

## ORIGINAL ARTICLE

# Effects of Acquisition Matrix Size on the Accuracy and Repeatability of Parameters of Left Ventricular Function: A Phantom Study for ECG-gated Myocardial SPECT

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## Abstract

**Background:** The voxel size in ECG-gated myocardial SPECT (GSPECT) is a compromise between geometric resolution and count statistics with varying values and is rather inconsistent in different centers. We investigated the influence of typical acquisition matrix sizes for GSPECT on the reproducibility and accuracy of left ventricular function parameters using a dynamic heart phantom.

**Methods:** Ten paired acquisitions, each pair with slightly different phantom positions, were obtained using identical imaging parameters except acquisition matrix:  $128 \times 128$  matrix (3.3 mm voxel) and  $64 \times 64$  matrix (6.6 mm voxel). In the next step,  $128 \times 128$  data sets were compressed to an additional set of  $64 \times 64$  matrix images.

**Results:** Nominal value of left ventricular ejection fraction (LVEF) of the phantom was 67%. Both acquisition matrices led to significant overestimation of the LVEF. Overestimation was more pronounced in  $64 \times 64$  than in  $128 \times 128$  studies ( $79.8 \pm 2.5\%$  vs.  $73.6 \pm 1.4\%$ ,  $p < 0.05$ ). Calculated volumes were closer to the nominal values with  $128 \times 128$  than with  $64 \times 64$  studies. Variance showed a trend to be higher with  $64 \times 64$  matrix, but the effect did not reach the level of statistical significance.

**Conclusions:** LVEF overestimation and volume underestimation can be reduced by using finer matrix size without any negative effect on the reproducibility.

**Keywords:** Dynamic phantom, Gated-SPECT, Left ventricular ejection fraction, Left ventricular function, Left ventricular volumes, Reproducibility

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The acquisition of ECG-gated data in myocardial SPECT (GSPECT) makes the determination of parameters of left ventricular (LV) function possible (1, 2). For this purpose dedicated software solutions have been developed and validated in the past (3, 4). Comparing the results of GSPECT processing software with reference methods indicated fair agreement regarding values of LV function such as ejection fraction (EF), LV end-diastolic volume (EDV) and end-systolic volume (ESV) (4–6). Furthermore, comparison of different GSPECT processing tools documented similarly high

correlation with some systematic differences (3, 4, 7).

However, due to the limited geometric resolution of gamma camera systems, accurate determination of the left ventricular ejection fraction (LVEF) remains a challenge. Comparison of GSPECT results with high resolution reference methods demonstrated slight, but systematic underestimation of the LV volumes and overestimation of LVEF. This clinical observation was reproduced in different phantom studies (8–10). The problem is especially apparent in patients with “small” hearts with end-systolic volumes below 20–30 ml.

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To compensate for this “small heart effect”, iterative reconstruction methods with resolution recovery algorithms have been introduced and empirical correction factors were applied during post processing (10, 11).

We believe that this underestimation of LV volumes can be partly attributed to the rather large pixel size traditionally used in standard clinical SPECT protocols. The recommended pixel size of up to 7 mm in current guidelines is originally derived from the sampling theorem considering the typical geometric resolution of standard SPECT cameras (12). However, in our opinion, when using dedicated processing software, finer acquisition matrix size may be of advantage.

This assumption is supported by the publication of Hambye et al., who demonstrated that matrix size had a significant influence on functional parameters computed from GSPECT (13), and by Nakajima et al., who showed that zooming may improve accuracy of LV volume estimates in small hearts (11).

To further explore this hypothesis, we investigated the influence of different acquisition matrix sizes on the accuracy and repeatability of GSPECT results using a dynamic heart phantom.

## Methods

A Dynamic Heart Phantom (BSI Lübecke, Germany) was used. Nominal phantom parameters were EF: 67%, EDV: 112 ml and ESV: 37 ml. A detailed description of the phantom has been recently published elsewhere (14).

The phantom consisted of two functional units, one containing a pump and an ECG trigger, and the other representing the heart. The heart unit was positioned inside an empty NEMA IEC PET body phantom (15). The LV wall of the phantom was filled with 20 MBq of “<sup>99m</sup>Tc” solution ( $20.46 \pm 2.22$  MBq), while the LV chamber was filled with non-radioactive distilled water. Heart rate was set to 60 bpm for all acquisitions.

