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Early systolic lengthening by speckle tracking echocardiography predicts outcome after coronary artery bypass surgery

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ABSTRACT

Background: Early systolic lengthening (ESL), a paradoxical stretch of myocardial fibers, has been linked to loss of myocardial viability and contractile dysfunction. We assessed the long-term prognostic potential of ESL in coronary artery bypass graft (CABG) patients.
Methods: We retrospectively included patients (n = 709; mean age 68 years; 85% men) who underwent speckle tracking echocardiography (median 15 days) prior to CABG. Endpoints were cardiovascular death (CVD) and all-cause mortality. We assessed amplitude of ESL (%), defined as peak positive strain, and duration of ESL (ms), determined as time from Q-wave on the ECG to peak positive strain. We applied Cox models adjusted for clinical risk assessed as EuroSCORE II.
Results: During median follow-up of 3.8 years [IQR 2.7–4.9 years], 45 (6%) experienced CVD and 80 (11%) died. In survival analyses adjusted for EuroSCORE II, each 1% increase in amplitude of ESL was associated with CVD (HR 1.35 [95%CI 1.09–1.68], P = 0.006) and all-cause mortality (HR 1.29 [95%CI 1.08–1.54], P = 0.004). Similar findings applied to duration of ESL (per 10ms increase) and CVD (HR 1.12 [95%CI 1.02–1.23], P = 0.016) and all-cause mortality (HR 1.09 [95%CI 1.01––1.17], P = 0.031). The prognostic value of ESL amplitude was modified by sex (P interaction < 0.05), such that the prognostic value was greater in women for both endpoints. When adding ESL duration to EuroSCORE II, the net reclassification index improved significantly for both CVD and all-cause mortality.
Conclusions: Assessment of ESL provides independent and incremental prognostic information in addition to the EuroSCORE II for CVD and all-cause mortality in CABG patients.
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1. Introduction

Despite procedural improvements, coronary-artery bypass grafting (CABG) remains associated with a significant risk of post-operative mortality[1]. Several studies have demonstrated that outcomes for women differ from that of men following CABG[2]. Specifically, it has been suggested that women after CABG have a higher mortality rate compared to men[3]. The EuroSCORE II is highly useful for risk stratification prior to cardiac surgery and is based on clinical characteristics, including sex, and left ventricular

Abbreviations: A, late transmitral inflow velocity; CABG, coronary artery bypass graft; CK-MB, creatine kinase myocardial band; E, early transmitral inflow velocity; e', early diastolic tissue velocity; ESL, early systolic lengthening; GLS, global longitudinal strain; HR, hazard ratio; IDI, integrated discrimination improvement; IQR, interquartile range; LV, left ventricular; LVEF, left ventricular ejection fraction; NRI, net reclassification index.

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(LV) function[4]. Although assessment of LV ejection fraction (LVEF) routinely is performed prior to CABG, it may be within normal range when myocardial ischemia and scarring is limited. This is critical, as LVEF is the only echocardiographic parameter applied in the EuroSCORE II algorithm. More recently speckle tracking echocardiography (STE) was introduced, offering a novel tool to assess subtle changes in LV function and deformational patterns.

In the presence of ischemia, myocardial segments with reduced active force may exhibit a paradoxical lengthening when the LV pressure rises during early systole[5]. This deformational pattern, known as early systolic lengthening (ESL), may potentially inhibit LV systolic and diastolic function. Prior studies have linked ESL to subclinical myocardial damage in patients with ischemia[5,6], but ESL has never been investigated in the setting of CABG. Furthermore, our group has demonstrated that ESL contains prognostic information in patients from the general population and with myocardial infarction[7,8]. Based on this, our primary aim was to investigate if ESL yields prognostic information in addition to the EuroSCORE II in CABG patients. As the significance of STE parameters have been shown to differ between men and women[9,10], our secondary aim was to determine if sex modified the prognostic value of ESL.

