

Electrocardiographic findings during balloon angioplasty of the left circumflex coronary artery – influence of location of the ischemic segments with respect to the obtuse margin of the left ventricle

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Abstract

Background: Acute left circumflex coronary artery (LCx) occlusion is not easily detected by the standard 12-lead electrocardiogram (ECG).

Methods: In 16 patients continuous ECG recording was performed during balloon occlusion. The treated lesions were divided into proximal and distal based on the location of the ischemic segments with respect to the left obtuse margin of the heart.

Results: Mean Δ ST (=ST amplitude during inflation - pre-inflation ST) ≥ 0.5 mm in both leads I and aVL predicted a proximal occlusion site with sensitivity of 62.5% (95% confidence interval [CI] 24.9–91.5%), specificity 100% (95% CI 63.1–100%), positive predictive value 100% (95% CI 47.8–100%), and negative predictive value 72.7% (95% CI 39–94%). In lead III, mean Δ ST was +0.3 mm in the distal and –0.2 mm in the proximal group, respectively ($p = 0.036$).

Conclusions: ST elevation in leads I and aVL is associated with myocardial ischemia at or proximal to the left obtuse margin.

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Keywords:

Electrocardiographic; Balloon angioplasty; Left circumflex coronary artery; Left ventricle

Introduction

Patients with acute left circumflex coronary artery (LCx) occlusion may present with inferior or lateral ST-elevation myocardial infarction (STEMI) or non-ST elevation myocardial infarction (NSTEMI) [1]. In case of STEMI, the patients can be successfully triaged to primary percutaneous coronary intervention (PCI), but if the patient's working diagnosis is NSTEMI, reperfusion may be delayed by 2–3 days [2]. Evidence from the literature has shown that LCx occlusion is often missed by the 12-lead electrocardiogram (ECG) [2]. Recording additional ECG leads placed on the back may aid in recognizing acute vessel occlusion [3].

Balloon occlusion during PCI leads to severe regional myocardial ischemia [4]. Therefore, the procedure provides a useful human model of acute coronary occlusion with unique potential for studying the relationship between coronary artery anatomy and ECG. The STAFF studies, which were performed before the introduction of coronary stents, enabled the documentation of the first 5 min of complete coronary occlusion in man [5]. Subsequently with the near universal use of stents, inflation times are typically no more than 30 s.

Sudden coronary artery occlusion results in abrupt changes of the electrical activity of the heart, expressed as ischemic changes in the ECG; a prominent, positive T wave frequently appears before ST elevation [6]. While these changes occur sequentially with ischemia, the ensuing changes in the individual ECG leads are dependent on factors such as myocardial protection through collateral circulation or preconditioning and the size and location of the

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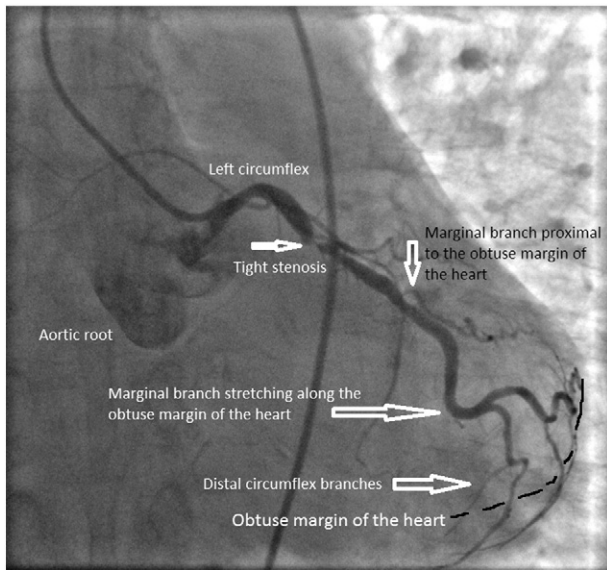


Fig. 1. The left circumflex artery originates directly from the left coronary cusp (left anterior oblique caudal or “spider” view). In the proximal part of the vessel there is a significant lesion to be treated with percutaneous coronary intervention. The figure illustrates the branching pattern of the artery with respect to the obtuse margin of the left ventricle, which is indicated with an interrupted line. The second marginal branch, which in its distal part stretches along the obtuse margin of the heart, extends to the left ventricular apex. In this case, the patient would be classified as *distal*, because the distal branches in the treated vessel extend beyond the obtuse margin of the heart.

ischemic region. Studies have shown that only 10% of all types of ST-elevation acute coronary syndromes are caused by LCx occlusion suggesting that many cases with LCx occlusion present as NSTEMI [7].

The LCx runs in the left atrioventricular sulcus and gives off obtuse marginal branches to the upper lateral left ventricular wall and the left atrium. In about one third of individuals, the artery terminates before or at the obtuse margin of the heart and in the majority of the two thirds of the cases, where it stretches beyond this landmark, it terminates before the posterior interventricular groove [8–11]. In 90% of individuals a marginal branch follows the left (obtuse) margin of the heart, and in the majority of cases it reaches the region of the apex [9] (Fig. 1). In 7–8% of hearts the coronary circulation is left dominant and the posterior descending branch arises from the LCx. The association between the location of the coronary artery occlusion within the LCx and ECG findings has not been well explored. Better understanding of possible anatomical factors that determine the ECG expressions of LCx occlusion complemented with more detailed description of the ECG changes might aid in identifying patients with an occluded coronary artery although the established reperfusion criteria are not fulfilled.

