (peak effect). Secondly, accelerating progress was strongly favored. Both factors had an exaggerated effect when located towards the end of the process (end effect). The paper concludes that participants have strong aversions to pauses and prefer a sense of rapid conclusion towards the end of an experience.[16]

Applying these findings to PET exams, it can be expected that patients perceive the scan duration as shorter if the pauses in stop and go acquisition are eliminated with continuous progress. Secondly, that perception should be further enhanced in a head first protocol with accelerating bed speeds over the lower extremities towards the end of the exam, as established by initial FlowMotion users.

To evaluate this approach, Siemens has surveyed 11 patients that have been scanned twice, once with a conventional stop and go and once with FlowMotion acquisition of identical acquisition time. The results are shown in the Table 4.

In summary, 9 out of 11 participants perceived the FlowMotion exam to be shorter or equivalent in duration (82%). The average perceived duration for stop and go was 11.4 min and for FlowMotion 9.1 min. Stop and go was, therefore, experienced on average 2.3 min or 25% longer than FlowMotion. With one exception, participants rated the FlowMotion experience as 'relaxed' or 'somewhat relaxed'. When asked for their preference, 6 of the 11 (55%) preferred the FlowMotion experience over stop and go.

Conclusion

The new FlowMotion technology of the Biograph mCT Flow is a revolutionary step towards optimized patient-centric care. The scan planning has unprecedented flexibility with freely selectable scan ranges and acquisition speeds. No longer are there limits based on discrete bed positions; no longer is optimal bed overlap a concern and no longer is there a need for extra dose from a CT overscan to match a full PET bed position. The intelligent range extension of FlowMotion and inherent detector averaging leads to more uniform and decreased axial noise variance that may positively impact SUV_{max} quantification. Combining the above features of FlowMotion leads to efficient patient-specific planning and acquisition–based on the patient's specific anatomy and clinical indication–so the finite scan time for each patient is optimized to the fullest.

FlowMotion, therefore, can be used to ensure optimum detectability and monitoring, enabling progress in diagnosing and treating challenging diseases. Overcoming the limitations of conventional PET/CT systems, FlowMotion is the end of stop and go.

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Global Business Unit Address
Siemens Medical Solutions USA, Inc.
Molecular Imaging
2501 N. Barrington Road
Hoffman Estates, IL 60192-2061
USA
Telephone: +1847 304 7700
www.siemens.com/mi

Global Siemens Headquarters
Siemens AG
Wittelsbacherplatz 2
80333 Munich
Germany

Global Siemens Headquarters
Healthcare Headquarters
Siemens AG
Healthcare Sector
Henkestrasse 127
91052 Erlangen
Germany
Telephone: +49 9131 84-0
www.siemens.com/healthcare

Address of legal manufacturer
Siemens Medical Solutions USA, Inc.
Molecular Imaging
810 Innovation Drive
Knoxville, TN 37932-2751
USA
Telephone: +1 865 218 2000
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