2. Methods

2.1. Population

We retrospectively identified 782 patients who underwent CABG at Department of Cardiology (Gentofte University Hospital, Denmark) in the period January 2006 to May 2011. Patients who underwent rescue CABG or had no echocardiography available (n = 59) or suffered from significant valvular disease (mitral or aortic; n = 14) were excluded, thus yielding a total study population of 709 patients eligible for the present analyses. Medical records were retrospectively assessed to gather information on clinical, paraclinical and angiographic findings during the hospitalization and surgery. Twenty patients had a history of atrial fibrillation. Echocardiographic examinations were conducted a median of 15 [interquartile range (IQR) 8–31] days prior to surgery. Paraclinical information included measurements of hemoglobin, platelets, leukocytes, C-reactive protein, creatinine and urea. Data on troponin I and creatine kinase myocardial band (CKMB) were collected within 2 days after surgery. The study was approved by the Danish Data Protection Agency and the local ethics committee and conforms to the principles outlined in the 2nd Declaration of Helsinki.

2.2. Echocardiography

Examinations were conducted using Vivid 7 Dimension (GE Heathcare, Horten, Norway) with a 3.5-MHz transducer. Images were transferred to a remote image vault for offline storage, and later they were post-processed and analyzed in EchoPAC (BT 11.1.0, GE Vingmed) by a single experienced medical doctor (FJO). The responsible investigator was blinded to all clinical information and outcomes. Analyses were conducted in accordance to present guidelines[11]. In the parasternal long-axis view at end-diastole we measured interventricular septal wall thickness, LV internal diameter and the left posterior wall thickness. Using the Devereux formula we calculated LV mass index[12]. The Simpson's biplane method was used to measure LVEF, and the biplane area-length method was used to estimate left atrial volume. The latter was indexed to body surface area in order to provide left atrial volume index. Early (E) and late (A) transmitral inflow velocities were measured in the apical four chamber view using pulsed-wave Doppler. Early diastolic tissue velocity (e') was obtained by pulsed-wave tissue Doppler imaging from the septal and lateral mitral annular sites. Accordingly, E/e' was calculated. Tricuspid annular plane systolic excursion was calculated by M−mode through the tricuspid annulus. The wall motion score index was obtained from the 16-myocardial segment model where motion of segments were graded as normal (1), hypokinesia (2), akinesia (3) and dyskinesia (4).

2.3. Speckle tracking

Speckle tracking echocardiography was performed in the apical views (two, three and four chamber) according to present guidelines[13]. We analyzed a total of 18 myocardial segments, allowing only for maximally one missing segment per projection. A semi-automated function was applied such that the software automatically detected the myocardial wall and created a region of interest. In cases of poor tracking, or when the region of interest did not span from the endocardial border to the epicardial surface, this was manually adjusted by the investigator. From each myocardial segment, we obtained peak positive strain, indicating the amplitude of ESL, and end-systolic strain, denoting global longitudinal strain (GLS) (Fig. 1). Duration of ESL was defined as defined as time from onset of the Q wave in the QRS complex on the ECG to time of peak positive strain[5,7]. If the Q wave was absent, we used the R wave. All parameters (ESL amplitude, ESL duration, and GLS) were obtained as the average value from all 18 myocardial segments, thus allowing us to define a single value for each patient. Our group has previously demonstrated reasonable reproducibility of ESL [8,14].

2.4. Follow-up

Data on all-cause mortality was obtained from the Danish National Board of Health's Patient Registry and information on cardiovascular death was obtained from the National Causes of Death Registry using the International Classification of Disease, 10th edition.