The aim of our study was to explore ECG changes induced by balloon occlusion of the LCx in various locations within the artery, considering the location of the myocardial segments rendered ischemic by the occlusion.

Material and methods

Patients

The study population consisted of 16 patients undergoing PCI of the LCx at the Tampere University Hospital in

2003–2004. Inclusion criteria were: 1) angiographically significant stenosis in the LCx technically feasible for PCI; 2) stable angina pectoris ($n = 9$) or NSTEMI ($n = 7$). Exclusion criteria were: 1) recent (within 2 weeks) STEMI; 2) hemodynamically unstable patient; 3) QRS duration ≥ 120 ms or pathological Q waves [3], in the baseline ECG. Standard anti-thrombotic treatment was used before and during the PCI procedure. No procedure-related complications occurred. The aim was to maintain balloon occlusion for 1–2 min, if tolerated by the patient.

The patients were divided into two groups based on the location of the myocardial segments rendered ischemic during the procedure. The angiographic left anterior oblique caudal (“spider”) view was used to determine the obtuse margin of the left ventricle for the differentiation between proximal and distal occlusion sites (Fig. 1). In this view the outer edge of the heart and the course of the coronary artery branches enable the identification of the obtuse margin of the heart. In the proximal group, all the myocardial segments subtended by the occluded coronary artery were located proximal to or at the obtuse margin of the heart (Fig. 2). In the distal group, myocardial segments beyond this anatomical landmark were affected by the balloon occlusion (Fig. 3), although some segments could be proximal to this margin.

Experienced pain was reported according to the visual analogue scale (VAS).

The Ethics Committee of the Pirkanmaa Hospital District approved the study protocol. All subjects gave their written informed consent for participation.

ECG analysis

During the PCI, continuous 25 mm/s 12-lead ECG was recorded using translucent ECG electrodes. Measurements were performed by comparing the baseline and PCI-induced R-, S-, ST- and T-wave amplitudes from all the 12 standard leads. The time point of maximal ST elevation was used for all ECG measurements during balloon inflation. The ST elevation was measured at the J point. R, S and T waves were measured in steps of 1 mm, while 0.5 mm steps were used for ST elevation. The measurements were performed manually by two investigators (AA and KN) and a magnifying glass was used if needed. The TP interval was used as the reference line. QRS durations were measured before the procedure and at maximal ST elevation. Delta (Δ) R-, S-, ST-, T-amplitude and QRS-duration were calculated by subtracting the preinflation value from the changes during balloon occlusion.

Statistical analysis

Categorical variables were expressed as numbers of patients or percentages and continuous variables as means or medians followed by inter-quartile range (IQR). We used the Fisher’s exact test for categorical variables and the Mann–Whitney U or Kruskal–Wallis test for numerical variables. A two-tailed p -value of <0.05 was considered statistically significant. All calculations were performed with the SPSS 22.0 statistical package.

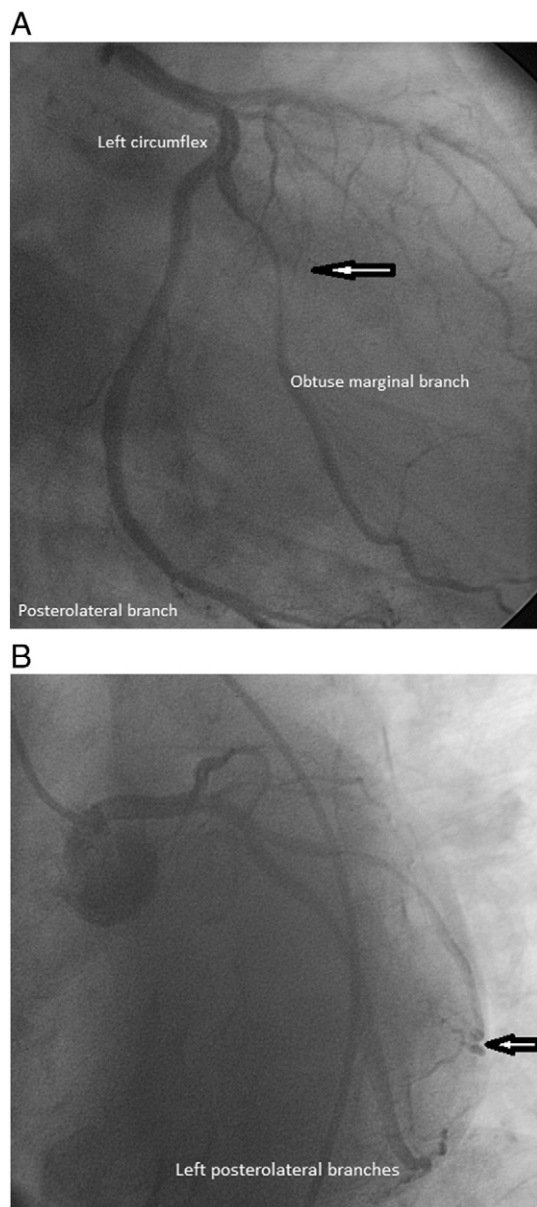


Fig. 2. (A) The lesion to be treated (arrow) is in the proximal part of the first marginal branch. From the caudal right anterior oblique view it is difficult to estimate the length of the side branch. In the left anterior oblique caudal view (B), the branch extends to the obtuse margin (arrow) but not distal to it. Hence, the treated lesion was classified as proximal. The circumflex artery also has large posterolateral branches stretching distally to the obtuse margin, but they will not be rendered ischemic by the balloon occlusion.

