Accuracy Errors in Longitudinal QCT Measurements of Cortical Thickness, Bone Mineral Density (BMD) and Bone Mineral Content (BMC) using Different Segmentation Techniques

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Introduction

Cortical and trabecular bone compartments can be quantified separately using quantitative computed tomography (QCT). However, due to limited spatial resolution of the CT equipment, the determination of the cortex depends on the segmentation technique. In our work, we simulated independent changes of cortical thickness and bone mineral density (BMD) and investigated the ability of three different segmentation techniques to measure these changes.

Material and Methods

Simulation of image acquisition:

A step function of varying width (cortical thickness, t_c) and height (BMD_c) represents the cortex. An additional step was used to include trabecular bone. The resulting step profile describing the density distribution form soft tissue to the trabecular compartment was convolved with a Gaussian distribution (fig. 1) representing the point spread function (PSF) of the CT scanner. The resulting curve simulates the density distribution within a reconstructed CT image. Finally a noise level of 30 mg/cm³ was added.

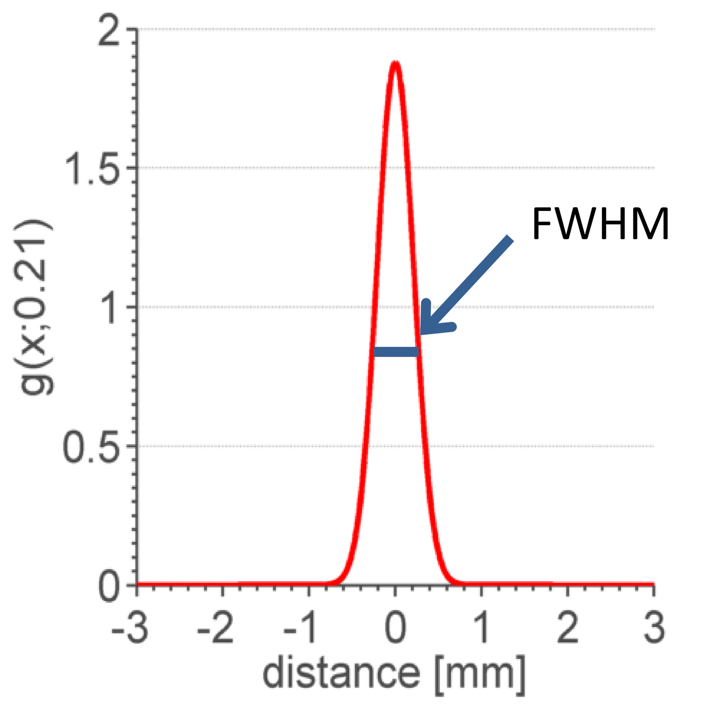

Figure 1: PSF was assumed to be a Gaussian distribution. The full width at half maximum (FWHM) corresponds to the scanner resolution.

Estimation of cortical thickness:

Three different algorithms were used to estimate cortical thickness t_c:

- Local adaptive 50% threshold (LAT)[1]
- Global threshold (GT): 400 mg/cm³ for cortex/soft tissue and 300 mg/cm³ for cortex/trabecular bone
- Optimization Method (OM): model-based deconvolution method using Levenberg-Marquardt algorithm[2]

Simulated parameters:

Effects of independently simulated changes of

1. **Cortical thickness t_c:** longitudinal increase of 5%, 10% and 20%
2. **Cortical BMD_c:** longitudinal increase of 2.5%, 5% and 7.5%

on measured parameters Δt_e, ΔBMD_e and ΔBMC_e were investigated. Each profile was simulated 200 times and the mean values of these parameters calculated.

