Clinical Research

Prospective versus retrospective ECG-gating for 64-detector computed tomography of the coronary venous system in pigs

Acquisition couplée à l’ECG prospective versus rétrospective en scanner 64-détecteurs concernant le système veineux coronaire chez le cochon

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Keywords
Multidetector computed tomography; Image quality; Coronary veins; Coronary sinus

Summary
Background. — Multidetector computed tomography (MDCT) provides a non-invasive anatomic description of the coronary veins that may be useful in patients candidates to cardiac resynchronization. Prospective gating reduces radiation exposure but its impact on image quality is unknown in this setting.
Aims. — This study compared image quality and reliability of MDCT angiography of the coronary veins between prospective and retrospective gating.

Abbreviations: AIV, anterior interventricular vein; ECG, electrocardiogram; CNR, contrast-to-noise ratio; CTDI, computed tomography dose index; GCV, great cardiac vein; LV, lateral vein; MCV, middle cardiac vein; MDCT, multidetector computed tomography; ROI, region of interest.
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Background

The coronary venous system is increasingly being used with accesion of percutaneous cardiac therapeutics, including percutaneous mitral annuloplasty [1], transvenous cellular cardiomyploasty [2], radiofrequency catheter ablation [3], mapping [4] and defibrillation [5]. Cardiac resynchronization therapy is now a widely used procedure in patients with end stage heart failure. This technique requires the optimal placement of an electrode in a left ventricular coronary vein close to viable myocardial tissue. Since a considerable morphological variability of the coronary veins exists in humans [6], prior anatomic assessment of these vessels is a critical issue to ensure that therapeutic procedures are achieved.

Methods. — Seven anaesthetized pigs underwent 64-detector row MDCT with prospective and retrospective ECG-gating. MDCT scans were evaluated for visibility of the veins, estimated radiation dose and vein characteristics. Inter- and intra-observer reproducibility was calculated.

Results. — Visibility grades of all veins were significantly decreased in prospective (0.82 ± 0.6) compared to retrospective gating (1.68 ± 0.9; P < 0.001), the lateral vein being missed in two cases when using prospective vs. retrospective gating. The maximal vein length was significantly increased when using retrospective gating (P = 0.015). Inter-observer but not intra-observer reproducibility was dependent on the gating technique for the maximal length and contrast-to-noise ratio (P = 0.003 for both). Heart rate was 82 ± 13 bpm and 86 ± 11 bpm during retrospective and prospective ECG-gating (P = ns) despite full dose of atenolol titration.

Conclusion. — Retrospective gating seems to be superior to prospective gating MDCT to describe the coronary venous system but the conclusions of our study should be confined to high heart rate condition.

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Résumé

Contexte. — Le scanner multidétecteurs permet une description anatomique non invasive des veines coronaires qui peut être utile chez les patients candidats à une resynchronisation cardiaque. L’acquisition en mode prospectif réduit l’irradiation mais son impact sur la qualité des images est inconnu dans ce cas précis.

Objectif. — Cette étude compare la qualité des images et la précision de l’imagerie des veines coronaires en scanner multidétecteurs entre le mode d’acquisition prospectif et rétrospectif.

Méthodes. — Sept cochons anesthésiés ont eu un scanner 64 détecteurs en mode prospectif et rétrospectif couplé à l’ECG. Les images scannographiques ont été évaluées sur la visibilité des veines, la dose de rayons reçue estimée et les caractéristiques des veines. La reproductibilité intra et inter-observateur a été calculée.

Résultats. — Les grades de visibilité de l’ensemble des veines coronaires ont été significativement diminués en mode prospectif (0,82 ± 0,6) en comparaison au mode rétrospectif (1,68 ± 0,9 ; p < 0,001), la veine latérale n’ayant pas été visualisée dans deux cas si nous comparons les acquisitions prospectives et rétrospectives. La longueur maximale des veines était significativement plus élevée lors des acquisitions en mode rétrospectif (p = 0,015). La reproductibilité inter-observateur mais pas celle intra-observateur était dépendante du mode d’acquisition pour la longueur maximale et le rapport contraste sur bruit (p = 0,003 pour les deux). La fréquence cardiaque était de 82 ± 13 bpm et 86 ± 11 bpm durant les acquisitions en mode rétrospectif et prospectif (p = ns) malgré une titration à doses pleines d’atenolol.

