**公益財団法人　医用原子力技術研究振興財団　上原雅恵　平成 24 年度医用原子力技術に関する研究助成　放射線診断における医療被ばく低減のための研究 320 列 CT における管電流曝射調節システム（volume exposure control）と逐次近似法（AIDR3D）の組み合わせによる心臓 CT の放射線被ばく低減法の確立**

このたびは公益財団法人　医用原子力技術研究振興財団　上原雅恵　平成 24 年度医用原子力技術に関する研究助成をいただき、“放射線診断における医療被ばく低減のための研究　320 列 CT における管電流曝射調節システム（volume exposure control）と逐次近似法（AIDR3D）の組み合わせによる心臓 CT の放射線被ばく低減法の確立”についての研究を行いました。

**背景**

CT の進歩と冠動脈 CT 血管造影所見を用いた予後に対するエビデンスの蓄積により、冠動脈 CT 血管造影（CTA）が活発に行われている。しかし 2012 年 6 月の JAMA で、CT をスクリーニングに使用する前に知っておくべき放射線被ばくに対する事項が特集された（文献 1-3）ように、循環器内科医は、心臓 CT の欠点である放射線被ばく低減に対する理解が必須となっている。

心臓 CT 放射線被ばく量低減の研究として、さまざまな報告がなされている。放射線被ばく低減を目的とした PROTECT Ⅳ研究(Prospective Randomized Trial On RadiaTion Dose Estimates OF CT AngIOgraphy In PatieNts Scanned With A High-Pitch First Scan Strategy)では、128 スライス 2 管球 CT の high pitch モードと通常の心電図同期モードで冠動脈 CTA 撮影を行い比較した。high pitch モードでは画像のぼやけが有意に通常の心電図同期モードより多かったが、放射線被ばく量は通常モードより 58%低減し、49%の症例で 1mSv 未満であり、正常洞調律で徐脈の症例には high pitch モードを推奨している（論文未）。LaBounty らは正常 body mass index (< 25 kg/m(2))をもつ症例において冠動脈 CTA 撮影時に管電圧を 80kV まで下げたことによる放射線量低減と画質への影響を評価した（論文 4）。前向き、多施設、複数の機種を用いた試験で、 管電圧 80kv と 100kv 群にわけたところ、100kv 群と比較して 80kv 群において 47%の放射線被ばくの低減が可能であったが、両群間に評価可能であった症例の比率、画質に有意差は無かったため、正常 body mass index 症例に対しては 80kv の使用も考慮に入れるべきであると報告した。Hou らは（文献 5）256 列 CT と逐次近似法と組み合わせ、従来の filtered back projection と比較して、画質を維持した上で約 55%の放射線被ばくの低減が可能であったと報告した。逐次近似法については Funama らはファントム実験で sharp kernel の再構成関数を組み合わせ、ステント内腔の画質と改善し、さらに放射線被ばく量の低減にも成功した

と報告している（文献 6）。

今回我々は、320 slice CT(Aquilion One, Toshiba Medical)に搭載された管電流曝射調節システム（volume exposure control＝VEC）と逐次近似法（AIDR3D）を組み合わせ、放射線被ばく低減と画質の評価をファントムと臨床での検討を行った。VEC は CT の本撮影前に行う位置決めのためのスカウト画像より、画像 NOISE を一定値になるように管電流を設定するシステムであり、とくに非肥満症例では通常撮影時の 1/2 から 1/3 の管電流に設定することが可能であるとされる。ただし実際にこのシステムで管電流を設定通りに下げ、従来の filtered back projection で画像再構成を行った場合に、放射線量が不足するため、Signal noise ratio が低く、実際の画像上で NOISE が目立つことがある。そこでファントムおよび、このシステムを実際に使用した臨床例で以下の検討を行った。ファントムの検討は 2012 Radiological Society of North America (RSNA) 98th Scientific assembly and annual meeting (McCormick Place, Chicago USA: 2012/11/25-11/30).で発表、英文雑誌 Int J Cardiol (Electronic publication 2013 Mar 7)（Impact factor 7.0）に医用原子力技術研究振興財団に謝辞を明記して発行されている。