2.5. Statistics

Baseline characteristics of the population were stratified according to tertiles of ESL amplitude (cutoffs: 6% and 10%) and ESL duration (cutoffs: 24 ms and 40 ms). Continuous normally distributed variables were reported as mean ± standard deviation and non-normally distributed variables as median [interquartile range (IQR)]. P for trend was calculated using linear regression models and Cuzick's nonparametric test for trend[15]. Cox proportional hazards regression models were used to estimate hazard ratios (HRs) with 95% confidence intervals (CIs). Two prespecified multivariable models were applied, the first adjusting for the EuroSCORE II, which involves 18 patient-, cardiac- and operation-related factors, and is recognized as a strong predictor of mortality[4]. The second model included confounders based on previous reports on ESL and comparison of clinical characteristics across tertiles of ESL[7,16]: age, sex, diabetes, peripheral artery disease, Canadian Cardiovascular Society Angina Score, creatinine, hemoglobin, CABG indication, left main stenosis, LVEF, E/e', wall motion score index and GLS. The assumption of proportional hazards was tested by Schoenfeld residuals. We examined if sex modified these relationships, and in subgroup analyses we only adjusted for the EuroSCORE II because of a limited number of events. In survival analyses we also assessed two different cut-offs: (i) two standard deviations above the mean (>24% for amplitude and >85 ms for duration) and (ii) the median value (>7% for amplitude, >32 ms for duration). Harrel's C-statistics was calculated from univariable

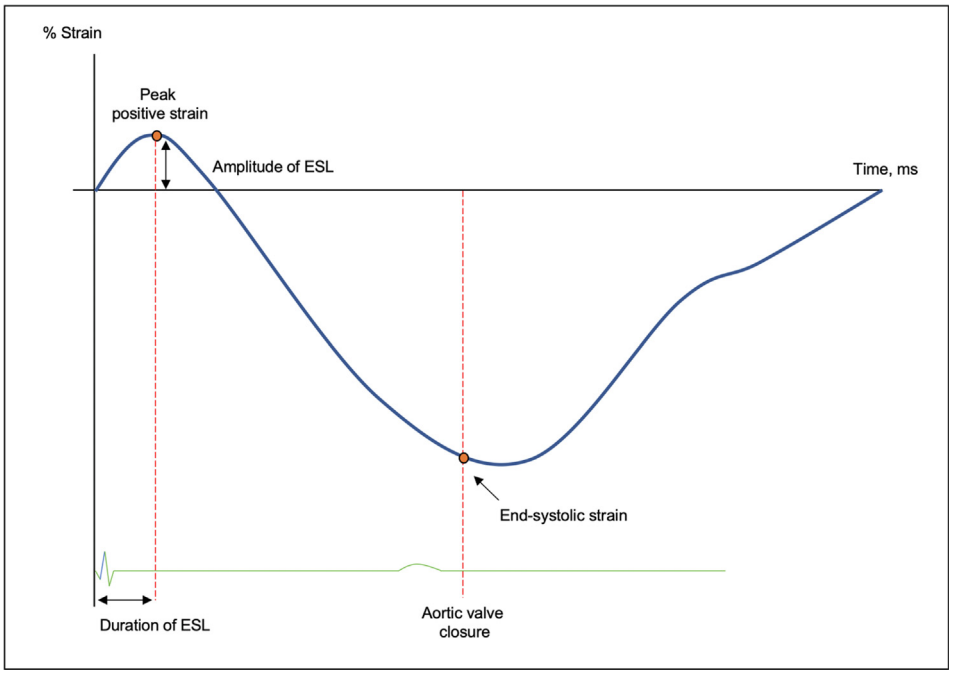

Fig. 1. Title: Schematic drawing of speckle tracking profile. Legend: Longitudinal strain profile displaying early systolic lengthening as indicated. ESL: early systolic lengthening.

Cox proportional hazards models to determine prognostic performance of ESL and GLS. Continuous net reclassification index (NRI) and integrated discrimination improvement (IDI) was calculated when adding ESL parameters to the EuroSCORE II. Restricted cubic spline models were constructed for the relationship between ESL parameters and endpoint events. The number of knots was determined according to the lowest Akaike information criterion. Linear regression models, adjusted for age and sex, were conducted to determine beta and standardized beta coefficients for the relationship between ESL and echocardiographic parameters. Reproducibility was assessed as mean difference ± 1.96SDs and by intra- and inter-class correlation coefficients. Analyses were conducted by two independent readers in 20 randomly selected patients from the study cohort. Both readers were blinded to clinical data.