Conclusion. — L’acquisition en mode rétrospectif du scanner multidétecteur semble être supérieure à celle en mode prospectif pour décrire le système veineux coronary mais les conclusions de notre étude restent confinées à des fréquences cardiaques élevées.

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Recently, multidetector computed tomography (MDCT) emerged as a non-invasive and accurate imaging technique for anatomic description of coronary veins by specifying their number, trajectory, diameter and possible blockages [7–13]. Despite the need for a higher radiation dose to the patient, retrospective electrocardiographic (ECG) gating remains widely used for assessing coronary artery atherosclerotic lesions due to a better coronary plaque assessment. However, we hypothesized that prospective gating could be sufficient for the description of cardiac venous anatomy, offering the opportunity to reduce radiation exposure without significant loss of detail in the anatomical description of the venous system.

Thus, the purpose of the present study was to compare radiation dose and image quality obtained from coronary
venous MDCT angiography between prospective and retrospective gating in anaesthetized pigs.

Methods

Animals and anaesthesia

All experimental studies were approved by our local and national Ethics Committee and conformed to the European Communities Council Directives guidelines (86/609/EEC) for the care and use of laboratory animals. Experiments were performed in seven male Landrace breed conventional pigs with body weights ranging from 50 to 60 kg. The pigs were delivered at least 24 h prior to the day of study and housed in individual cages. All solid foods were withdrawn during the 12 hours before experiments but the animals had access to water ad libitum. Prior to the MDCT procedure, the pigs were sedated by intramuscular injection of ketamine (15 mg/kg) and xylazine (1 mg/kg). Anaesthesia was induced by 2.5% sevoflurane and intravenous propofol (110 μg/kg per minute) via a 20-G venous access placed in an ear vein. Endotracheal intubation was then performed and anaesthesia was maintained with sevoflurane (0.8%) and 66% nitrous oxide in oxygen plus propofol (50–110 μg/kg per hour) along with a continuous intravenous perfusion of atracurium (0.75 mg/kg per hour) to achieve adequate muscular relaxation. Intravenous buprenorphine (0.3 mg/kg) was used for additional analgesia. The pigs were placed on intermittent positive pressure ventilation (Aestiva 5/MRI 7900, GE Healthcare, France) at 15 breaths/min and the respiratory volume (8–12 mL/kg) adjusted so as to maintain normocapnia. Catheters were placed in the carotid artery and jugular vein to allow for the continuous measurement of arterial pressure and administration of drugs and contrast agent (see below), respectively. Thereafter, the pigs were transferred to the scanner for investigation. Before the imaging protocol, and if tachycardia was present, intravenous atenolol (1 mg/min in titration) was administered in order to maintain heart rate below 70 bpm.

At the end of the experiments, sevoflurane was increased to 4% for 15 minutes and a super-saturated solution of potassium chloride (15 mL, i.v.) was injected rapidly to induce cardiac arrest.

Multidetector computed tomography

All examinations were performed at Cycern research center using a 64-detector MDCT scanner (Lightspeed VCT RX, GE Healthcare, Milwaukee, WI) during a single end-expiratory breath-hold, in the supine position. Each pig underwent a MDCT angiography of the cardiac venous system with both retrospective and prospective ECG-gating (rotation time: 350 ms; detector collimation: 64 × 0.625 mm; tube voltage: 120 to 140 kV at a current of 500 to 600 mA depending on animal weight; craniocaudal direction). For prospectively gated MDCT scans, a commercially available protocol was used (Snapshot Pulse, GE Healthcare, Milwaukee, WI), centred at 65% of the R-R interval with a padding of 125 ms. In each experiment, tube voltage and current were set at similar values for both prospective and retrospective ECG-gated acquisitions. Retrospective and prospective ECG-gated MDCT were performed in a random order. A dual-head power injector (Medrad, Warrendale, PA) was used to provide a three-phase bolus at a rate of 5 mL per second: first, 70 mL of iomeprol 350 mg/mL (Iomeron 350, Bracco Imaging) was administered. Thereafter, 50 mL of a 50%/50% blend of iomeprol and saline was administered. Finally, 20 mL of saline was administered. The MDCT scan acquisition was triggered 7 to 11 seconds (according to heart rate) after the contrast bolus reached the ascending aorta.