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① ファントム実験

**Adaptive-iterative-dose-reduction 3D with multisector-reconstruction Method in 320-Slice CT may Maintain Accurate-Measurement of the Agatston-Calcium-Score of Severe-Calcification Even at Higher Pulsating-Beats and Low Tube-Current in Vitro**

**（320 列 CT を用いた高度石灰化病変評価において､高心拍数かつ低管電流のときに AIDR3D と Multisector reconstruction の組み合わせは､正確な Agatston 石灰化スコア計測に有用である。ファントム実験における検討）**

ファントム研究の要旨

**方法**　拍動ファントムに高度石灰化ファントムを装着し、さまざまな拍動数、管電流、再構成法で心電図同期 320 列 CT 撮影を行った。管電圧は 120kV に固定し、管電流は 50,100,200,300,400,500mA に条件を変えた。拍動数 65/分以下では half reconstruction、66/分以上では half reconstruction と時間分解能を改善する multisector reconstruction の両者で画像作成を行い、さらに各々で通常の filtered back projection と AIDR3D を使用した遂次近似法を用いて画像再構成を行った。ファントムの石灰化スコアの平均値と標準偏差を測定し、後者を画像 noise の程度とみなし、各々の条件でファントムが静止時（＝拍動数が 0 の時）のデータを基準(100%)として評価を行った。**結果**　特に低い管電流(＝50mA)での撮影時に AIDR3D を使用することで、石灰化の平均値と標準偏差が静止状態に近似した。また拍動数が高くなっても multisector reconstruction を組み合わせることで石灰化の平均値と標準偏差が静止状態に近似した。**結語**　非肥満例で VEC を用いて管電流を下げることで冠動脈石灰スコアの平均値と標準偏差がとくに高心拍数で増加すると予想されるが、低管電流には AIDR3D、高心拍には multisector reconstruction の使用を対応させることで正確な冠動脈石灰化評価が可能であると考えた。

**Introduction:**

To reduce radiation exposure in 320 slice computed tomography (CT), a volume exposure control (VEC) system, is used frequently. The VEC system considers the degree of transmission of radiation, which correlates strongly with the body mass index and the degree of obesity and reduces the tube current. The information is acquired from scout images and its validity is achieved as a reduction of tube current, especially in non obese subjects. However, if tube current is reduced, images noise may increase, especially in pulsating heart images.

To reduce image noise and improve image quality, Adaptive Iterative Dose Reduction 3D (AIDR3D)® (Toshiba Medical) was developed. Furthermore, to improve temporal resolution for pulsating heart images especially at higher heart rates, multisector reconstruction methods are still used in 320 slice CT [1, 2].

In this study, we evaluated the utility of a combination of AIDR3D and multisector reconstruction methods in 320 slice CT for measuring severe coronary arterial calcification at various heart rates and tube currents in vitro.

**Materials and Methods:**

A calcified mock-vessel with a maximum CT value of 400 HU was made to pulsate at 40-100 beats/min (BPM) using a pulsating device (AZ-631N, Anzai Medical) (Figure 1).

Retrospective ECG gated 320 slice CT (Aquilion ONE, Toshiba Medical) was performed with a fixed tube voltage of 120 kV and a tube current of 50, 100 or 500 mA, and images were reconstructed using half reconstruction (all BPM) and also multisector reconstruction (only >65 BPM) at the most static phase both without and with AIDR3D. Mean and standard deviation (SD) of CT values of the calcified part were measured (Virtual Place, AZE), and the Agatston calcium score (ACS) was measured. The SD of those values was considered the degree of image noise.