Results

Table 1 shows the baseline characteristics of the two study groups. In the distal group, more patients were on beta blockers, otherwise no statistically significant differences were observed. The heart rate changes were minimal: in the proximal group heart rate increased less than 1 bpm and in the distal group it decreased by less than 1 bpm. Mean value for perceived pain was 3.6 (IQR 3–5 for proximal and 1–5 for distal) in both the study groups. Time of balloon occlusion was longer in the proximal than in the distal group (89.9 s vs. 74.3 s), but the difference was not statistically significant.

In the extremity leads, proximal occlusion resulted in a minor, mostly positive ΔR , while during distal occlusion,

ΔR was positive in the lateral leads I and aVL and negative in the inferior leads. However, no statistically significant differences were observed and there was no significant shift of the electrical axis in the frontal plane. Regarding ΔS , no significant differences were observed, and no clear Δ “pattern” was present when comparing the proximal and distal group.

Mean ΔST values are shown in Fig. 4. The extremity leads are displayed in an anatomical order (Cabrera lead system). ΔST was significantly higher in the lateral leads I and aVL in the proximal than in the distal group. For lead I, mean ΔST was +0.7 mm (IQR 0.125–1) in the proximal and –0.6 mm (IQR –0.375–0) in the distal group ($p = 0.008$). Corresponding values for lead aVL were +0.5 (IQR 0–1) mm and –0.2 mm (–0.5–0) ($p = 0.006$). In the leads III and aVF mean ΔST was negative in the proximal and positive in the distal group; lead III showed a significant difference: –0.2 (IQR –0.5–0) and +0.3 (IQR 0–0.5), respectively ($p = 0.036$).

During balloon inflation 6/8 patients in the proximal group had ST elevations ≥ 0.5 mm in both the lateral leads I and aVL (Fig. 5), while this criterion was not fulfilled in any of the patients in the distal group. All of the patients with ST elevation in I and aVL during inflation had concomitant ST elevation ≥ 0.5 mm in both the leads V5 and V6 and 3/6 also in V4 (Fig. 5). Regarding inferior ST elevations, 3/8 patients in the distal and 1/8 in the proximal group had ≥ 0.5 mm ST elevations in ≥ 2 of the leads II, III and aVF (Fig. 6). ST elevation ≥ 0.5 mm in at least one of the inferior leads was seen in 4/8 cases. Inferior ST ≥ 0.5 mm appeared both with and without concomitant changes in V5–V6 in the distal group. Two patients in the distal group had ST ≥ 0.5 mm in V5 and V6 without ST elevations in the inferior leads.

During balloon inflation, there were two patients in the proximal and three in the distal group, who did not have ST depression in any of the leads V1–V4 (Figs. 5–6). Using

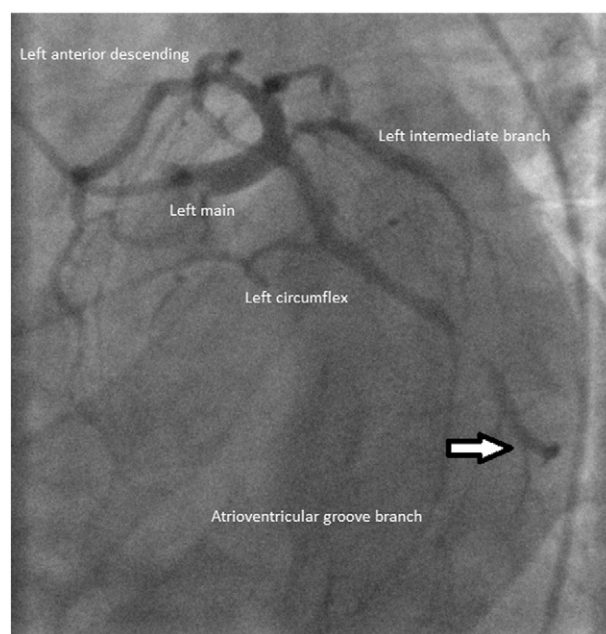


Fig. 3. A case where PCI will render myocardial segments distal to the obtuse margin (arrow) ischemic, because the LCx extends beyond that point (“spider” view).

Table 1

Baseline characteristics according to left circumflex coronary artery lesion level classification. Variables are given as median values followed by inter-quartile ranges (IQR).