Terminology

The terminology used to describe the various tributary veins is based on previous studies [11,14]. Anatomical studies of the pig heart showed a coronary venous system close to that of humans with the exception of a prominent left ayzygous vein draining into the coronary sinus [15].

Anterior interventricular vein

The anterior interventricular vein (AIV) originates in the lower or middle third of the anterior interventricular groove. It follows this groove then turns posteriorly at the left atrioventricular groove to enter the great cardiac vein (GCV).

Great cardiac vein

The great cardiac vein corresponds to the venous segment that runs in the left atrioventricular groove before entering the coronary sinus at approximately a 180° angle. Its ostium coincides with the valve of Vieuxsens in the majority of cases.

Middle cardiac vein

The middle cardiac vein (MCV) originates close to the left ventricular apex, and courses within the posterior interventricular groove toward the base. It usually drains into the coronary sinus just before it arrives in the right atrium.

Lateral vein

Also called left marginal vein, the lateral vein (LV) originates from the lateral face of the left ventricle and drains into the great cardiac vein.

Image analysis

Multiphase reconstructed MDCT acquisitions were processed on a dedicated workstation (Advantage Workstation 4.4; GE Healthcare, Milwaukee, WI). A systematic review of reconstructed images from 5 to 95% R-R interval was undertaken to select the stage with fewest motion artefacts. Three-dimensional volume-rendered reconstructions were used to obtain a global approach of the anatomy of the cardiac veins. Then, the course of the veins was evaluated in three orthogonal planes using multplanar reformatting. As described previously [16], visibility of the coronary sinus and each vein was evaluated visually using a 4-point scale (grade 0: not visible; grade 1: visible with discontinuity; grade 2: visible with irregular borders; grade 3: visible as a smoothly bordered vascular structure). According to this classification, visibility was classified as good (grade 2–3) or poor (grade 0–1). The length of the centre lumen line of
each vein from the ostium to the most proximal discernable point was measured through the use of multiplanar reconstructions. The ostium of the coronary sinus was defined as the site where the coronary sinus makes an angle with the right atrium. The size of the ostia of the coronary sinus was measured in two orthogonal axes (anteroposterior and superoinferior axis) and all the visible veins perpendicularly to the vessel axis using multiplanar reconstructions. The contrast-to-noise ratio (CNR) of the coronary sinus and each vein was calculated using a previously described technique [7]. A 3-dimensional region of interest (ROI) encompassing the vein lumen was placed centrally in the vein close to its ostium and then copied and pasted in adjacent tissues near the ostium of the vein. The difference between mean vessel and mean adjacent tissue density (in CT units) was divided by image noise, determined as the standard deviation of CT attenuation in a 3-dimensional ROI placed within the contrast-enhanced ascending aorta. The CNR could then be calculated as follows:

\[
\text{CNR} = \frac{\text{CT attenuation in lumen} - \text{CT attenuation in adjacent tissue}}{\text{image noise}}
\]

Images were analysed by two independent observers. Discrepancies in visibility grade assessment were resolved by consensus. One of the two observers performed an additional blinded analysis one month later to evaluate intra-observer reproducibility. The averaged results of these two measurements were used for further statistical analysis of quantitative data. Intra- and inter-observer reproducibility was calculated using linear regression.