The SDs of the CT values of the calcified part, as the degree of image noise, are small at standard state, due to the relatively high radiation dose. This is different from data obtained from an actual human body CT. Therefore, the calcified mocked phantom was surrounded by absorption material, the main component of which is acrylic water-absorption polymer (PPY-01®, Hogy Medical) (Figure 2).

**Results**

**ACS of calcified mocked vessel (Figure 3)**

Without the AIDR3D and with half reconstruction at all BPM, the ACS at 40-100 BPM relative to the static state was 93,100, 99, 94, 90, 103, and 82% at a tube current of 500 mA; 93, 95, 96, 101, 102, 99, and 83% at 400 mA; 96, 98, 96, 102, 100, 219, and 96% at 300 mA; 101, 94, 99, 97, 96, 92, and 216% at 200 mA; 165, 114, 157, 165, 171,100, and 104% at 100 mA; and 192, 213, 217, 184, 189, 180, and 209% at 50 mA. However, with the AIDR3D and with half reconstruction at all BPM, the ACS at 40-100 BPM relative to the static state was

improved, especially at low tube current, to 155, 114, 106, 102, 96, 94, and 106% at 50 mA. Furthermore, if multisector reconstruction was performed at >65 BPM only, the ACS relative to the static state was improved to 155, 114, 106, 98, 96, 97, and 95% at 50 mA.

**The SD of ACS of calcified mocked vessel (Figure 4)**

Without AIDR3D and with half reconstruction at all BPM, the SD of the CT values of the calcified part at 40-100 BPM relative to the static state was 86, 103, 91, 100, 93, 77, and 79% at a tube current of 500 mA; 97, 95, 92, 87, 87, 91, and 73% at a tube current of 400 mA; 96, 107, 90, 92, 96, 150, and 91% at a tube current of 300 mA; 99, 107, 109, 104, 107, 86, and 153% at a tube current of 200 mA; 138, 100, 114, 115, 126, 111, and 97% at 100 mA; and 168, 137, 124, 123, 152, 154, and 136% at 50 mA. With AIDR3D and with half reconstruction at all BPM, the SD of the CT values of the calcified part at 40-100BPM relative to the static state was improved, especially at low tube current, to 125, 100, 95, 93, 106, 107, and 88% at 50 mA. Furthermore, if multisector reconstruction was performed at >65 BPM only, the results were further improved to 125, 100, 95, 96, 101, 97, and 92% at 50 mA.

**Conclusion:**

Our results demonstrate that the AIDR3D with multisector reconstruction method in 320 slice CT reduces image noise of severe calcification at higher pulsating beats (>65 BPM) and low tube current. Also, the method maintains accurate measurement of ACS of severe calcification, which is improved at higher pulsating beats (>65 BPM) and low tube current. In conclusion, at low tube current, ACS and image noise increased, especially at higher pulsating beats. But using VEC with AIDR3D and multisector reconstruction, accurate measurement of coronary calcium is possible.

**Acknowledgement**

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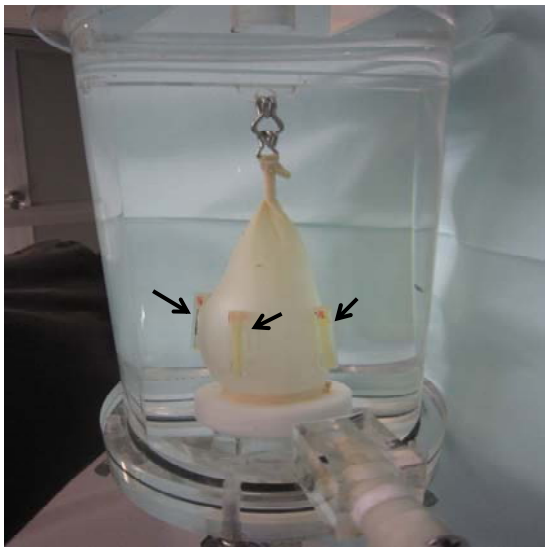
**Figure Legend**

**Figure 1**

A: Four calcified mock-vessels with a maximum CT value of 50, 200, 300 and 400 HU (red arrows) were made to pulsate at 40-100 beats/min using a pulsating device (AZ-631N, Anzai Medical). In this analysis, only the calcified mock-vessel with a maximum CT values of 400HU was used.