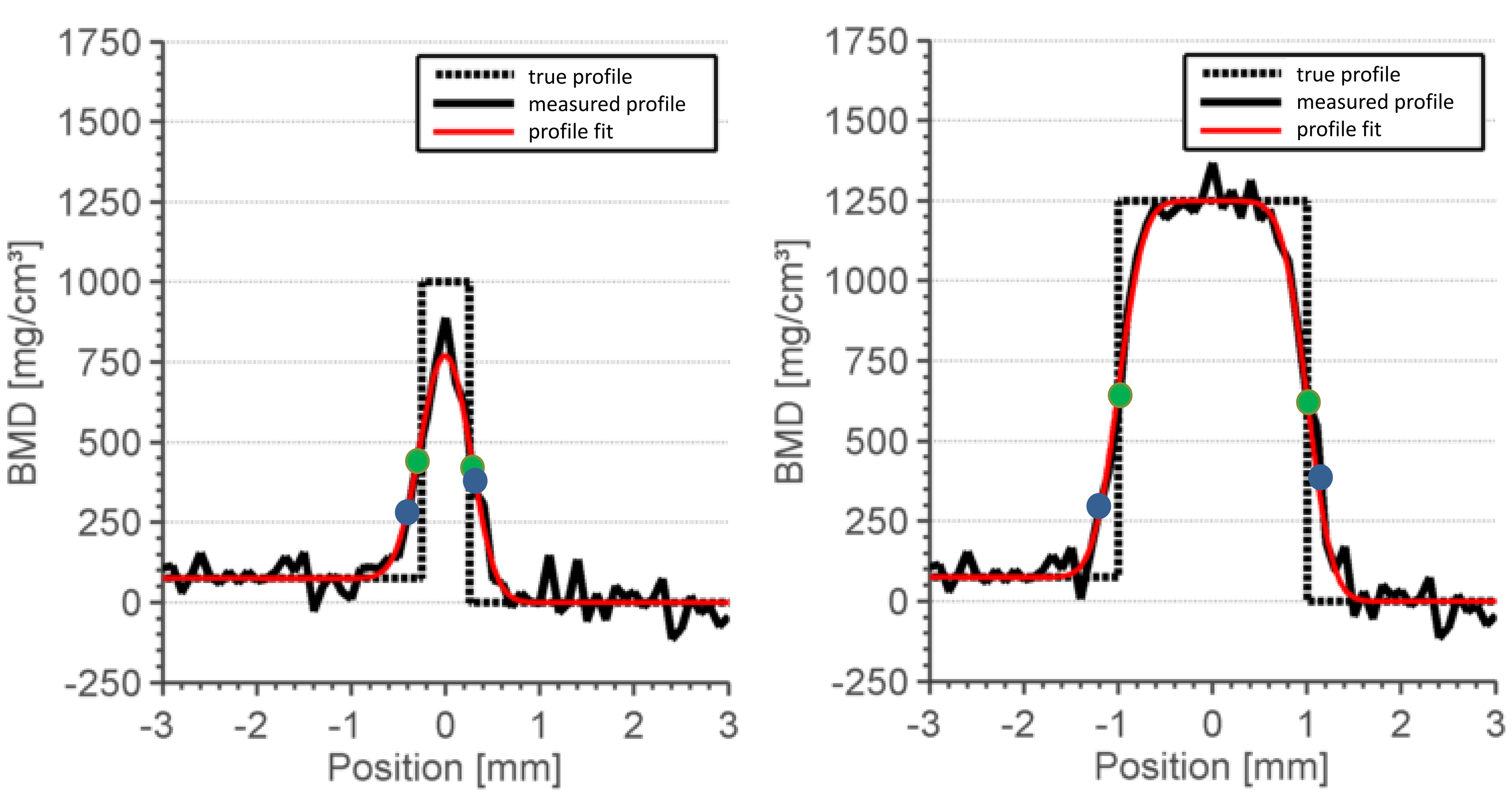

Figure 2: True and measured BMD profile for two different tc and BMDc values. Also shown are the positions of the endosteal and periosteal surface estimated using LAT (green) and GT (blue). The fitted curve calculated using OM is shown in red.