	LCX				P-value
	Proximal		Distal		
	N = 8		N = 8		
	N	%/IQR	N	%/IQR	
Baseline characteristics					
Age (yr), median (IQR)	52.5	50–62	53.5	46.3–68.5	0.96
Males	7	87.5	5	62.5	0.25
Hypertension	5	62.5	5	62.5	1
Diabetes	1	12.5	0	0	0.3
Current smoker	4	50	2	25	0.3
Previous MI	1	12.5	1	12.5	1
Previous PCI or CABG	2	25	2	25	1
Prior angina (>3 months)	4	50	5	62.5	1
CCS class					
1–2	4	50	3	37.5	0.5
3–4	0	0	2	25	
Systolic blood pressure, median (IQR)	143	137.8–152	143	134–146	0.79
Diastolic blood pressure, median (IQR)	84.5	81.5–91	75.5	74.3–76.8	0.10
Ejection fraction (%)	64	59.25–70.75	61	58.5–71.8	1
Medical treatment					
Aspirin	4	50	6	75	0.3
Clopidogrel	1	12.5	3	37.5	0.25
Beta-blocker	3	37.5	7	87.5	0.03
ACE-inhibitor	0	0	1	12.5	0.3
ARB	2	25	1	12.5	0.3
Calcium-antagonist	0	0	2	25	0.13
Digitalis	0	0	2	25	0.13
Nitrate	1	12.5	3	43	0.25
Diuretic	0	0	2	25	0.13
Statin	3	37.5	4	50	0.61
Warfarin	0	0	1	12.5	0.3
Laboratory findings					
Creatinine, median (μmol/l)	78.5	70.3–82.3	75	62.5–75.5	0.45
CRP (mg/l), median (IQR)	1.2	0.6–2.72	0.9	0.75–4	0.41
Total cholesterol (mmol/l), median (IQR)	4.6	4.1–5.45	4.3	4.25–4.9	0.9
HDL (mmol/l), median (IQR)	1.2	1.06–1.28	1.0	0.99–1.01	0.38
LDL (mmol/l), median (IQR)	2.3	2.25–3	2.4	2.14–2.85	0.81
Triglycerides (mmol/l), median (IQR)	1.26	1.09–1.92	2.63	2.1–2.86	0.13

MI, myocardial infarction; PCI, percutaneous coronary intervention; CABG, coronary artery bypass surgery; CCS, Canadian Cardiovascular Society; ACE, angiotensin-converting enzyme; ARB, angiotensin receptor blockers; CRP, C-reactive protein; HDL, high density lipoprotein; LDL, low density lipoprotein.

0.5 mm as cut-off, 3/8 patients in the distal group had ST depressions in leads V1/V2–V3/V4 without concomitant ST elevations in the lateral or inferior extremity leads; in two cases the ST depression included lead V1 (Fig. 7). Of these patients, two did not have ST elevations in V5–V6 (“STEMI equivalent pattern”). ΔT values behaved in a similar way as the ΔST values, but the differences did not reach statistical significance (Fig. 8).

Anatomically, in the proximal group, the treated branches were the second marginal ($n = 5$), the first marginal ($n = 2$) and the intermediate branch ($n = 1$). In the distal group, posterolateral branches were the most frequent ($n = 5$), followed by the second marginal ($n = 2$) and the first marginal ($n = 1$) (Fig. 9). In none of the patients left dominant coronary circulation was observed.

$\Delta ST \geq 0.5$ mm in both leads I and aVL predicted a proximal occlusion site with a sensitivity of 62.5% (95% confidence interval [CI] 24.9–91.5%), specificity of 100% (95% CI 63.1–100%), positive predictive value 100% (95%

CI 47.8–100%), and negative predictive value 72.7% (95% CI 39–94%).

Discussion

We found that balloon occlusion of the LCx not affecting myocardial segments distal to the obtuse margin of the heart induces ST elevations in the leads I and aVL (“lateral STEMI pattern”) (Fig. 5). The ECG responses in patients, where the balloon occlusion affected parts of the left ventricle distal to the obtuse margin were less uniform: both inferior ST elevation (“inferior STEMI pattern”) (Fig. 6) and predominant ST depression (“STEMI equivalent pattern”) (Fig. 7) resulted. A ΔST of ≥ 0.5 mm in both leads I and aVL predicted a proximal occlusion site.

In the precordial leads, no significant differences were observed between the proximal and distal group. Overall, there was a decrease in ST amplitude from preinflation to inflation in

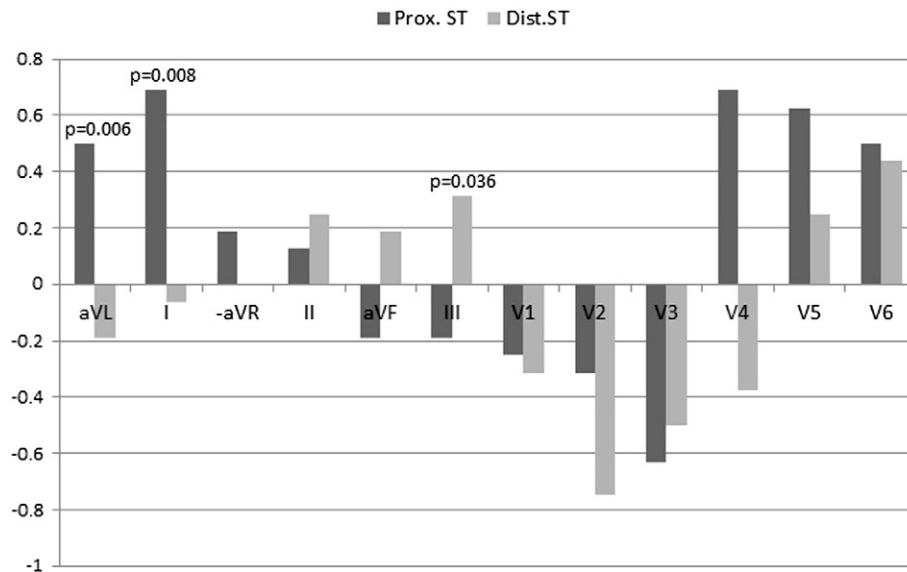


Fig. 4. Mean Δ ST values (ST level during balloon inflation - preinflation ST level). The leads are arranged anatomically (Cabrera lead system).

the right precordial leads. However, when looking at absolute ST changes, we found that two patients in the proximal and three in the distal group did not show ST depressions in any of the leads V1–V4. One patient in the proximal group showed ST elevations up to 3 mm in these leads, thereby fulfilling the criteria for anterior STEMI; there were 1 mm concomitant ST elevations in the leads I and aVL. Based on these changes, the proximal left anterior descending coronary artery would have been predicted as the culprit artery.