B: Pulsating device (AZ-631N, Anzai Medical) (arrow).

**Figure 2**

A: Absorption material which surrounded calcified mocked vessel.
Main component of this material is Acrylic Water-Absorption Polymer (PPY-01) ® Hogy Medical

B: Absorption material which surrounded calcified mocked vessel. Main component is Acrylic Water-Absorption Polymer (PPY-01) ® Hogy Medical

**Figure 3**

**Agatston calcium score (ACS) of calcified mocked vessel**

Without the Adaptive Iterative Dose Reduction 3D (AIDR3D)® (Toshiba Medical) and with half reconstruction at all beats/min (BPM), the ACS at 40-100 BPM relative to the static state was 93,100, 99, 94, 90, 103, and 82% at a tube current of 500 mA; 93, 95, 96, 101, 102, 99, and 83% at 400 mA; 165, 114, 157, 165, 171, 100, and 104% at 100 mA; and 192, 213, 217, 184, 189, 180, and 209% at 50 mA. However, with the AIDR3D and with half reconstruction at all

BPM, the ACS at 40-100 BPM relative to the static state was improved, especially at low tube current, to 155, 114, 106, 102, 96, 94, and 106% at 50 mA. Furthermore, if multisector reconstruction was performed at >65 BPM only, the ACS relative to the static state was improved to 155, 114, 106, 98, 96, 97, and 95% at 50 mA.

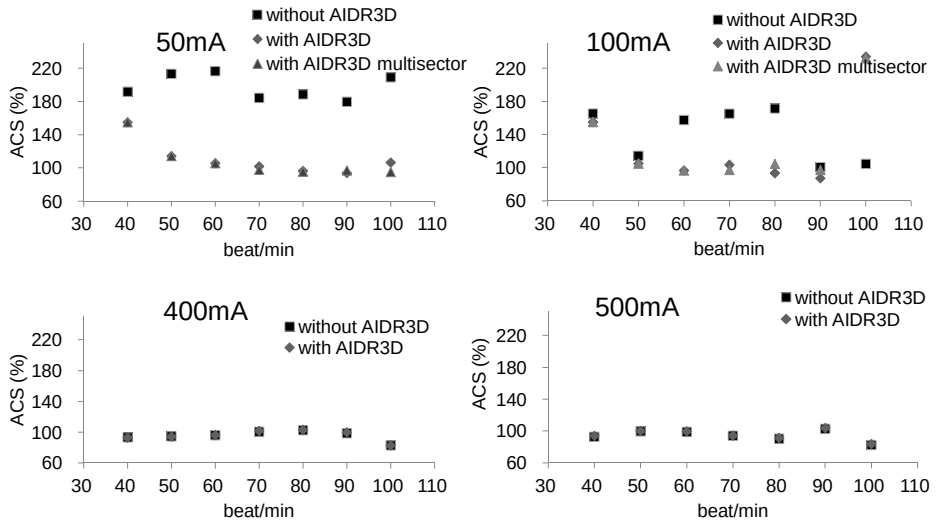
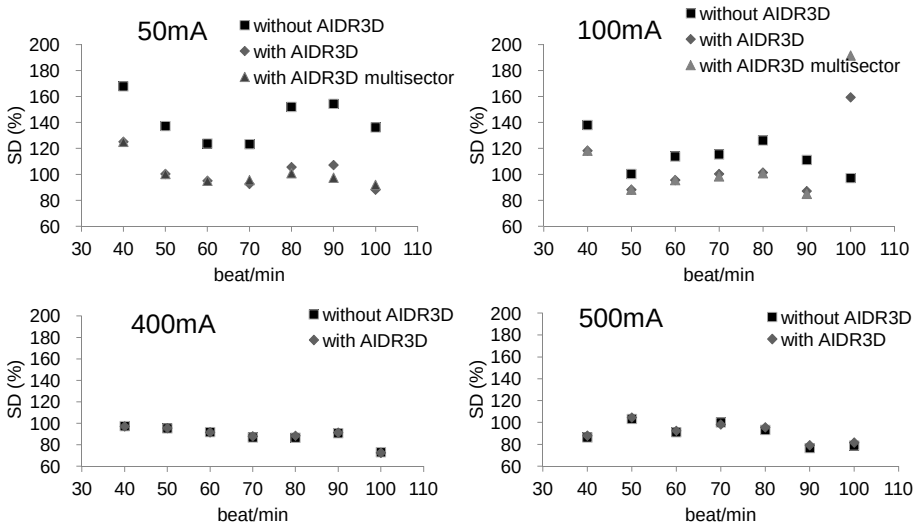