Radiation dose estimates for MDCT examinations of the heart are expressed by using the volume CT dose index in milligrays (mGy) and the dose-length product in milligray-centimeters (mGy cm). Radiation doses were derived from a 32 cm diameter phantom measurement provided by the manufacturer. The effective dose was not calculated as the \( k \) factor value (in mSv mGy\(^{-1}\) cm\(^{-1}\)) is not yet established in pigs.

**Statistical analyses**

Quantitative data are expressed as mean ± standard deviation and categorical variables as frequencies. Kappa statistics were performed for intra- and inter-observer agreement of image quality assessment. Linear regression and Bland-Altman were used to determine the intra- and inter-observer correlation for quantitative variables. The impact of ECG-gating on reproducibility was evaluated by a paired \( t \)-test for the significance of the difference between the correlation coefficients obtained from linear regression (retrospective vs. prospective). Mann-Whitney \( U \)-test was performed to determine the differences between the two acquisition modes (retrospective and prospective ECG-gating) for quantitative variables (radiation dose, diameter, maximal length and contrast-to-noise ratio) and the contrast-to-noise ratio differences between two groups of visibility grades (grade 0–1 and grade 2–3).

Analysis of variance with a post hoc Fisher test was used to evaluate the possible interactions between categorical variables on the assessment of quantitative data. A

\[ P \text{ value} < 0.05 \] was considered statistically significant. The Statview 4.0 software package (Abacus, CA) was used for the statistical analyses.

**Results**

**Multidetector computed tomography data**

All pigs showed a constant sinus rhythm with a mean heart rate of \( 82 \pm 13 \) bpm and \( 86 \pm 11 \) bpm during retrospective and prospective ECG-gating respectively (\( P = \) ns) despite full dose of atenolol titration. The optimal temporal window for assessing the coronary venous system without significant motion artefacts ranged from 60% to 80% of the R-R interval: 80% in two cases, 60% in one case, 70% in one case and 75% in three cases.

The coronary sinus was visualized in all cases. The visibility grade of the coronary sinus was similar using retrospective and prospective ECG-gating (respectively \( 3 \pm 0 \) and \( 2.7 \pm 0.5 \), \( P = 0.37 \); ns). No difference was observed between the two gating techniques for the contrast-to-noise ratio, and anteroposterior or superoinferior diameters of the coronary sinus (Table 1).

The great cardiac vein and the anterior interventricular vein were visualized in all cases. The middle cardiac vein was not found in 1/7 cases (14%) using retrospective gating and in 3/7 cases (43%) using prospective gating. The lateral vein was not found in 3/7 cases (43%) using retrospective gating and in 5/7 cases (71%) using prospective gating. All veins visualized using prospective gating were also seen using retrospective gating. The mean visibility grade for all veins was significantly decreased in prospective (0.82 ± 0.6) compared to retrospective gating (1.68 ± 0.9; \( P < 0.001 \)). Moreover, multiple analysis of variance showed that both the type of coronary veins (\( F = 10.523 \), \( P < 0.0001 \)) and the gating technique (\( F = 26.585 \), \( P < 0.0001 \)) had a significant impact on the visibility grade without interaction (\( F = 1.231 \), \( P = 0.3088 \), ns). The visibility grades are depicted in Fig. 1 showing a decreased grade for each vein using prospective gating. The lack of visibility of the lateral vein using prospective gating is illustrated in Fig. 2. Grade 0/1
Table 1  Characteristics of the coronary sinus according to prospective and retrospective ECG-gating.

<table>
<thead>
<tr>
<th>Data</th>
<th>Retrospective gating</th>
<th>Prospective gating</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visibility grade</td>
<td>3 ± 0</td>
<td>2.7 ± 0.5</td>
<td>0.37</td>
</tr>
<tr>
<td>Anteroposterior diameter (mm)</td>
<td>7.8 ± 1.2</td>
<td>8 ± 1</td>
<td>0.75</td>
</tr>
<tr>
<td>Superoinferior diameter (mm)</td>
<td>10.4 ± 1.1</td>
<td>10.5 ± 1.5</td>
<td>0.65</td>
</tr>
<tr>
<td>Contrast-to-noise ratio</td>
<td>4 ± 1.6</td>
<td>3.5 ± 0.9</td>
<td>0.75</td>
</tr>
</tbody>
</table>

Veins showed decreased contrast-to-noise ratio compared to grade 2/3 (3.8 ± 1.8 vs. 5.4 ± 2, P = 0.01).