Berry et al. performed balloon occlusion 54 patients [12]. In the surface ECG ≥ 1 mm ST elevation was less often (32%) produced when the treated artery was the LCx ($n = 19$) compared to the LAD (84%) and the RCA (92%). Of the patients with LCx as the treated artery, nine had no ST elevations and four had ST depression. Interestingly, intracoronary ECG recording revealed similar magnitudes of ST elevations between the three coronary arteries. In a recent study with ECG recording during balloon occlusion, ST elevation ≥ 0.5 mm in V6 differentiated the LCx from the left anterior descending and the right as the occluded coronary artery [13]. Also in our study, ST elevation typically appeared in lead V6, but there were no differences between the proximal and distal groups (Fig. 4). Probably, the presence of lead V6 ST elevation is caused by side branch extension apically (Fig. 1) and not necessarily by proximal or distal occlusion [14]. Using the previously mentioned STAFF dataset, investigators have developed and validated improved vessel-specific leads for detecting acute myocardial ischemia [15]. They found that the most significant improvement in diagnostic performance appeared in patients with LCx occlusion.

It is well known from the literature, that acute occlusion of the LCx may result in varying ECG presentations, ranging from inferior or lateral STEMI to minor, or even no ST changes. Huey et al. found that only half of the patients with LCx occlusion had ST elevation in the acute phase, 38% had no ST change, while 15% presented with isolated ST depression [16]. Also recent studies have shown that fewer patients with an

acutely occluded LCx present with ST elevation compared with left anterior descending or right coronary artery occlusion [17]. The variation in ECG presentation has been attributed to the anatomy of the LCx, which also varies a lot between individuals [18]. In some individuals, the LCx periphery consists mainly of obtuse marginal branches with a very small posterolateral branch. These patients have a clearly dominant or even super-dominant right coronary artery.

It has been proposed that occlusion of a marginal branch results in lateral (I and aVL) ST elevations. Zhong-qun et al. found no significant ST-segment differences between patients with a culprit lesion proximal or distal and the first obtuse marginal branch [1]. In patients with inferior STEMI, Hasdai et al. defined proximal LCx occlusion as a lesion proximal to the first marginal branch or a lesion affecting the proximal portion of a high first marginal branch [19]. This is the traditional way of defining the level of occlusion. They found that six of seven patients with a proximal LCx stenosis had no significant ST depression in lead aVL. This was ascribed to the fact that concomitant high lateral involvement canceled out (reciprocal) ST depression typical for inferior STEMI in this lead.

We decided to define the level of vessel occlusion by the ventricular region irrigated by the occluded coronary artery and not in the traditional way by locating the occlusion site with respect to side branches. Using the obtuse margin of the heart as the anatomical landmark to differentiate proximal from distal occlusion, we were able to predict a proximal occlusion by ST elevations in both I and aVL. Our preliminary findings seem to indicate that this anatomical landmark distinguishes between inferior and lateral STEMI in LCx occlusion, although the ECG changes in the distal group were less uniform than that in the proximal group.

Anatomical aspects of the branching pattern of the LCx seem to offer a plausible explanation for these disparate ECG patterns. Fig. 10 illustrates how the obtuse margin of the heart divides the obtuse marginal branches into those irrigating the anterolateral wall (branch #14 in the figure), which run close to