**Figure 4**

**Standard Deviation (SD) of CT values of calcified mocked vessel**

Without Adaptive Iterative Dose Reduction 3D (AIDR3D)® (Toshiba Medical) and with half reconstruction at all beats/min (BPM), the SD of the CT values of the calcified part at 40-100 BPM relative to the static state was 86, 103, 91, 100, 93, 77, and 79% at a tube current of 500 mA; 97, 95, 92, 87, 87, 91, and 73% at a tube current of 400 mA; 138, 100, 114, 115, 126, 111, and 97% at 100 mA; and 168, 137, 124, 123, 152, 154, and 136% at 50 mA. With AIDR3D and with half reconstruction at all BPM, the SD of the CT values of the calcified part at 40-100BPM relative to the static state was improved, especially at low tube current, to 125, 100, 95, 93, 106, 107, and 88% at 50 mA. Furthermore, if multisector reconstruction was performed at >65 BPM only, the results were further improved to 125, 100, 95, 96, 101, 97, and 92% at 50 mA.

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2012 Radiological Society of North America (RSNA) 98th Scientific assembly and annual meeting (McCormick Place, Chicago USA: 2012/11/25-11/30). Adaptive iterative dose reduction 3D with multisector reconstruction method in 320 slice CT may maintain accurate measurement of the Agatston calcium score of severe calcification even at higher pulsating beats and low tube current in vitro. Ochi S, Funabashi N, Irie R, Yanagawa N, Aiba M, Morimoto R, Masuda Y, Uehara M, Takaoka H, Kabashima T, Fujii S, Kobayashi Y.

② 臨床例での検討

**Automated Volume Exposure Control with Adaptive Iterative Dose Reduction 3D Method in 320-Slice CT Can Reduce Total Radiation Exposure and Image-Noise, Especially in Non-Obese Patients**

（320 列 CT において VEC と AIDR3D を組み合わせることで、特に非肥満例において総放射線被ばく量と画像 noise を低減できる。）


日本語要旨

**目的:** 320 列 CT において VEC と AIDR3D を組み合わせることで、実際の臨床例で総放射線被ばくと画像 noise を低減できるか検討する

**対象と方法:** 本研究は Retrospective ECG gating with tube current dose modulation と VEC を用いて 320 列 CT 撮影を行った連続 35 例(男性 21 名, 平均 57 歳, 平均 body mass index (BMI) 24.2±5.4 (15-35))の後ろ向き検討である。撮影時、管電流は 120kV で固定され、スカウト画像情報より VEC により管電流が決定された（最大 580mA）。画像は、通常の filtered back projection と AIDR3D を使用した逐次近似法を用いて RR 間隔の 75%で画像再構成を行った。体軸方向に同じ高さの左室と下行大動脈内腔の CT 値の平均と標準偏差が計測され、標準偏差は画像 noise の指標にした。