### Data acquisition

Data acquisition was performed using a dual head large field-of-view SPECT camera (E. CAM<sup>TM</sup> variable angle, Siemens Medical Solutions, Inc., Hoffman Estates; IL, USA) equipped with low energy high resolution collimators (LEHR).

Acquisition parameters corresponded to the in-house standard values for clinical GSPECT [energy window 140 keV width 15%, zoom 1.45, detector configuration 90°, starting angle 45°, rotation 90°, time per view 40 seconds, gating window 30%, gating type forward, 12 gates, and noncircular orbit (NCO) with pre-scan performed prior to each data acquisition].

Ten pairs of acquisitions were performed. Each acquisition started with a 128 × 128 matrix (3.3 mm pixel size) and was

immediately repeated using a 64 × 64 matrix (clinical standard at our institution, 6.6 mm pixel size).

After each pair of acquisitions, the position of the phantom was slightly changed to simulate different heart axis orientation in clinical practice.

### Image processing

In addition to the native 64 × 64 images, all native 128 × 128 images were compressed from 128 × 128 matrix size to 64 × 64 matrix size on a dedicated processing workstation (SyngoMMWP VE61A, Siemens Medical Solutions, Inc., Hoffman Estates, IL, USA).

The images were reconstructed using filtered back projection. In agreement with our routine clinical protocol a Butterworth filter order 5 with a cut-off of 0.50 cycles/pixel was applied using the Syngo processing tools.

The determination of LV function parameters was then carried out using a dedicated processing software (Corridor 4DM version 2013.1.2.63).

The influence of the filter cut-off on the results was tested using cut-off values between 0.2 and 0.7 cycles/pixel.

### Statistical analysis

All values are expressed as mean with standard deviation (SD). The nominal phantom parameters were considered as true values and mean deviations from nominal parameters were calculated for each data set. One sample *t*-test was performed to compare calculated functional parameters to nominal phantom values.

In order to support visual comparability of results, boxplots were generated for each parameter of ventricular function. The boxes show the distance between the quartiles (interquartile range: IQR), and whiskers indicate the extremes. For display purposes, values whose distance to the edge of the box is more than 1.5 times the IQR are not included in the whiskers, but displayed separately as dots (16).

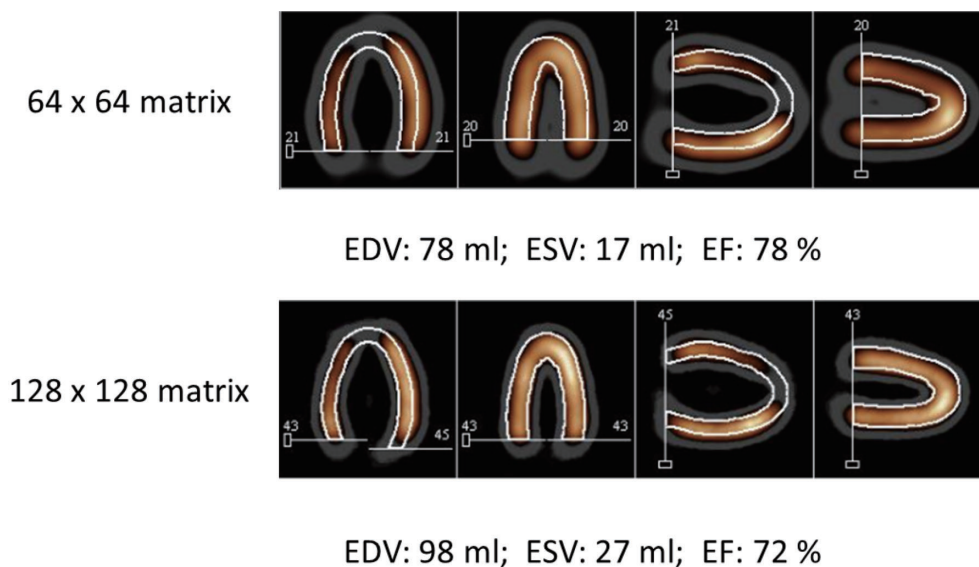
The mean values of parameters obtained using different matrix sizes were compared by unpaired *t*-test. Variances were compared using standard two sample *F*-test.