As shown in Table 2, the gating technique did not influence either the measurement of the vein diameter or the contrast-to-noise ratio, but significantly impacted on the maximal visible length of coronary veins, that increased from 37.7 ± 19.3 mm to 55.8 ± 24.2 mm (P = 0.015) according to prospective vs. retrospective gating, respectively.

Figure 2.  Computed tomography axial images of the great cardiac vein (GCV), the anterior interventricular vein (AIV) and the lateral vein (LV) using retrospective and prospective ECG-gating in one pig. The lateral vein could not be visualized using prospective ECG-gating.
Table 2. Characteristics of coronary veins according to prospective and retrospective ECG-gating (mean and standard deviation): maximal length, diameter and contrast-to-noise ratio.

<table>
<thead>
<tr>
<th>ECG-gating</th>
<th>Maximal length (mm)</th>
<th>Diameter (mm)</th>
<th>CNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retrospective</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GCV</td>
<td>77 ± 3.5'</td>
<td>4.5 ± 0.5</td>
<td>6.1 ± 2.4</td>
</tr>
<tr>
<td>AIV</td>
<td>70.5 ± 13.9'</td>
<td>3.9 ± 0.2</td>
<td>5.1 ± 2.2</td>
</tr>
<tr>
<td>LV</td>
<td>20.1 ± 4.2</td>
<td>2.6 ± 0.4</td>
<td>3.5 ± 1.2</td>
</tr>
<tr>
<td>MCV</td>
<td>37.6 ± 10</td>
<td>3.1 ± 0.3'</td>
<td>4.6 ± 1.9</td>
</tr>
<tr>
<td>Mean value</td>
<td>55.8 ± 24.2'</td>
<td>3.7 ± 0.8</td>
<td>5 ± 2.1</td>
</tr>
<tr>
<td>Prospective</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GCV</td>
<td>43.2 ± 21.4</td>
<td>4.8 ± 0.6</td>
<td>5.3 ± 2.1</td>
</tr>
<tr>
<td>AIV</td>
<td>47.3 ± 14.2</td>
<td>4.8 ± 0.6</td>
<td>5.3 ± 2.1</td>
</tr>
<tr>
<td>LV</td>
<td>16.8 ± 1.5</td>
<td>3.1 ± 0.3</td>
<td>3.2 ± 0.1</td>
</tr>
<tr>
<td>MCV</td>
<td>21.5 ± 11</td>
<td>3.6 ± 0.2</td>
<td>3.3 ± 1.3</td>
</tr>
<tr>
<td>Mean value</td>
<td>37.7 ± 19.3</td>
<td>4 ± 0.8</td>
<td>4.1 ± 1.9</td>
</tr>
</tbody>
</table>

GCV: great cardiac vein; AIV: anterior interventricular vein; LV: lateral vein; MCV: middle cardiac vein; CNR: contrast-to-noise ratio.

* P < 0.02 vs. prospective gating.

Multiple analysis of variance showed that both the type of coronary veins (F = 22.807, P < 0.0001) and the gating technique (F = 19.709, P < 0.0001) significantly impact on the maximal length of coronary veins, without interaction between these two factors (F = 2.035, P = 0.1263, ns). The maximal length of the veins differed according to the type of vein, especially between the lateral vein and GCV (P < 0.001) or AIV and between middle cardiac vein and GCV or AIV (P < 0.001).

Estimate of the radiation dose

The volume computed tomography dose index (CTDI) was increased with retrospective compared to prospective ECG-gating (83.1 ± 30.6 and 28 ± 10.3 mGy, respectively; P = 0.009), as well as the dose-length product (1635 ± 604 and 435 ± 175 mGy cm, respectively; P = 0.002).