**結果:** VEC を使用することで、管電流は通常の 580mA から 463±135mA と平均 21%低減することができた。管電流は症例の BMI と強い正の相関（相関係数 0.60）を示した。左室と下行大動脈内腔の CT 値は通常の filtered back projection でそれぞれ 492±36、526±26HU、AIDR3D を使用した逐次近似法でそれぞれ 499±34、527±23HU であり、左室、下行大動脈内腔の CT 値の標準偏差は AIDR3D 使用で通常の filtered back projection より有意に小であった(P<0.05). 通常の filtered back projection の左室内腔の CT 値の標準偏差は、管電流、BMI と有意な負の相関（相関係数はそれぞれ -0.33、-0.36）を示した。AIDR3D を使用した逐次近似法での左室内腔の CT 値の標準偏差と管電流（相関係数-0.15）、BMI（同-0.33）の相関係数の絶対値は通常の filtered back projection より小であった。

**結語:** VEC を使用することで管電流は BMI が低い非肥満例で減らすことができる。その場合、通常の filtered back projection では画像 noise は増加するが、AIDR3D を使用した逐次近似法で画像 noise を減らすことができた。320 列 CT において VEC と AIDR3D を組み合わせることで、特に非肥満例で総放射線被ばく量と画像 noise を減らすことができると考えた。

**Purpose:** We evaluated whether combination of automated volume exposure control (VEC) with Adaptive Iterative Dose Reduction 3D (AIDR3D) (both were Toshiba Medical) method in 320 slice CT could reduce total radiation exposure and image noise in an in vivo study.

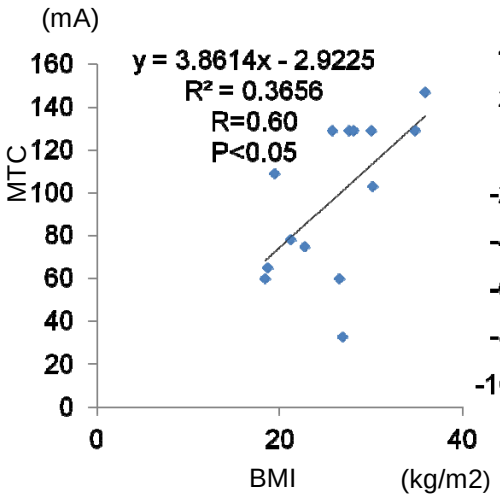
**Materials and Methods:** This was a retrospective analysis of 35 consecutive patients (21 male, mean age 57 years, mean body mass index (BMI) 24.2±5.4 (range 15-35)) who underwent retrospective ECG gated enhanced 320 slice CT (Aquilion one, Toshiba Medical) with tube current dose modulation and VEC; images were reconstructed at 75% of the RR interval with and without AIDR3D. Tube voltages were fixed at 120kV and tube currents were determined by VEC from scout acquisition information (maximum 580mA). Mean and standard deviation (SD) of CT values of the circle of 100mm$^2$ in the center of the cavity of mid levels of left ventricle (LV) and descending aorta (DA) at the same levels filled with contrast material were measured; SD of these values were regarded as degree of noise**.**

**Results:** Using VEC, maximum tube current (MTC) was 463±135mA which constituted a 21% reduction compared with full dose MTC (580mA). MTC on VEC significantly and strongly correlated with BMI (correlation coefficient was 0.60). The mean and SD of CT values of LV and DA were 492±36 Hounsfield Units (HU) and 526±26HU without AIDR3D, respectively; these values were 499±34HU and 527±23HU with AIDR3D, respectively and SDs of LV and DA with AIDR3D were significantly lower than those without AIDR3D (both $P<0.05$). The SDs of LV without AIDR3D were significantly negatively correlated with MTC and BMI (correlation coefficients of SDs of LV with MTC and BMI were -0.33 and -0.36, respectively). However, absolute values of the correlation coefficients of SDs of LV with AIDR3D with MTC (0.15) and BMI (0.33) were reduced compared with those without AIDR3D (0.33 for MTC and 0.36 for BMI, respectively).

