Anomalous coronary arteries can be benign or life threatening. Novel advances on multi-detector computed tomography (MDCT) provide a noninvasive technique and offer an accurate diagnostic modality to visualize the origin and course of anomalous coronary arteries by a 3D display of anatomy. Thus we demonstrated anomalies of coronary arteries shown by 64-MDCT in our institution.

540 subjects referred to our Hospital for MDCT coronary angiography were included in this study. These subjects were between the ages of 12 and 90 years (mean 59±12.6 years) including 297 (55%) male and 243 (45%) female. Post-processing techniques such as volume rendering (VR) and maximum intensity projection (MIP) were applied to demonstrate the coronary artery anatomy. Both a radiologist and a cardiologist evaluated all examinations.

The incidence of anomalous anatomical origin and course of the coronary arteries in our study group was 15% (n = 81). The anomalies found in our study are absence of left main coronary artery (n = 3, 0.5%), high take-off origin of left main coronary artery (n= 1, 0.2%), ectopic origin of right coronary artery from the left coronary sinus (n = 8, 1.5%), and myocardial bridging (n = 68, 12.6%).

MDCT with VR and MIP techniques is practical for assessment of anomalous coronary arteries and helpful for radiologist, cardiologist and surgeon.

Anomalous coronary arteries can be benign or life threatening [1, 2]. Anomalous coronary arteries are usually incidental findings during conventional coronary angiography [3, 4, 5]. Identification of anomalous coronary anatomy is important for cardiologist and surgeon because of difficulty during catheterization, operation of great vessels and its rare complications such as myocardial ischemia and sudden cardiac death [2]. Novel advances on multidetector computed tomography (MDCT) provide a noninvasive technique and offer an accurate diagnostic modality to visualize the origin and course of anomalous coronary arteries by a 3D display of anatomy [2, 4, 5, 6, 7, 8, 9]. In this article, we aimed to demonstrate remarkable anomalies of coronary arteries shown by 64-multidetector computed tomography (64-MDCT) coronary angiography in our institution.

MATERIALS AND METHODS

Subjects

Five hundred and forty subjects referred to our Hospital from Jun. 2006 to Jun. 2007 were recruited in this study. The subjects were between the ages of 12 and 90 (mean 59±12.6 years), including 297 (55%) male and 243 (45%) female; 432 for health examination, 105 for coronary symptoms, and 3 under 18 years old with past history of Kawasaki disease. When performing the practice in young persons, we adjusted kV(100-120), mA (250-350) and pitch (0.3-0.4) to decrease the radiation dose. We had no attempt to perform MDCT angiography for patients with history of sustained arrhythmia (such as atrial fibrillation, ventricular premature contraction),
known allergic reaction to contrast media, deteriorated renal function (serum creatinine, >1.6 mg/dl), pregnancy, respiratory insufficiency, poor clinical condition, bronchial asthma and atrioventricular conduction block in which use of β-blocker was contraindicated, and those unable to hold their breath up to 10 seconds.

Pre-medication

Patients were all in sinus rhythm and received oral β-blocker (10-40 mg of oral Propranolol administered 0.5 hour before the scan) except for those with a heart rate below 65 beats per minute. For those who received β-blockers, when their heart rate below 70 beats per minute we started the examinations. Those who had poor control of heart rate (over 70) were excluded in this study. The dosage of β-blockers applied to the subjects was from 10mg to 40 mg and it was depended on the subjects' heart rate.

Scan Protocol

MDCT was performed in a 64-MDCT scanner (Brilliance; Philips Medical Systems, Cleveland, OH) during one breath hold period (8-10 seconds). The parameters of our scanning protocol were: 64 × 0.625-mm collimation, 120-140 kV, 400-600 mA, 0.42 second rotation time, a pitch value of 0.2, 0.8-mm slice thickness, and 0.6-mm reconstruction interval. Bolus-tracking method was used and the scanning field included entire heart from proximal aorta (1-2 cm below the carina) to cardiac apex. Sixty to 90 ml of iodinated contrast medium (Optiray 350, Ioversol 350 mg/ml, Canada) was injected intravenously via antecubital vein at a flow rate of 5-8 ml/s followed by 50 ml of saline at a flow rate of 5 ml/s. Retrospective ECG-gated reconstructions were routinely generated every 5% of the R-R interval from 0% to 95% of the R-R interval. Among these different data sets, we chose the best one to evaluate existence, origin, calibration, and course. In addition, the maximum intensity projection (MIP) and volume rendering (VR) techniques, and the unique display of globe views and 2D map (Philips Extended BrillianceTM Workspace v 3. 0. 1. 3200, Netherland) were used.