Statistical significance level was defined as a *p* level of less than 0.05.

## Results

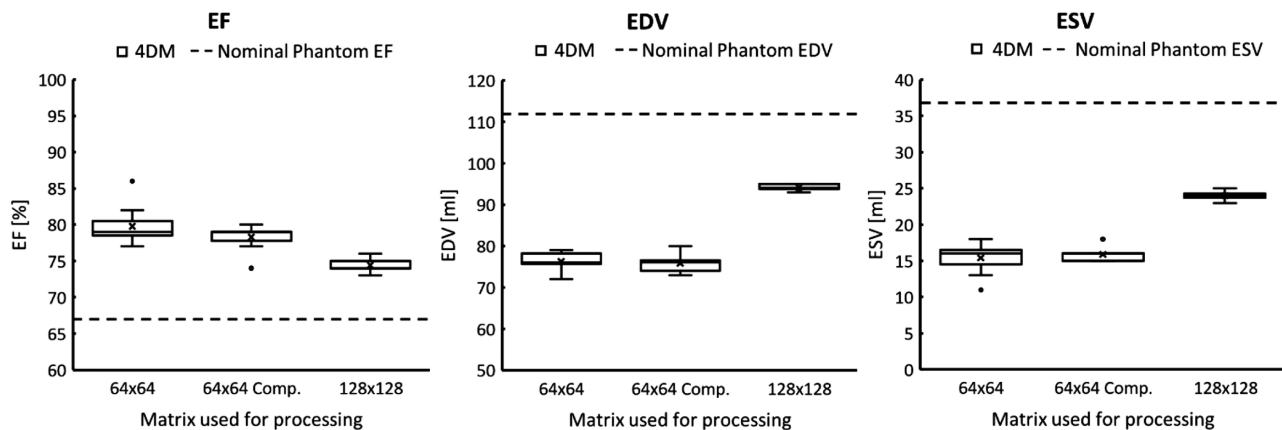
An example for the delineation of heart contours in 128 × 128 and 64 × 64 matrix imaging is shown in Figure 1.

We generated boxplots for EF, EDV and ESV (Figure 2). The measured values are compared between different matrix sizes and nominal phantom parameters. The two modes of acquisition with 64 × 64 matrix and compressed 64 × 64 matrix data sets resulted in similar mean values across all LV function parameters, whereas 128 × 128 matrix imaging



**Figure 1** Delineation of heart contours.

The image shows the results of automated heart contour delineation in a  $128 \times 128$  and a corresponding  $64 \times 64$  image using Corridor 4DM processing software.



**Figure 2** Ejection Fraction (EF).

The Boxplots show the distribution of EF, EDV and ESV values for  $64 \times 64$  ( $79.8 \pm 2.5\%$ ;  $76.2 \pm 2.0$  ml;  $15.4 \pm 2.0$  ml),  $64 \times 64$  compressed ( $78.1 \pm 2.3\%$ ;  $77.2 \pm 3.3$  ml;  $16.6 \pm 2.1$  ml) and  $128 \times 128$  ( $73.6 \pm 1.4\%$ ;  $96.0 \pm 2.5$  ml;  $25.4 \pm 2.0$  ml) matrix sizes. Nominal phantom EF (67%), EDV (112 ml) and ESV (37 ml) are indicated as dotted lines. For details see statistical analysis.

resulted in mean values closer to the nominal phantom parameters.

#### 64×64 matrix acquisition

Using  $64 \times 64$  acquisition matrix we obtained  $79.8 \pm 2.6\%$  for LVEF,  $76.3 \pm 2.1$  ml for EDV and  $15.4 \pm 2.1$  ml for ESV.

Compared with reference values of nominal phantom parameters, the deviation of measured values was overestimation of  $12.8 \pm 2.6\%$  for LVEF, and underestimation of  $35.7 \pm 2.1$  ml and  $21.6 \pm 2.1$  ml for EDV and ESV, respectively.