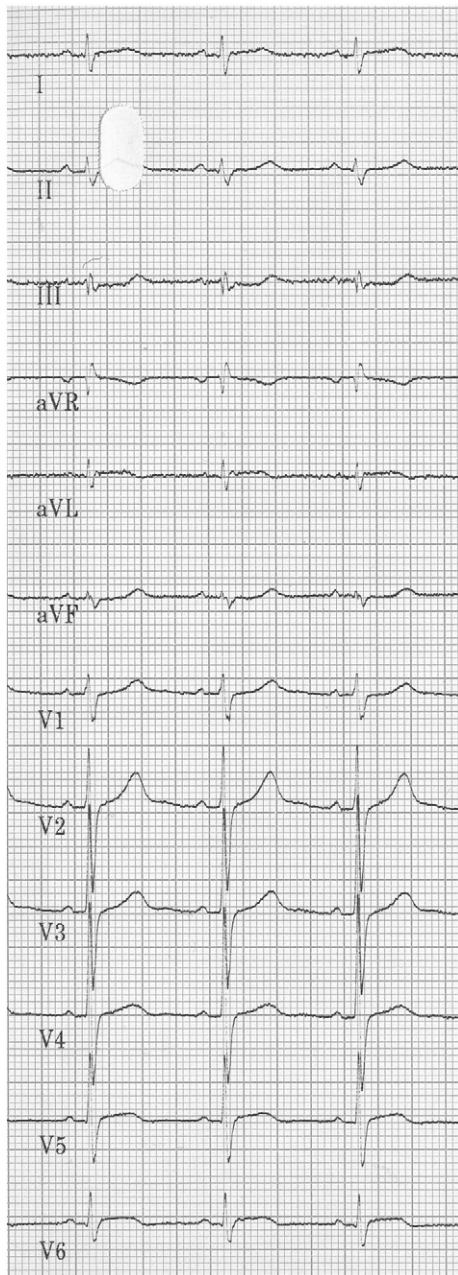


Fig. 5. ECG in proximal occlusion. 12-lead ECG during balloon occlusion shows 0.5 mm ST elevations in leads I and aVL. In this patient there is also (reciprocal) ST depression of 0.5 mm in lead III and ST elevation in leads V4–V6. No ST depressions are present in leads V1–V4.

the diagonal branches (#12) and those subtending the inferolateral wall (#15). Interestingly, similar to the ECG findings in 6/8 patients in our proximal group, acute diagonal branch occlusion was associated with ST elevation in leads I and aVL in a previous study [20]. On the other hand, Fig. 10 also shows the proximity of a marginal branch irrigating myocardium distal to the obtuse margin (#15) with distal branches of the right coronary artery (#5–7). In the present study, 4/8 patients in the distal group had ST elevation in at least one of the inferior leads II, III and aVF, which is the typical finding in right coronary artery occlusion. However, the ECG findings in the distal group were less consistent than those of the proximal group. Our material was too small to enable further

sub-division based on the type of distal branches and their correlation with the ECG findings. Probably, opposite injury vectors – a concept previously described in left anterior descending coronary artery occlusion – from anterolateral and inferior/inferolateral ischemia play a significant role in determining the ECG responses [21].

Dunn et al., when exploring the clinical features of LCx disease, found that the inferior leads were most often affected in distal LCx stenosis, while proximal stenosis was associated with changes in the lateral (I and aVL +/- V5–V6) leads [22]. However, the authors used ST depression, not ST elevation, and also Q- and T-wave changes as ECG markers in their study.

When the coronary circulation is left dominant, the posterolateral and the posterior descending branches rise

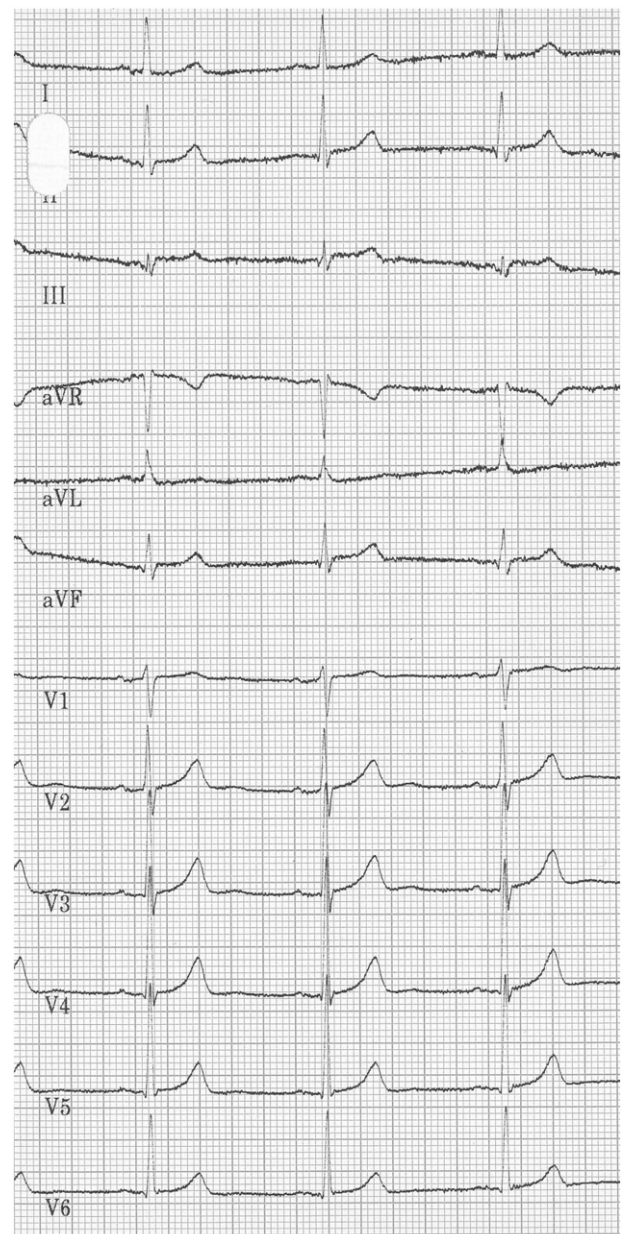


Fig. 6. ECG in distal occlusion. During balloon occlusion, there is 1 mm ST elevation in leads II, III and aVF with (reciprocal) ST depression of 0.5 mm in aVL. The precordial leads were not affected.