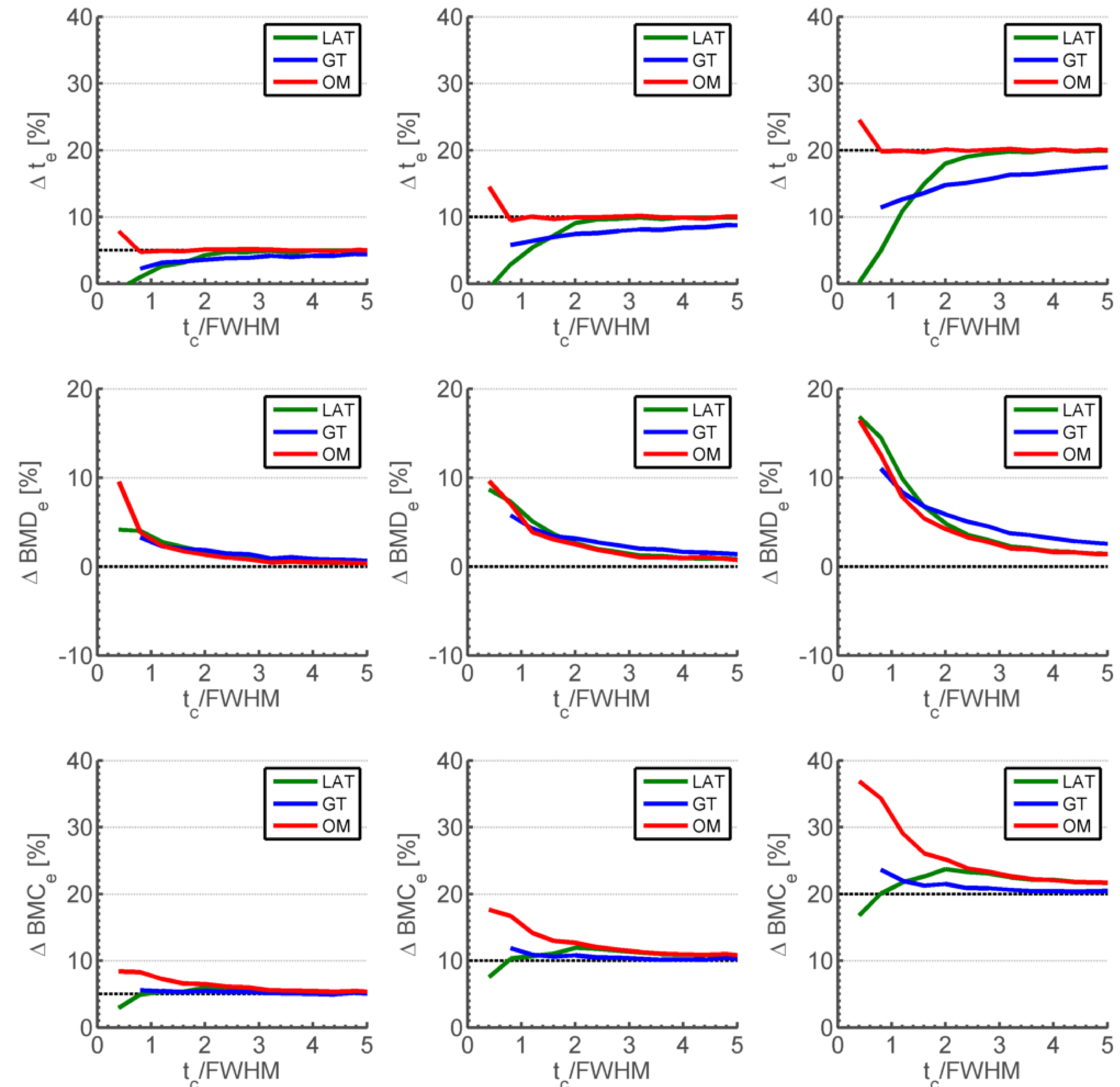

Figure 3: **Increase of t_c, ΔBMD_c = 0.** Mean values of measured Δt_e (first row), ΔBMD_e (second row) and ΔBMC_e (third row) as a function of t_c / FWHM for an assumed increase in t_c of 5% (left), 10% (center) and 20% (right).