Definition and collection of coronary anomaly

The 4 main coronary arteries evaluated are the left main coronary artery (LMCA), left anterior descending artery (LAD), left circumflex artery (LCx) and right coronary artery (RCA). Normal LMCA arises from the left coronary sinus, and is 5 to 10 mm in length. It passes leftward posterior to the pulmonary trunk and bifurcates into the LAD and LCx arteries. The LAD artery runs in the anterior interventricular groove and terminates near the apex of the heart. It gives off diagonal branches to the anterior free wall of the left ventricle and septal branches to the anterior interventricular septum. The LCx artery runs in the left atrioventricular groove. It gives off obtuse marginal branches to the lateral left ventricle. The RCA arises from the right coronary sinus and runs rightward posterior to the pulmonary outflow tract and then inferiorly in the right atrioventricular groove toward the posterior interventricular septum [2].

The anomalous coronary arteries we attempted to collect include (1) absent LMCA. Absent LMCA means the LAD and LCx arteries arise separately [6]. (2) High take-off LMCA. It means origin of LMCA gets off from the point above junctional zone. (3) Ectopic origin of LMCA from right coronary sinus. (4) Double LAD and ectopic origin of LAD from RCA. (5) Ectopic origin of LCx from right coronary sinus. (6) Ectopic origin of LCx from RCA, absence of RCA. (7) Ectopic origin of RCA from left coronary sinus. (8) Ectopic origin of RCA from LAD. (9) Myocardial bridging. Coronary arteries are normally located superficial to myocardium. Myocardial bridging is present when a segment of an epicardial coronary artery runs through the myocardium rather than on the surface [8, 9, 10].

RESULTS

The incidence of anomalous anatomical origin and course of the coronary arteries in our study was 15 % (n = 81). The anomalies found in our study are absence of the left main coronary artery (n = 3, 0.5%) (Fig. 1a, 1b), high take-off origin of left main coronary artery (n= 1, 0.2 %) (Fig. 2a, 2b), ectopic origin of RCA from the left coronary sinus (n = 8, 1.5%) (Fig. 3a, 3b, 3c), and myocardial bridging (n = 69, 12.6%). Among these 69 myocardial bridging cases, 68 were located in proximal, middle and distal portion of LAD (Fig. 4a, 4b, 4c), 1(1.4%) located in proximal and middle LAD, 47(68.1%) located in proximal and middle LAD, 47(68.1%) located in middle LAD, 6(8.7%) located in middle and distal LAD, 14(20%) located in distal LAD. Only 1(1.4%) located in terminal RCA (Fig. 5a, 5b). The mean length of myocardial bridging is 10.2 mm (ranging from 3.6 to 30.2 mm), and the mean depth is 2.2 mm (ranging from 1.0 to 5.6 mm). Thirty-five (51%)
of these cases underwent MDCT as part of health examination, and 34 (49%) are for evaluation of suspicious coronary artery disease.

DISCUSSION

Conventional coronary catheter angiography is the standard to assess coronary artery disease, but it has some limitations [2, 4, 7]. Coronary angiography is an invasive and expensive procedure. It only selectively visualizes one vascular tree at a time and it may be difficult to delineate the vascular tree due to its complex 3D geometry displayed in 2D fluoroscopically. Another limitation is adequate procedure and reading depends on the experiences of angiographers, and this causes a large percentage of coronary artery anomalies to be classified incorrectly on conventional catheter angiography. However, novel...
Diagnosis of anomalous coronary arteries

Advances on MDCT provide a noninvasive technique and offer an accurate diagnostic modality to visualize the origin and course of anomalous coronary arteries by a MIP and 3D VR display of heart [2, 4, 5, 6, 7, 8, 11]. Recent developments in helical CT technology had greatly increased its utility in the evaluation of the coronary arteries [12]. With overlapping reconstruction during the cardiac cycle,