Reproducibility

Linear regression and Bland-Altman analysis demonstrated a high intra- and inter-observer reproducibility for measurement of the coronary sinus diameters and contrast-to-noise ratio (Table 3).

Intra- and inter-observer reproducibility was optimal for the visibility grades of the coronary sinus (kappa values of 1 and 0.64 respectively) and the coronary veins (kappa value of 0.8 for both).

In a similar manner, the intra- and inter-observer reproducibility was good for the maximal length of the veins (respectively R = 0.95; P < 0.001, Fig. 3a and R = 0.91; P < 0.001, Fig. 3b), diameters (respectively R = 0.86; P < 0.001, Fig. 4a and R = 0.89; P < 0.001, Fig. 4b) and contrast-to-noise ratio (respectively R = 0.90; P < 0.001, Fig. 5a and R = 0.78; P < 0.001, Fig. 5b).

However, inter- but not intra-observer reproducibility was dependent on the gating technique for the maximal length of the veins and contrast-to-noise ratio (P = 0.003 for both. Table 4).

Discussion

This is the first study in which prospective vs. retrospective ECG-gating for MDCT of the coronary venous system has been...
evaluated. The results demonstrate that retrospective gating is superior to prospective gating in terms of visibility of the coronary venous system, with the exception of the coronary sinus. The visibility grades varied between veins and were decreased especially for the lateral vein. In addition, intra- and inter-observer reproducibility were good with the inter-observer reproducibility being better when using a retrospective gating approach. Despite an increased radiation dose, these results are compatible with a clinical use of retrospective versus prospective gating for planning therapeutic interventions that requires catheterization of the venous coronary veins.

**Visibility of the coronary venous system**

Previous results demonstrated that MDCT with retrospective ECG-gating provided a valuable anatomical description of the coronary venous system in humans [7,9–13,16]. This was particularly obvious in patients with heart failure who were evaluated before cardiac resynchronization, as the location of the coronary sinus ostium [17] and the length of the coronary veins are frequently altered in these patients [18]. Cardiac MDCT is non-invasive but involves exposure of patients to significant radiation doses [19]. Recent studies suggested that prospective ECG-gating reduced the administered radiation dose without deterioration of the image quality of the coronary artery CT angiography in humans [20,21]. In the present experimental study, imaging the coronary venous system yielded different results. Visibility grades were significantly decreased when using prospective gating. The maximal vein length was also reduced with prospective gating because of an apparent smaller vein diameter that further decreased from the ostia to the distal bed, with even a loss of distal visibility for some segments.

**Table 3** Intra- and inter-observer reproducibility for coronary sinus measurements (linear regression and Bland-Altman analysis).

<table>
<thead>
<tr>
<th>Reproducibility</th>
<th>Linear regression</th>
<th></th>
<th></th>
<th>Bland-Altman</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Regression equation</td>
<td>R value</td>
<td>P value</td>
<td>Mean difference [95% CI]</td>
<td>R value</td>
<td>P value</td>
</tr>
<tr>
<td>Intra-observer</td>
<td>Anteroposterior diameter</td>
<td>$Y = 1.04 + 0.89X$</td>
<td>0.83</td>
<td>&lt;0.001</td>
<td>0.21 [−1.1; 1.51]</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>Superoinferior diameter</td>
<td>$Y = 4.2 + 0.52X$</td>
<td>0.80</td>
<td>&lt;0.001</td>
<td>−1.02 [−2.98; 0.94]</td>
<td>−0.60</td>
</tr>
<tr>
<td></td>
<td>Contrast-to-noise ratio</td>
<td>$Y = 0.62 + 0.75X$</td>
<td>0.87</td>
<td>&lt;0.001</td>
<td>0.39 [−1; 1.77]</td>
<td>0.31</td>
</tr>
<tr>
<td>Inter-observer</td>
<td>Anteroposterior diameter</td>
<td>$Y = −0.71 + 1.04X$</td>
<td>0.90</td>
<td>&lt;0.0001</td>
<td>0.43 [−0.72; 1.58]</td>
<td>−0.30</td>
</tr>
<tr>
<td></td>
<td>Superoinferior diameter</td>
<td>$Y = −5.78 + 1.59X$</td>
<td>0.93</td>
<td>&lt;0.0001</td>
<td>−0.05 [−1.84; 1.74]</td>
<td>−0.83</td>
</tr>
<tr>
<td></td>
<td>Contrast-to-noise ratio</td>
<td>$Y = 1.17 + 0.88X$</td>
<td>0.72</td>
<td>0.003</td>
<td>−0.36 [−2.89; 2.17]</td>
<td>−0.049</td>
</tr>
</tbody>
</table>

