The winding road towards respiratory motion correction: is this just another dead-end or do we finally get breathing under control?

Dominik C. Benz, MD,^a and Ronny R. Buechel, MD^a

^a Department of Nuclear Medicine, Cardiac Imaging, University Hospital Zurich, Zurich, Switzerland

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Cardiac positron emission tomography (PET) imaging steadily continues to evolve into a pivotal imaging modality for the management of patients with cardiovascular diseases. While there is accumulating evidence that PET myocardial perfusion imaging may be the first choice in the evaluation of ischemic heart disease,^{1,2} other indications such as prosthetic heart valve endocarditis,³ atherosclerotic plaque imaging,⁴ cardiac amyloidosis,⁵ or cardiac sarcoidosis⁶ are either already established or about to be implemented into clinical routine in the near future. There are, however, several important limitations still to be addressed. Despite the substantial refinements in various aspects of hardware and software technology, exploiting the potential spatial resolution of PET systems remains challenging in the field of cardiac imaging as image quality is inherently and simultaneously affected by cardiac contractions, respiratory motion, and patient movements. As a consequence, the high theoretical spatial resolution of state-of-the-art PET scanners does not translate into the effective global spatial resolution of PET images obtained in the clinical setting. Naturally, several techniques have been developed over the years to compensate for this loss in spatial resolution.

However, while the road towards correction of cardiac contractions basically starts and ends with ECG gating, the road towards getting respiratory motion under control has proved to be much less straightforward.

Initial studies tested the feasibility and impact of scanning at deep inspiration on myocardial perfusion imaging.⁷ Although the technique significantly reduces image artifacts and improves image quality, patient cooperation is crucial. Another approach is to monitor and measure respiratory motion by an external device such as a pneumatic belt around the patient's abdomen or by an infrared tracking camera with a reflective marker placed on the patient's chest (real-time position management systems).⁸ By correlating the breathing cycle and the acquisition of the imaging data (i.e., respiratory gating), image acquisition or reconstruction is limited to certain respiratory phases. The tradeoff for this image truncation and reduction in counts, however, is either increased image noise levels or longer acquisition time which in turn may even provoke more patient motion.⁹ Furthermore, the external devices may produce significant patient discomfort. Fortunately, more recent developments allow the derivation of the respiratory signal directly from the scan data (i.e., data-driven). The need for any external devices, additional staff action, or patient cooperation can then be omitted. Moreover, respiratory motion can be compensated without losing any image data.^{10–13} Although the potential of these data-driven motion correction algorithms to improve spatial resolution is auspicious, the techniques have not yet found widespread adoption into clinical routine. The reason for this may very well be due to complex set-up procedures and vendor-specific algorithms (Table 1).

In the current issue of the Journal, *Lassen et al.* investigate a data-driven, projection-based respiratory motion compensation (DPR-MoCo) approach for cardiac PET data by modeling each motion in projection space and performing correction in the listmode data

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Reprint requests: Ronny R. Buechel, MD, Department of Nuclear Medicine, Cardiac Imaging, University Hospital Zurich, Ramistrasse 100, 8091 Zurich, Switzerland; ronny.buechel@usz.ch

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Table 1. A selection of respiratory motion compensation and correction algorithms for nuclear cardiac imaging

Group	Year	Algorithm for motion correction	System	Additional software needed	Staff action during acquisition	Patient cooperation required	Truncation of data	Data-driven
Büther et al. ¹⁴	2009	COM tracking/Sensitivity method	PET	Yes	No	No	No	Yes
Buechel et al. ⁷	2010	Manual real-time breath-hold triggering	CZT-SPECT	No	Yes	Yes	Yes	No
Ko et al. ¹⁵	2015	COM tracking	CZT-SPECT	Yes	No	No	No	Yes
Daou et al. ¹¹	2017	REGAT	CZT-SPECT	Yes	No	No	No	Yes
van Dijk et al. ¹²	2018	MDC for Alcyone (GE Healthcare)	CZT-SPECT	Yes	No	No	No	Yes
Lassen et al.	2019	DPR-MoCo	PET	Yes	No	No	No	Yes

COM, center-of-mass; CZT, cadmium-zinc-telluride; REGAT, Respiratory gating software; DPR-MoCo, Data-driven, projection-based respiratory motion compensation

before the images are reconstructed. The first validation using analytical simulations of a phantom and experimental phantom tests demonstrated similar noise and higher contrast compared to the original data without motion compensation as well as lower noise and similar contrast compared to the gated data. Nevertheless, noise and contrast did not differ from the image-based, standard reconstruction-transform-average (RTA) approach. In the subsequent validation in seven patients studied by $^{13}\text{N-NH}_3/^{18}\text{F-FDG}$ PET/MR, not only noise but also contrast was comparable between the DPR-MoCo and the original data without motion compensation. In contrast, noise significantly increased in the gated and the RTA images. Finally, ejection fraction (EF) from DPR-MoCo data was closer to the EF obtained from cardiac MR than the original data without motion compensation, although the correlation did not reach statistical significance. The authors conclude that the DPR-MoCo method improves cardiac PET image quality without the need for an external device to track respiratory motion.

The authors should be congratulated for this pilot study on a promising, projection-based technique to compensate for respiratory motion. The study is well conducted and comprises validations in simulations, phantom scans, and patient studies. Furthermore, the DPR-MoCo method offers several strengths that deserve closer attention. First, thanks to the feature that motion compensation is performed prior to the image reconstruction, the algorithm could potentially be applicable to any PET device able of acquiring data in listmode, regardless of any vendor-specific post-processing. Additionally, the algorithm could potentially also be modified for application in cardiac SPECT imaging with solid-state detector technology. Second, the ability to perform combined ECG- and respiratory-gating is a *conditio sine qua non* for cardiac PET imaging—fortunately, the DPR-MoCo algorithm integrates that. Third, although the current implementation needs manual segmentation of the myocardium before extraction of the respiratory signal and motion compensation, future versions could fully automatize this process. Nonetheless, as for any research, some weaknesses and limitations exist and should be mentioned briefly. First, it must be noted that the present pilot study did not reveal statistically significant improvements for the figures of merit (e.g., image contrast or total perfusion defect) and the functional parameters as compared to the original data without motion compensation. Second, the results of the present study are limited to rest scans. However, both respiratory rate and motion are expected to increase when patients are stressed. Third, the current work only analyzed the last 10 min from NH₃ and FDG PET studies (i.e., data with high count statistics) to validate the algorithm. This may be a valid approach for

viability testing by FDG PET, but when it comes to perfusion imaging by NH₃ PET, dynamic acquisitions for accurate quantification of myocardial blood flow are key. For these, however, count statistics per frame are not only lower, but respiratory motion during stress is at maximum as well.

To conclude, the presented approach for respiratory motion compensation offers more strengths than weaknesses. Therefore, one can be optimistic that if the promising results of this pilot study are validated in a larger sample—and yet unknown pitfalls are identified and better understood—the DPR-MoCo method might be an effective and widely applicable tool to better control respiratory motion ... and not just another bump in a winding road.

Disclosure

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