**Figure 3.** This is a 29 years old female with ectopic origin of RCA (right coronary artery) from left coronary sinus. 

a. Axial maximum intensity projection image (slice thickness 5mm). RCA is arising from the left sinus of Valsalva and runs between aorta and pulmonary artery. 

b. Volume rendering display. RCA is arising from the left sinus of Valsalva. 

c. The 2D map (slice thickness: 6mm) demonstrates the anomalous origin of RCA clearly. (Ao: aorta, PA: pulmonary artery)

**Figure 4.** Myocardial bridging locates at left anterior descending artery (LAD). 

a. Curved multi-planar reconstruction (cMPR) displays myocardial bridging in middle LAD (arrows) 

b. Sagittal maximum intensity projection image. It displays the intramyocardial course and embedding in the myocardium of the middle LAD (white arrows). 

c. Volume rendering displays from anterior view. Intramyocardial course and embedding into the myocardium of the LV indicates left ventricle. (white arrow)
100(0-99% R-R interval) phases can be obtained. The better temporal resolution and the ability to choose the optimal cardiac phase result in a near cessation of physiologic motion.

Common post-processing methods include MIP, VR, cMPR, etc. 2D map and Globe view are unique in Phillips, and it can help to demonstrate the origin and course of coronary arteries very well. However, it is not accurate to measure the length and depth of myocardial bridging. The slab thickness is also an important factor to display the images clearly.

An anomalous origin and course of the coronary arteries can be benign or life threatening. The prevalence of coronary artery anomalies is about 0.3-1.2% in angiography [1, 2, 6, 13], and in 0.3% of patients at autopsy [14, 15]. The ratio of coronary artery anomalies is 15% in our study. But when excluding myocardial bridging, the number decreases to 2.4%. Congenital coronary artery anomalies are the second most common cause of sudden death due to structural heart disease in young athletes [15]. In particular, an anomalous vessel that crosses between the aorta and the main pulmonary artery, either a left coronary artery originating from the right sinus or a right coronary artery emanating from the left sinus, may be associated with a poorer outcome [15, 17].

In the past years, some studies have proposed a possible anatomical-clinical classification of coronary artery anomalies that divides them into “minor” and “major” according to their clinical relevance [18, 19, 20, 21]. In 2003, Rigatelli et al. [22] proposed a more complete classification, which divided coronary artery anomalies into four classes based on their clinical relevance (Table 1) [23, 24, 25], and gave aids in management and clinical follow-up. These 4 classification are benign, relevant, severe and critical, and myocardial bridges are divided into five groups (score 1-5) on the basis of their length (<1 or >1 cm) and their reduction in diameter during cardiac contraction (<25%, 50% or >75%) [18, 24].

### Table 1. Clinical relevance based classification of coronary artery anomalies in the adults.

<table>
<thead>
<tr>
<th>Class</th>
<th>Coronary artery anomalies</th>
</tr>
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<tbody>
<tr>
<td>I-Benign</td>
<td>Ectopic origin of the LCx from the RS</td>
</tr>
<tr>
<td></td>
<td>Separate origin of the LCx and LAD</td>
</tr>
<tr>
<td></td>
<td>Ectopic origin of the LCx from the RCA</td>
</tr>
<tr>
<td></td>
<td>Ectopic coronary origin from the AO</td>
</tr>
<tr>
<td></td>
<td>Dual LAD type I-IV*</td>
</tr>
<tr>
<td></td>
<td>Myocardial bridge (score ≤ 5)*</td>
</tr>
<tr>
<td></td>
<td>Coronary artery fistula</td>
</tr>
<tr>
<td>II-Relevant</td>
<td>Single coronary artery (R-L, I-II-III, A-P*)</td>
</tr>
<tr>
<td></td>
<td>Ectopic origin of the LCA from the PA</td>
</tr>
<tr>
<td></td>
<td>Atresic coronary artery</td>
</tr>
<tr>
<td></td>
<td>Hypoplastic coronary artery</td>
</tr>
<tr>
<td>III-Severe</td>
<td>Ectopic origin of the LCA from the RS</td>
</tr>
<tr>
<td></td>
<td>Ectopic origin of the RCA from the LS</td>
</tr>
<tr>
<td></td>
<td>Ectopic origin of the RCA from the PA</td>
</tr>
<tr>
<td></td>
<td>Single coronary artery (R-L, I-II-III, B*)</td>
</tr>
<tr>
<td></td>
<td>Myocardial bridge (score 5)*</td>
</tr>
<tr>
<td>IV-Critical</td>
<td>Class II and superimposed CAD</td>
</tr>
<tr>
<td></td>
<td>Class III and superimposed CAD</td>
</tr>
</tbody>
</table>