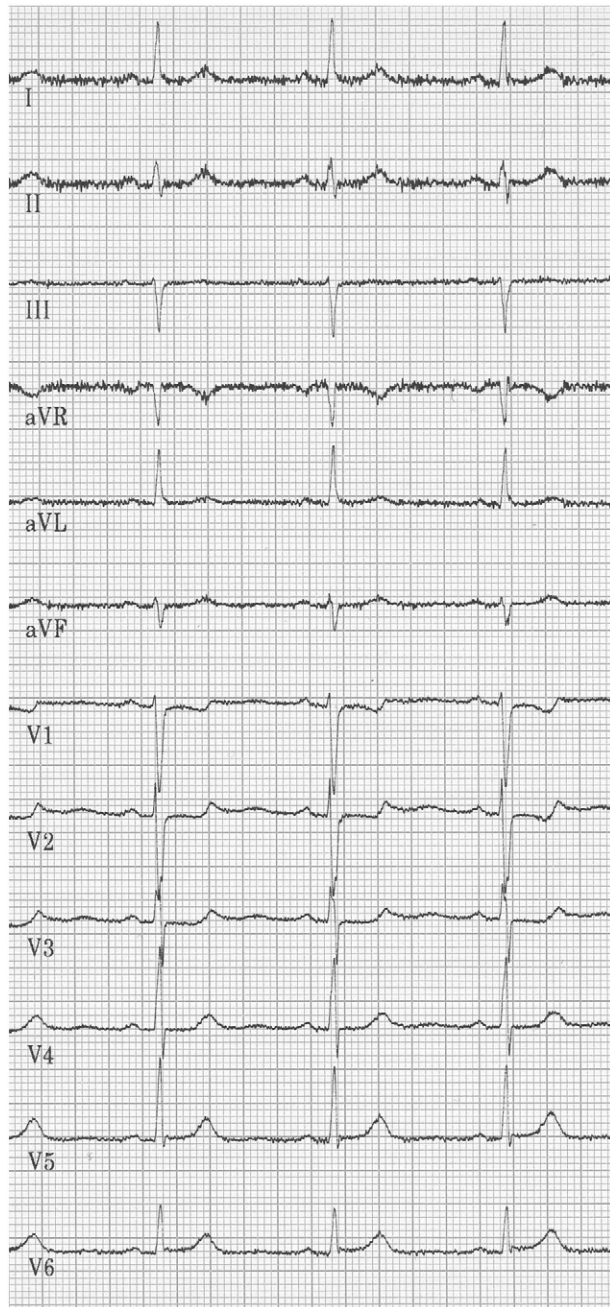


Fig. 7. ECG during balloon occlusion in a patient from the distal group shows mild ST depressions in V1–V3 without concomitant ST elevations.

from the LCx and not from the right coronary artery. Hence, the ECG pattern of STEMI is similar to that in right coronary artery occlusion. In fact, Tahvanainen et al. showed that left dominance was associated with failure to predict the culprit artery in inferior STEMI [23]. Inferolateral MI (“mirror-image” STEMI) patients may present with ST depressions in the leads V1/V2–V3/V4 without ST elevations in the extremity leads [24]. This ECG pattern was previously named “posterior” MI [25]. In our patient material we found two patients, both belonging to the distal group, who presented with this “STEMI equivalent pattern”. In these cases the circumflex branch to be dilated extended beyond the obtuse margin of the heart but not to the apex (Fig. 9).

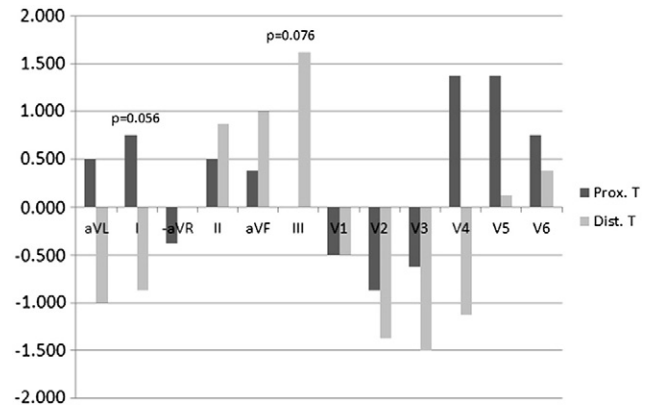


Fig. 8. ΔT values (T-wave amplitude during balloon inflation - preinflation T wave amplitude). The leads are arranged anatomically (Cabrera lead system).

Limitations

This study has clear limitations. The number of patients was small, which resulted in wide IQRs in the statistical analyses. We were also lacking certain anatomic variants,