#### 128×128 to 64×64 matrix compression

After  $128 \times 128$  to  $64 \times 64$  matrix reformatting, we obtained  $78.3\% \pm 1.7\%$  for LVEF,  $75.8 \pm 2.0$  ml for EDV and  $15.9 \pm 0.9$  ml for ESV, which were similar to the  $64 \times 64$  matrix

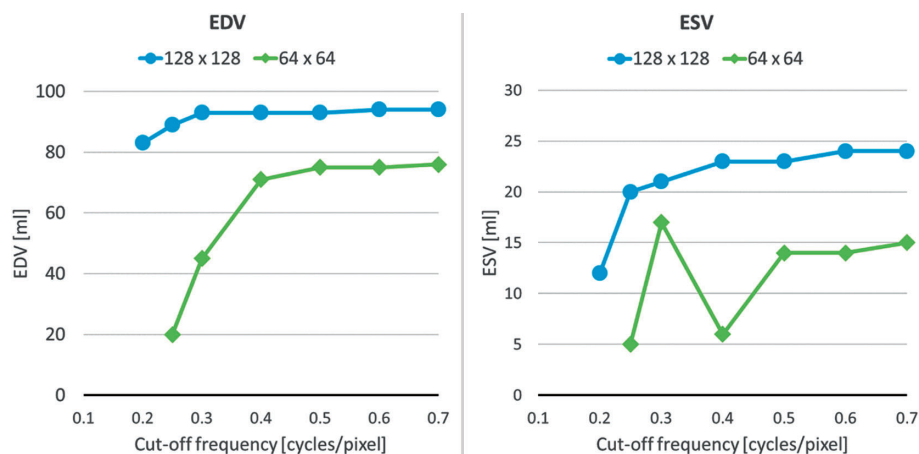
acquisition data.

The deviation of EF values from nominal phantom parameters was  $11.3\% (\pm 1.7\%)$ , and that of EDV and ESV values was  $-36.2$  ml ( $\pm 2.0$  ml) and  $-21.1$  ml ( $\pm 0.9$  ml), respectively.

#### 128×128 matrix acquisition

Using  $128 \times 128$  acquisition matrix, we obtained  $74.4\% \pm 0.8\%$  for LVEF ( $p < 0.0001$  vs.  $64 \times 64$  compressed data),  $94.1 \pm 0.7$  ml for EDV and  $24.0 \pm 0.7$  ml for ESV ( $p < 0.0001$ , vs.  $64 \times 64$  compressed data for both).

The deviation of measured LVEF, EDV and ESV from nominal phantom parameters was  $7.4 \pm 0.8\%$ ,  $-17.9 \pm 0.7$  ml and  $-13.0 \pm 0.7$  ml, respectively.



**Figure 3** Influence of Butterworth filter cut-off.

The Graph shows the calculated EDV and ESV values from the same study, reconstructed using different cut-off values between 0.2 and 0.7 cycles/pixel.

### Comparison of different matrix sizes

All acquisition protocols resulted in significant overestimation of the LVEF and significant underestimation of EDV and ESV ( $p < 0.001$ ). However, the differences between nominal and measured values were significantly smaller using  $128 \times 128$  acquisition matrix compared to the results with  $64 \times 64$  acquisition matrix ( $p < 0.001$ ).

When comparing results with primer and compressed  $64 \times 64$  acquisition matrix we found no significant differences in LVEF, EDV and ESV.

*F*-testing showed no significant difference in the variance of the measurement series.

### Influence of filter parameters on results

Reconstruction using different cut-off values for the Butterworth filter demonstrated that our cut-off of 0.5 cycles/pixel is a good compromise between counting statistics and stable contouring of LV border (Figure 3). Both EDV and ESV values remained stable at cut-off values of 0.5 and higher. Using  $64 \times 64$  matrix an abrupt decrease was observed below cut-offs of 0.4 and 0.5 for EDV and ESV, respectively. Furthermore, end-systolic contouring became unstable below cut-off 0.5. With  $128 \times 128$  matrix both EDV and ESV values were calculated lower at cut-off values of 0.2.

## Discussion

This study investigated the influence of different acquisition matrix sizes on the accuracy and reproducibility of LV function parameters computed from GSPECT studies using a dynamic heart phantom.

Using a phantom for this purpose was necessary, as the real value of ventricular functional parameters is usually unknown in clinical situations.

We therefore used the Dynamic Heart Phantom for this purpose, which is convenient for validating the accuracy of

LVEF and volume determination (14). CT verification of a similar phantom showed high accuracy of the manufacture's nominal parameters (15).