LCx = left circumflex artery; RS = right sinus; LAD = left anterior descending artery; RCA = right coronary artery; AO = ascending aorta; LCA = left coronary artery; PA = pulmonary artery; LS = left sinus; CAD = coronary artery disease, * according to the classification Sindola-Franco et al. [23]; † according to Angelini et al. [24], ‡ according to the classification of Lipton ea al. [25].
However, our cases were not classified into these 4 classes, because we could not divide myocardial bridges into 5 groups. The limitation is due to motion artifacts during systolic phase, which caused difficulty in assessing the ratio of cardiac contract.

Recognition of coronary anomalies is important in patients who are going to undergo coronary catheter angiography, coronary interventions, and cardiac surgery. Some specific anomalies of the origin and course of the coronary arteries have been recognized as a leading cause of sudden cardiac death, especially in military recruits and young athletes [2, 3, 6, 26]. The patients in whom the aberrant arteries pass between the main pulmonary artery and aorta are at highest risk [27, 28]. Such patients may be indicated in coronary artery bypassing grafting [29].

The coronary artery anomalies in this study are discussed as following.

**Absent LMCA**

In 0.41% of cases, the left main artery is absent. This anomaly contributes to 30.4% of all coronary anomalies. If the LMCA is absent, one of the following may occur: (a) LAD and LCx arteries may arise from the left sinus of Valsalva via separate ostia, with both of normal length and course; (b) the LCx artery may arise from the right sinus of Valsalva or RCA and follow a course posterior to the aorta; (c) LAD may arise from the right sinus of Valsalva or RCA and follow either a septal course or an anterior free wall course; or (d) LAD may arise from the noncoronary aortic sinus, with its initial portion posterior to the aorta and following a course anteriorly toward its normal position [2]. In our institution, the ratio of absent LMCA is 0.5%. This anomaly is 3.7% of all coronary anomalies in our study, which is 10 times lower than the result that Duren et al. published [2], may be due to myocardial bridging including in our study. The anomaly of myocardial bridging is 85% of all coronary anomalies in our study group.

**High take-off of the LMCA**

Vlodaver et al. reported that both coronary ostia were situated above the sinutubular junction in 6% of randomly selected adult hearts. High take-off of the coronary arteries usually presents no major clinical problems, but it may cause difficulty in cannulating the vessels during coronary catheter angiography [10].

**Ectopic origin of RCA from the left coronary sinus**

Normal RCA arises from the right coronary sinus and runs rightward posterior to the pulmonary outflow tract and then inferiorly in the right atrioventricular groove toward the posterior interventricular septum [2]. Ectopic origin of RCA from left coronary sinus refers as abnormal RCA arises from the left coronary sinus. Three subtypes of anomalous origin of the RCA from the left coronary sinus are classified based on the path of the anomalous artery retroaortic, interarterial, and anterior to the pulmonary trunk [13]. Ectopic origin of RCA from the left coronary sinus is uncommon, comprising less than 1% of all congenital coronary anomalies. It can cause syncope, myocardial infarction, and sudden death in the absence of a critical fixed stenosis. It significantly increases mortality rate for an anomalous left coronary artery and RCA. A case of interarterial subtype possesses the highest risk of exercise-induced ischemia, myocardial infarction, and sudden death, and is regarded as malignant [14, 15]. A recent study the authors observe that all of their patients with anomalous left coronary artery died suddenly, compared only 43% of patients with anomalous right coronary artery, whereas the remaining 57% had death unrelated to coronary artery anomaly [2].