P values < 0.05 in two-sided tests were regarded as significant. We used STATA v. 14.2 (StataCorp LP, Texas).

3. Results

A total of 709 patients (mean age 68 ± 8.8 years; 85% men) underwent CABG. During a median follow-up time of 3.8 [IQR 2.7–4.9] years, 45 (6%) experienced CVD and 80 (11%) died from all causes. Median values of ESL amplitude and ESL duration were 7% [IQR 4–12%] and 32 ms [IQR 21–48 ms]. A total of 22 patients (3%) did not display any ESL. Characteristics of the population are displayed in Table 1. Patients in the highest tertile of ESL amplitude more frequently had affected laboratory markers (urea, C reactive protein and creatinine) and suffered from low LVEF, GLS, and high LVMI. Similar observations applied to increasing tertiles of ESL duration (Supplemental Table 1).

3.1. Prognosis

In unadjusted Cox proportional hazards models, each 1% additional increase in ESL amplitude was significantly associated with CVD (HR 1.37 [95%CI 1.13–1.66], P = 0.001) and all-cause mortality (HR 1.31 [95%CI 1.13–1.54], P = 0.001). In multivariable models, both associations remained significant (Table 2). Similarly, in unadjusted models per 10 ms increase in ESL duration was associated with CVD (HR 1.17 [95%CI 1.08–1.26], P < 0.001) and all-cause mortality (HR 1.14 [95%CI 1.07–1.21], P < 0.001). As indicated in Table 2, both associations remained significant in multivariable models. When patients with atrial fibrillation were excluded (n = 20) all associations remained significant (P < 0.05). When excluding patients (i) who suffered from CVD (n = 5) or all-cause mortality (n = 5) within 30 days from the procedure and (ii) patients with LVEF < 45%, all associations remained significant (Supplemental Table 2 and 3). In sensitivity analyses, a cut-off of two standard deviations above the mean yielded the highest HRs for both endpoint events (HR range 1.07–4.43), but did not remain significant for ESL duration in adjusted analyses (Supplemental Table 4). By contrast, when using the median values of ESL parameters as cut-off, all associations remained significant in multivariable models (P < 0.05 for all; Supplemental Table 4).

3.2. Effect modification by sex

Population characteristics stratified by sex are displayed in Supplemental Table 5 and no difference in ESL amplitude and duration was observed between women and men. For endpoint events, women had 9 (8%) CVD and 15 (14%) died from all causes, whereas men had 36 (6%) CVD and 65 (11%) died from all causes. There was no significant difference in the number of events between the sex (P < 0.05 for both events). Sex modified the relationship between ESL amplitude and endpoint events (P interaction CVD: 0.001 and all-cause mortality: 0.048; Fig. 2A-B), such that ESL amplitude was significantly associated with the endpoints for both sex but the effect size was greater in women (Fig. 2C). Although we found no interaction between ESL duration and sex (P interaction CVD: 0.46 and all-cause mortality: 0.31), it remained a significant predictor in women (Fig. 2C). Importantly, when adjusting the associations for EuroSCORE II, all associations remained significant in women (Fig. 2C).

Table 1
Population characteristics by tertiles of early systolic lengthening amplitude.