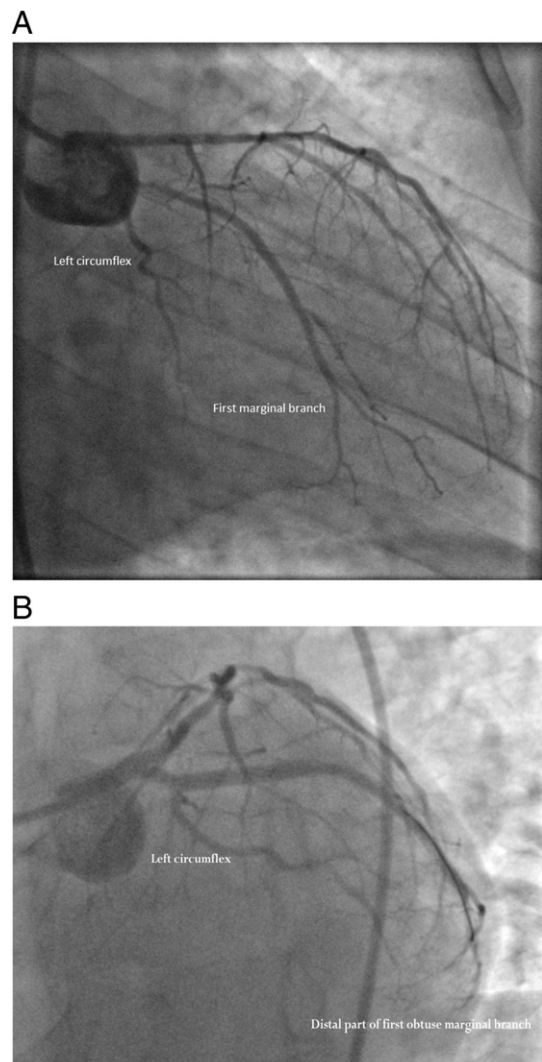


Fig. 9. Right (A) and left (B) caudal anterior oblique projections of a first marginal branch extending beyond the obtuse margin but not to the left ventricular apex. During balloon occlusion there was ST depression in leads V2–V5, maximally 2 mm in V2.

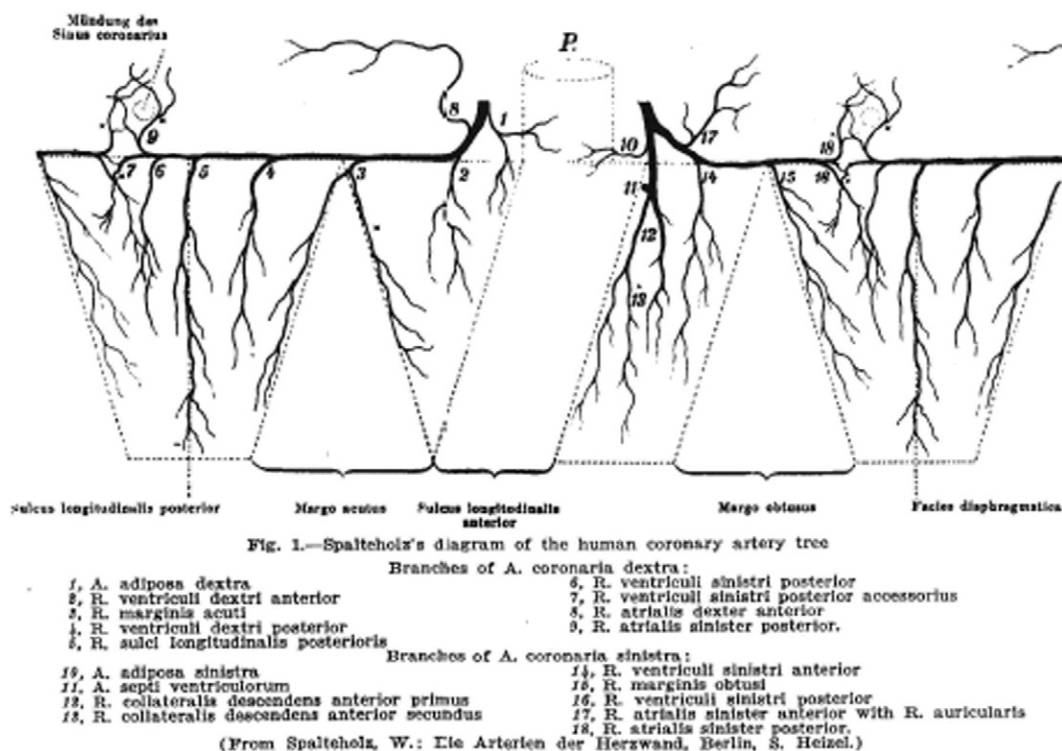


Fig. 10. A diagrammatic presentation of the human coronary artery tree. According to modern nomenclature vessel #5 is called the posterior interventricular or posterior descending branch (in this case arising from the right coronary artery), #12 is called a diagonal branch, #13 the left anterior descending coronary artery, #14 the first and #15 the second obtuse marginal branch, and #16 the posterolateral branch. (From: Schlesinger MJ. An injection plus dissection study of coronary artery occlusions and anastomoses. *Am Heart J* 1938;15:531, published with permission).

such as left dominant circulation. The time of coronary occlusion was relatively short. Before the introduction of stents, it was easier to perform studies with many minutes of occlusion, but nowadays it is more difficult to justify. In a recent study, balloon occlusion was restricted to maximally 60 s for ethical reasons [13]. Because of the relatively short duration of vessel occlusion, we used a cut-off of 0.5 mm to predict a proximal occlusion site, instead of 1 mm that is recommended in the guidelines regarding STEMI. ECG changes during balloon occlusion are not necessarily identical to changes in acute STEMI, but there is no reason to believe that the location of changes within the individual ECG leads differs. This study also suffers from the lack of data on the size of the ischemic area, which could have given additional information about the background factors for the different ECG manifestations of LCx occlusion. Also, use of additional ECG leads could have given additional clinical insights into the studied topic.

Conclusions

During balloon occlusion of the LCx, ST elevation in leads I and aVL is associated with myocardial ischemia at or proximal to the left obtuse margin of the left ventricle. ST elevation in the lead III is associated with involvement of ischemic regions distal to the obtuse margin.

Disclosure of interest

The authors state no conflict of interest related to the study.

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