**Table 4** Correlation coefficients and Bland-Altman analysis for intra- and inter-observer reproducibility according to ECG-gating.

<table>
<thead>
<tr>
<th></th>
<th>Linear regression</th>
<th></th>
<th></th>
<th>Bland-Altman</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Retrospective gating</td>
<td>Correlation coefficient</td>
<td>Retrospective gating</td>
<td>Correlation coefficient</td>
<td>Mean difference [95% CI]</td>
<td>R value</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Correlation coefficient</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Mean difference [95% CI]</td>
<td>R value</td>
<td>P value</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mean difference [95% CI]</td>
<td>R value</td>
<td>P value</td>
</tr>
<tr>
<td>Intra-observer Maximal length</td>
<td>0.96</td>
<td>0.90</td>
<td>0.1</td>
<td>4.71 [−8.47; 17.89]</td>
<td>0.16</td>
<td>(0.44)</td>
</tr>
<tr>
<td>Diameter</td>
<td>0.89</td>
<td>0.81</td>
<td>0.35</td>
<td>−0.01 [−0.79; 0.77]</td>
<td>0.22</td>
<td>(0.28)</td>
</tr>
<tr>
<td>CNR</td>
<td>0.92</td>
<td>0.87</td>
<td>0.45</td>
<td>0.20 [−1.57; 1.97]</td>
<td>−0.06</td>
<td>(0.80)</td>
</tr>
<tr>
<td>Inter-observer Maximal length</td>
<td>0.95</td>
<td>0.80</td>
<td>0.03</td>
<td>−0.11 [−15.85; 15.63]</td>
<td>−0.04</td>
<td>(0.83)</td>
</tr>
<tr>
<td>Diameter</td>
<td>0.90</td>
<td>0.90</td>
<td>0.91</td>
<td>0.42 [−0.32; 1.16]</td>
<td>−0.21</td>
<td>(0.32)</td>
</tr>
<tr>
<td>CNR</td>
<td>0.90</td>
<td>0.66</td>
<td>0.03</td>
<td>−0.05 [−2.06; 1.97]</td>
<td>−0.15</td>
<td>(0.50)</td>
</tr>
</tbody>
</table>

CNR: contrast-to-noise ratio.
MDCT allowed the visualization of the main cardiac venous tributaries but other imaging techniques such as coronary venous angiography was reported recently to provide better results for second- and third-order tributaries [9,22]. Mulhenbruch et al. [16] visualized 6/7 lateral veins compared to conventional contrast angiography, and Abbara et al. [7] missed 4 lateral veins out of 54 patients. Van de Veire et al. [13] correctly identified the lateral vein in healthy subjects (71%) but the visibility rate decreased to 61% in patients with coronary artery disease and to 27% in patients with a history of myocardial infarction. In the present study, the lateral vein had the smallest diameter. As previously described, the lateral vein was not identified in several cases when using prospective gating, in a higher proportion compared to retrospective gating.

Regarding the coronary sinus, no difference was noted between the two acquisition modes for the visibility grade, vein diameter or the contrast-to-noise ratio. The coronary sinus is a large vascular structure, which can be imaged even without any iodinated contrast injection. Because of its size, the coronary sinus was not pooled with the coronary veins for statistical analysis. According to previous data collected in humans, the superoinferior diameter of the coronary sinus is greater than the anteroposterior diameter [10,13].