Tertiles of ESL amplitude	1st tertile (n = 237)	2nd tertile (n = 236)	3rd tertile (n = 236)	P trend
Cut-off	<6%	6–10%	>10%	
Clinical				
Age, years	67 ± 9	68 ± 9	68 ± 9	0.47
Male, n(%)	202 (85%)	198 (84%)	200 (85%)	0.78
Body mass index, kg/m^2	27 ± 3	28 ± 4	27 ± 4	0.20
Diabetes, n(%)	53 (22%)	65 (28%)	58 (25%)	0.37
Hypertension, n(%)	151 (64%)	167 (71%)	166 (70%)	0.06
Peripheral artery disease, n(%)	28 (12%)	24 (10%)	28 (12%)	0.87
Hypercholesterolemia, n(%)	157 (66%)	152 (64%)	142 (60%)	0.16
Chronic obstructive pulmonary disease, n(%)	17 (7%)	16 (7%)	22 (9%)	0.29
CCS Angina Score				0.66
1	22 (9%)	16 (7%)	20 (9%)	
2	181 (76%)	185 (78%)	187 (79%)	
3	31 (13%)	33 (14%)	28 (12%)	
4	3 (1%)	2 (1%)	1 (<1%)	
Prior myocardial infarction, n(%)	59 (25%)	48 (20%)	61 (26%)	0.81
Paraclinical				
Urea, mmol/L	4.7 [3.9, 5.7]	4.8 [4.1, 6.1]	5.0 [4.1, 6.4]	0.011
Hemoglobin, mmol/L	8.5 ± 0.9	8.4 ± 0.8	8.4 ± 0.9	0.20
Platelets, 10^9/L	259 [217, 309]	263 [222, 311]	269 [227, 329]	0.046
Leukocytes, 10^9/L	8 [7,9]	8 [7,9]	8 [7,10]	0.022
C-reactive protein, mg/L	2 [2,9]	4 [2,9]	5 [2,10]	0.018
Creatinine, μmol/L	92 [81, 104]	96 [83, 109]	99 [84, 113]	<0.001
Troponin I, μg/L	7 [4,11]	7 [4,11]	6 [3,10]	0.08
Creatine kinase MB, μg/L	29 [22,39]	27 [20,38]	26 [20,39]	0.14
Invasive				
Indication, n(%)				0.17
Stable angina pectoris	122 (52%)	120 (51%)	111 (47%)	
Non-STEMI or UAP	94 (40%)	95 (40%)	92 (39%)	
STEMI	21 (9%)	21 (9%)	33 (14%)	
Left main stenosis, n(%)	97 (41%)	90 (38%)	73 (31%)	0.028
Unstable at operation, n(%)	8 (3%)	17 (7%)	12 (5%)	0.38
Extra corporal perfusion time, min	82 ± 26	81 ± 23	81 ± 23	0.45
Three vessel disease	185 (78%)	190 (81%)	187 (79%)	0.70
Echocardiography				
LV ejection fraction, %	54 ± 9	50 ± 11	46 ± 13	<0.001
LV mass index, g/m^2	88 ± 24	95 ± 25	105 ± 44	<0.001
Left atrial volume index, ml/m^2	26 ± 10	25 ± 10	25 ± 10	0.58
E/e'	10 ± 3	11 ± 4	11 ± 5	0.005
E/A	1.1 ± 0.5	1.0 ± 0.4	1.0 ± 0.5	0.003
TAPSE, cm	2.5 ± 0.5	2.4 ± 0.4	2.3 ± 0.5	<0.001
Wall motion score index	1.1 ± 0.3	1.2 ± 0.4	1.4 ± 0.5	<0.001
Global longitudinal strain, %	−16.7 ± 3.0	−14.8 ± 3.1	−12.6 ± 3.9	<0.001

ESL: early systolic lengthening, CCS: Canadian Cardiovascular Society, MB: myocardial band, STEMI: ST-elevated myocardial infarction, UAP: unstable angina pectoris, LV: left ventricular, TAPSE: tricuspid annular plane systolic excursion.

Table 2
Association between parameters of early systolic lengthening and endpoint events.