The 8 cases of this group in our study group are all interarterial subtype. Its ratio of all coronary anomalies is 10% in our study. Seven of these subjects suffer from chest tightness on and off, but only one had done cardiac catheterization. Five of these seven cases had 50% stenosis at RCA orifice.

**Myocardial Bridging**

The incidence of myocardial bridge varies consistently between angiographic (0.5-2.5%) and pathologic (15-85%) series [30, 31]. Myocardial bridge is most commonly localized in the middle segment of the LAD artery [8, 32, 33, 34, 35]. Although it is silent in most cases, sometimes it causes severe ischemia. Angina, myocardial ischemia, myocardial infarction, left ventricular dysfunction, myocardial stunning, and paroxysmal atrioventricular blockage, as well as exercise-induced ventricular tachycardia and sudden cardiac death, are accused sequels of myocardial bridging [2, 8]. Therefore, diagnosis and treatment of myocardial bridging are important. Even when a few muscle fibers cause myocardial bridging, MDCT can reveal the vessel shifting into the myocardium. Besides, 3D VR and cMPR (curved multi-planar reconstruction) images make it possible to identify the anomaly. In addition, MDCT helps to evaluate the incidence of myocardial bridging in vivo [2]. In our study, the
incidence is 12.6%, which is 6 to 20 times higher than that according to findings of conventional catheter angiography. It is probably because the aid of 3D VR images can get better detection rate than 2D conventional catheter angiography.

Our results revealed an overall myocardial bridge prevalence of 12.6%, which was closer to that reported in autopsy studies, the ultimate gold standard for detecting this anomaly. However, even in autopsy studies a wide variation of the incidence of myocardial bridge has been reported, therefore the difference between the results may be of the ethnicity or other factors. Further large series studies to investigate the incidence would be helpful.

Searching for an anomalous orifice, selective probing, and interpretation of vascular anatomy may be difficult in catheter angiography. Conventional catheter angiography does not provide any depth information and is thus unable to provide the exact 3D course of the anomalous coronary artery [1, 2, 9, 36]. MDCT provides us a high quality and accurate modality to visualize and diagnose coronary anomalies [2, 4, 6, 8, 9, 36].

One of the limitations in MDCT angiography is the lack of hemodynamic information. Although MDCT provides insight into the anatomy of the aberrant artery and its surrounding structures, the assessment of the cause of ischemia in these patients is not yet easy. Various artifacts can degrade image quality at coronary CT angiography [1, 7]. In addition, patients who had arrhythmia and poor breathing cannot be examined [2, 36].

In conclusion, MDCT with VR and MIP techniques, are useful and helpful for assessment of anomalous coronary arteries for radiologist, cardiologist and surgeon. Comparing to other examinations for displaying coronary artery anomaly, MDCT is the modality of choices.

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64 切電腦斷層於冠狀動脈異常的診斷

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冠狀動脈異常可分為良性及惡性（致命）兩類。以往這類異常大都由心導管診斷得知。有
別於侵入性的心導管檢查，新進的多切片電腦斷層檢查可提供非侵入性及高準確度的冠狀動脈
影像。本項檢查可利用三維影像顯示異常冠狀動脈的開口、走向及解剖位置。

我們從 2006 年 6 月到 2007 年 6 月收集了 540 位受檢者接受 64 切電腦斷層冠狀動脈血管
檢查的資料。這些受檢者包括接受健康檢查者及有心臟疾病病史的病人。結果診斷出有 81 位
受檢者有冠狀動脈異常，其中 3 位沒有左側冠狀動脈、1 位左側冠狀動脈有高位開口、8 位右
側冠狀動脈開口異常，開口起源自左側冠狀竇，其它 69 位冠狀動脈有心肌橋異常。

雖然惡性的冠狀動脈異常很少導致死亡，但這項診斷對於心臟科醫師進行心導管檢查及外
科醫師實施手術有極大的貢獻，所以診斷出冠狀動脈異常是很重要的。利用 64 切電腦斷層的
容積重建（volume rendering，VR）及最大密度投影（Maximum Intensity Projection; MIP）可
清楚顯現冠狀動脈異常。與其他檢查方式相比，多切片電腦斷層是目前信賴度很高的診斷方式
之一。