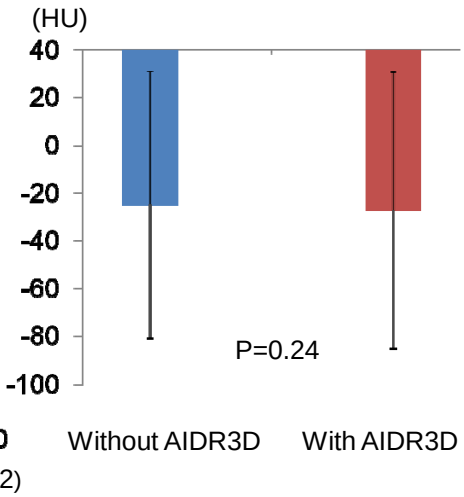
**Conclusions:** Using VEC, MTC would be reduced especially in non obese subjects with low BMI. Without AIDR3D, image noises were increased when MTC decreased. However, with AIDR3D, image noise improved.

**A Clinical Relevance Statement:** Combination of VEC with AIDR 3D in 320 slice CT can reduce total radiation exposure and image noise especially in non obese subjects.

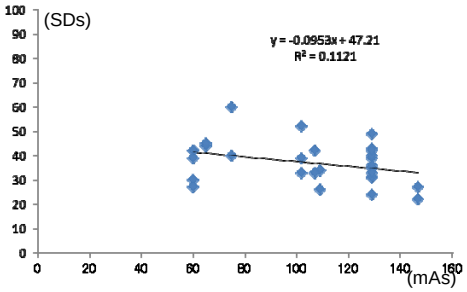
Maximum tube current (MTC) on volume exposure control significantly and strongly correlated with body mass index (BMI)



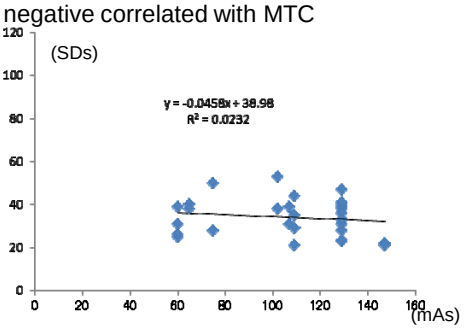

Mean differences of CT values of the cavities of the left ventricle and descending aorta



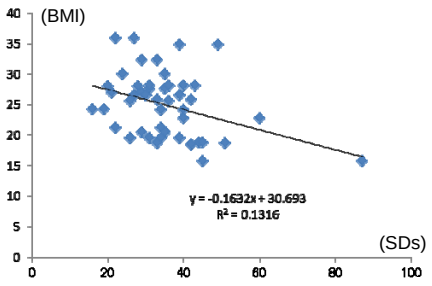

The SDs of LV without ADIR3D significantly negative correlated with MTC



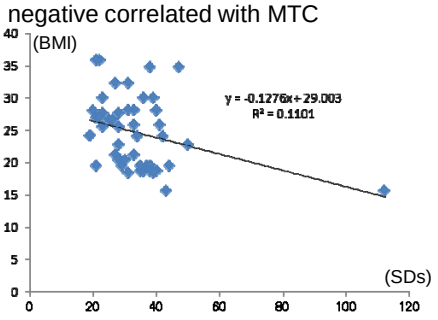

The SDs of LV with ADIR3D significantly negative correlated with MTC




The SDs of LV without ADIR3D significantly negative correlated with BMI




The SDs of LV with ADIR3D significantly negative correlated with MTC



The mean differences of CT values of the cavities of the LV and DA