	Cardiovascular death HR [95%CI]	P	All-cause mortality HR [95%CI]	P
ESL amplitude, per 1% increase				
Unadjusted	1.37 [1.13–1.66]	0.001	1.31 [1.13–1.54]	0.001
Model 1*	1.35 [1.09–1.68]	0.006	1.29 [1.08–1.54]	0.004
Model 2†	1.54 [1.15–2.06]	0.004	1.41 [1.14–1.74]	0.001
ESL duration, per 10 ms increase				
Unadjusted	1.17 [1.08–1.26]	<0.001	1.14 [1.07–1.21]	<0.001
Model 1*	1.12 [1.02–1.23]	0.016	1.09 [1.01–1.17]	0.031
Model 2†	1.13 [1.00–1.26]	0.043	1.10 [1.01–1.20]	0.037

ESL: early systolic lengthening.
*Model 1: EuroSCORE II.
†Model 2: Age, sex, diabetes, peripheral artery disease, Canadian Cardiovascular Society Angina Score, creatinine, hemoglobin, coronary artery bypass graft indication, left main stenosis, left ventricular ejection fraction, E/e', wall motion score index and global longitudinal strain.

3.3. Additional prognostic value

When parameters of ESL were added to LVEF, wall motion score index and GLS, for both endpoints events, C-statistics increased significantly (P < 0.05; Supplemental Table 6). As displayed in Supplemental Table 6, ESL amplitude and duration yielded the highest values of C-statistics for both endpoint events, but this was not significantly higher compared to LVEF or GLS (P > 0.05 for all). When ESL amplitude was added to EuroSCORE II this yielded no increase in NRI or IDI for the assessed endpoints (Supplemental Table 7). By contrast, when adding ESL duration to EuroSCORE II the risk prediction increased for both CVD (NRI 0.476 [0.129–0.802]; IDI 0.011 [0.000–0.046]) and all-cause mortality (NRI 0.320 [0.061–0.590]; IDI 0.012 [0.000–0.038]).