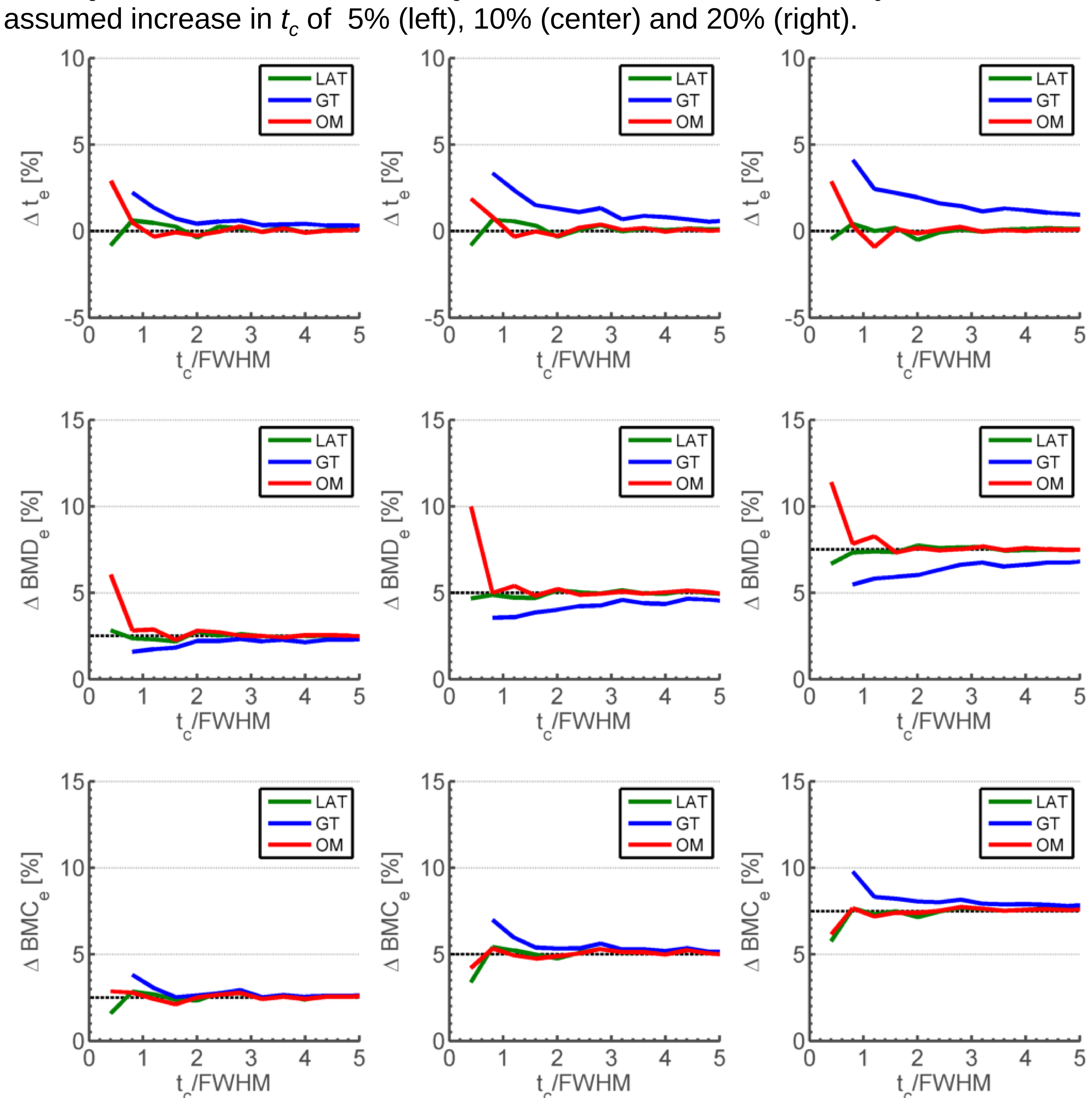

Figure 4: **Increase of BMD_c, Δt_c = 0.** Mean values of measured Δt_e (first row), ΔBMD_e (second row) and ΔBMC_e (third row) as a function of t_c / FWHM for an assumed BMD_c increase of 2,5% (left), 5,0% (center) and 7,5% (right).

Results

The results for an **increase of t_c** are shown in fig. 3.

- All three algorithms show good results for t_c > 2FWHM.
- The results for FWHM < t_c < 2FWHM show:
  - LAT and GT underestimate Δt_e; OM shows the best results.
  - LAT and GT shows better results for ΔBMC_e than OM.
  - All three algorithms result in falsely estimated ΔBMD_e values.

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  - All three algorithms result in falsely estimated Δt_e values.
  - LAT and OM show better results for ΔBMC_e than GT.
  - GT underestimate ΔBMD_e; LAT and OM show the best results.

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Discussion

- For **t_c > 2FWHM** all algorithm show good results in measuring Δt_e, ΔBMD_e and with some limitations also in measuring ΔBMC_e.
- For **FWHM < t_c < 2FWHM**:
  - LAT and GT underestimate Δt_e, here OM works best.
  - For all methods true t_c increases result in incorrect increases of ΔBMD_e. In particular OM also measures incorrect increases of ΔBMC_e.
  - For GT true BMD_c increases result in incorrect increases of Δt_e and ΔBMC_e.
- For **t_c < FWHM** due to high variances (not shown in graphs), results for Δt_e, ΔBMD_e and ΔBMC_e are not reliable.

[1] Prevrhal S et al. Accuracy limits for the determination of cortical width and density: the influence of object size and CT imaging parameters. Phys Med Biol. 1999;44(3):751.

[2] Treece G et al. High resolution cortical bone thickness measurement from clinical CT data. Med Imag Anal. 2010;14(3):276 – 290.