Recommended pixel size in GSPECT is generally derived from the sampling theorem considering the geometric resolution of current multipurpose two detector SPECT cameras as a limiting parameter. As reconstructed image resolution is about 10 to 15 mm FWHM (full width half maximum) in these devices, pixel sizes of less than 5 to 7 mm are rarely used (17).

However, when working within this pixel range, a systematic underestimation of left ventricular volume, especially below 20–30 ml at end-systole, has been observed both clinically and in phantom studies (8, 11, 13). Using a simulated phantom with standard acquisition and reconstruction parameters, Nakajima et al. found an underestimation of 15% for 101 ml, 25% for 52 ml and 50% for 37 ml ventricular volume (11). This magnitude of underestimation corresponds to our observation; namely, nominal ESV of 37 ml was underestimated by about 58% using  $64 \times 64$  matrix.

In order to compensate for this systematic error, several solutions have been proposed in the past. A high cut-off reconstruction filter, restorative reconstruction algorithm, hardware zooming, and finer acquisition matrix have been tested.

While restorative algorithms are rather controversially discussed in recent publications (17, 18), a promising effect has been attained by refinement of sampling during acquisition. In this context, Nakajima et al. demonstrated that  $2 \times$  hardware zooming (corresponding to reduction of pixel size from 6.4 to 3.2 mm in their work) may eliminate the underestimation of ventricular volume from 37 ml and above (11).

Hambye et al. investigated the effect of reducing pixel length from 6.9 mm ( $64 \times 64$  acquisition matrix) to 3.45 mm

( $128 \times 128$  acquisition matrix) on values of LV volume in patients with ESV  $< 30$  ml. Larger pixel sizes were associated with significantly smaller (probably underestimated) volumes determined by quantitative gated SPECT (QGS) software (13).

In our study, using standard acquisition parameters, the EF was systematically overestimated due to greater underestimation of ESV values relative to the EDV values. Changing the acquisition matrix size from  $64 \times 64$  to  $128 \times 128$ , the overestimation of EF is reduced from 19% to 11%.

The increased accuracy of the measurement of ventricular volumes using pixel sizes below the recommended range, published even in recent guidelines, could be explained by the mode of operation of current contouring algorithms. To our knowledge, because present processing programs are using integer pixel grids, contouring may be more accurate using finer matrix sizes. In this context, zooming and refinement of acquisition matrix will probably lead to similar effects. Matrix refinement may have the advantage of unchanged field of view, therefore possible truncations can be avoided.

Another important quality parameter of GSPECT is its inherent methodical variability, which is usually determined by repeated data acquisitions (19). In order to keep the so-called repeatability coefficient low, accurate contouring is essential. However, it may be suboptimal when pixel counts are too low. Simulations from Nakajima et al. have shown that within certain limits the effect of decreased counts per pixel and increased noise may be of limited importance (11). In our study, variance of ventricular functional parameters remained stable after changing the acquisition matrix size from  $64 \times 64$  to  $128 \times 128$  with a tendency to be even lower in the latter case.

Our study has several limitations. We used a relatively simple dynamic phantom with fixed EDV, ESV and a constant heart rate. The processing was performed with one program, Corridor 4DM. However, since similar underestimation of ventricular volumes, especially at end-systole has been shown in Cedars QGS and Emory Cardiac Toolbox (11, 13), our results of difference in matrix size could be applied to other software types. However, the transferability of our results to the new dedicated cardiac cameras needs further investigations. The applied activity of “ $^{99m}\text{Tc}$ ” was rather high, corresponding to the upper range of clinical studies.

## Conclusion

Based on our preliminary results, the refinement of acquisition matrix may contribute to gain more realistic values of ventricular volume especially at end-systole without negative effect on the reproducibility. Although the lower limit of voxel size should be elaborated in future investigations,  $128 \times 128$  matrix data acquisition could be a good option for clinical works at present. This initial fine

acquisition matrix can be easily resized for the investigation of myocardial perfusion, if required.

## Abbreviations

EDV: end diastolic volume

ESV: end systolic volume

GSPECT: gated myocardial single photon emission computed tomography

IQR: interquartile range

LVEF: left ventricular ejection fraction

LEHR: low energy high resolution

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## Conflicts of interest

None.

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