**Veins diameters**

The diameter of the veins is an important criterion for planning a cardiac resynchronization procedure, especially for the selection of both the target vein and left ventricular lead in patients scheduled for multisite stimulation. Diameters were measured at the ostia and were found to be larger using the prospective than the retrospective mode. When using retrospective ECG-gating, the phase that offers the most optimal image quality in pigs was centred on 75% of the R-R interval in our study. However, according to human studies [7,16], the prospective ECG-gated acquisition was set at 65% of the R-R interval. It is likely that this difference may explain the discrepancies in assessing vein diameters. Nevertheless, vein diameters were in accordance with previous gross pathologic findings in humans. In 19 human hearts obtained at necropsy in which the coronary venous system was injected and fixed with neoprene latex, Hood [23] reported mean vein diameters (with a wide range of variability) of 4.1, 4.4, 2.8 and 2.5 mm for the middle cardiac vein, great cardiac vein, lateral vein and posterior cardiac vein, respectively.

**Image quality**

To our knowledge, there is no published data about quantitative analysis of MDCT image quality of the coronary venous system in pigs. Indeed, the available data in humans is sparse. Abbara et al. [7] found a higher contrast-to-noise ratio than that reported in the present study, with values ranging from 6 to 8.5, but the details of contrast and image noise measurements were not provided. Several
explanations are possible. In the latter study, MDCT was originally indicated for the assessment of the coronary arterial system in humans. Retrospectively, the authors selected MDCT data allowing a reliable analysis of the venous system, while introducing a possible enrolment bias. Moreover, attenuations measurements of the lumen of veins and adjacent tissue was performed using small 2-dimensional ROIs (3–4 mm$^2$) regarding both the size of anatomic structures and the resolution of the CT scanner (16 detectors of 0.75 mm). Under these conditions, the reliability of contrast-to-noise ratio assessment remains uncertain and the reproducibility was not provided. In the present study, the use of larger 3-dimensional ROIs (30 mm$^2$) provides a more reliable evaluation of CT attenuation. Lembcke et al. reported higher contrast-to-noise ratio values obtained when examining coronary arteries using MDCT in swine [24], most likely due to a direct access of iodine contrast-to the coronary arterial system.

Reproducibility

Studies focusing on the coronary venous system usually did not provide the reproducibility of quantitative parameters [7,10–13,16–18]. In the perspective of treatment planning based on a suitable assessment of coronary veins for the insertion of a left ventricular pacemaker lead, MDCT should provide reproducible data. Our study showed a good intra- and inter-observer reproducibility for both quantitative and qualitative assessment of the coronary venous system, especially when using a retrospective gating.

Study limitations

This study is based on an animal model in which the cardiovascular system is very similar to human heart anatomy. However, our investigation did not include the use of gross pathological vessels or conventional contrast angiography of the venous system. Thus, we cannot conclude whether the failure to visualize the left lateral vein using retrospective gating was related to a substantial variation in the cardiovascular anatomy of the pig or to a technical failure to image a vascular structure with lumen diameter of less than 2 mm. Another limitation of the present study is related to the fact that, despite intravenous beta-blockade, the pig’s heart rate could not be maintained steadily below 70 bpm, possibly impacting on the acquisition quality when using prospective ECG-gating. However, we should note that cardiac resynchronisation is indicated in patients with heart failure with a New York Heart Association functional class III or IV, in whom sinus tachycardia is a common finding.

Conclusion

In the present preclinical study, retrospective ECG-gating computed tomography was superior to prospective ECG-gating to describe the coronary venous system, especially for analyzing the lateral vein, which is a privileged site for left ventricular lead implantation. With prospective ECG-gating, the coronary sinus and origin of its tributaries were correctly visualized although the quality of MDCT imaging of small veins was decreased. These results suggest that the use of retrospective ECG-gating should be preferred for MDCT analysis of the coronary venous system but the conclusions of our study should be confined to high heart rate condition.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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