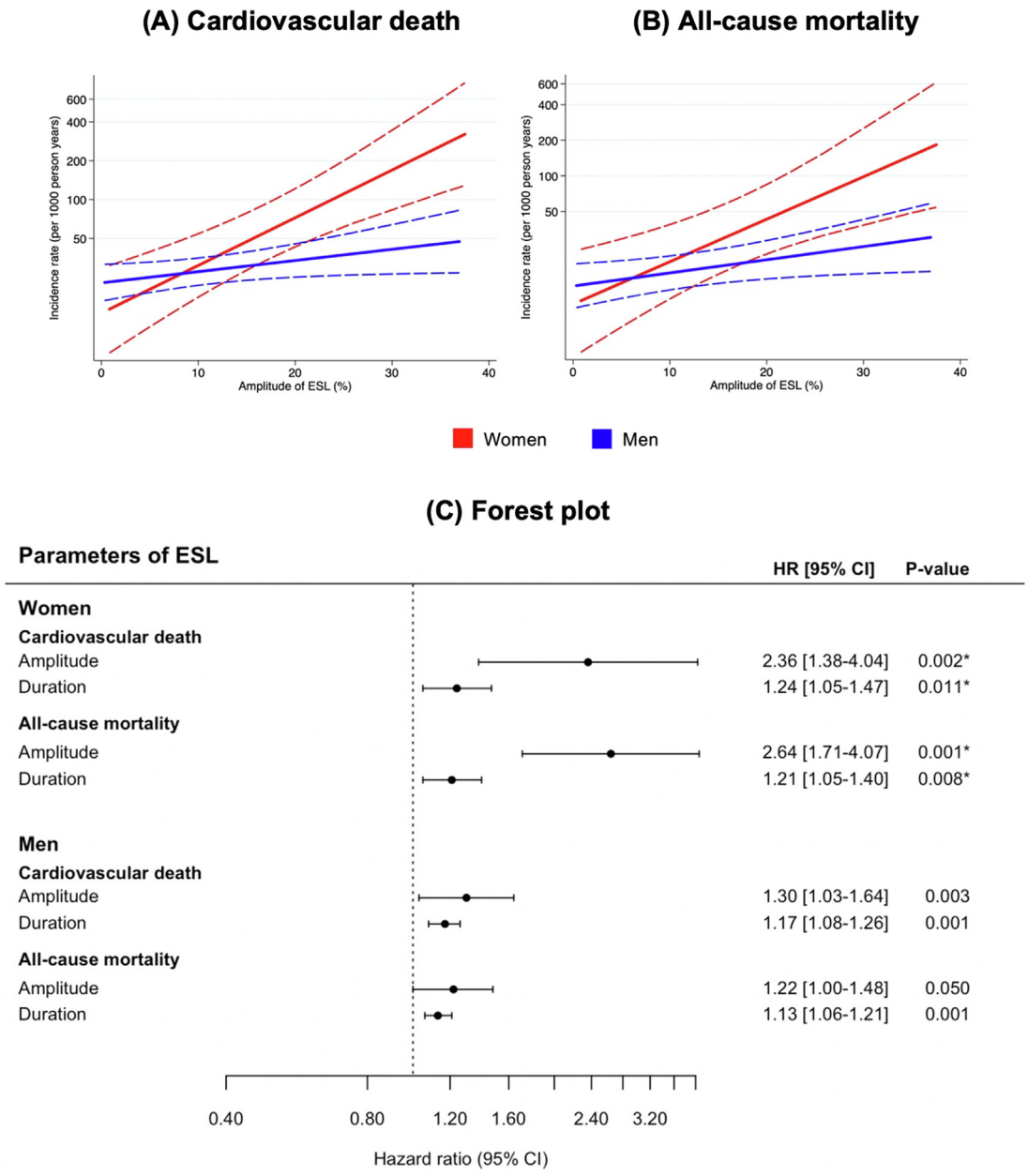

Fig. 2. A–C. Title: Cubic spline models and Forest plot. Legend: Association between amplitude of early systolic lengthening stratified by sex and the risk of cardiovascular death (A) and all-cause mortality (B). The red line indicates women and blue line men. Dotted lines indicate 95% confidence intervals. (C) Associations between parameters of early systolic lengthening amplitude (per 1% increase), duration (per 10 ms increase) and endpoint events stratified by sex. Associations that remained significant after adjusting for EuroSCORE II are indicated by (*). ESL: early systolic lengthening. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

3.4. Relationship with echocardiographic parameters

Both ESL amplitude and duration were significantly associated with worsening in LVEF, LVMI, wall motion score index, tricuspid annular plane systolic excursion and GLS ($P < 0.05$ for all in sex and age adjusted analyses; Table 3). Whereas ESL duration was associated with E/e' (beta = 0.12, $P < 0.001$), no significant association was found for ESL amplitude (beta = 0.02, $P = 0.06$).

3.5. Reproducibility

Reproducibility analyses showed only little bias for ESL amplitude (0.00 ± 0.03% for intra-observer and 1.8 ± 3.0% for inter-observer variability) and ESL duration (0.4 ± 8.5 ms for intra-observer and 1.0 ± 4.2 ms for inter-observer variability). Correlation coefficients for ESL amplitude were moderate to good (intra-class 0.93 [95%CI 0.83–0.97] and inter-class 0.65 [95%CI 0.13–0.86]) and the same applied to ESL duration (intra-class 0.92 [95%CI 0.79–0.97] and inter-class 0.63 [95%CI 0.11–0.85]).

4. Discussion

Although CABG is a commonly performed surgical procedure, it remains associated with significant risk of long-term mortality[17]. We hypothesized that a paradoxical stretch of myocardial fibers, ESL, might be useful for risk stratification of CABG patients. We found that amplitude and duration of ESL provided independent prognostic information on the risk of CVD and all-cause mortality,

Table 3
Association between ESL and selected echocardiographic parameters.

	ESL amplitude per 1% increase			ESL duration per 10 ms increase		
	Coefficient (β)	Standardized coefficient (β)	P	Coefficient (β)	Standardized coefficient (β)	P
LV ejection fraction	−0.02	−0.23	<0.001	−0.09	−0.41	<0.001
LV mass index	0.004	0.18	<0.001	0.02	0.26	<0.001
E/e'	0.02	0.08	0.06	0.12	0.21	<0.001
TAPSE	−0.002	−0.12	0.001	−0.11	−0.19	<0.001
Wall motion score index	0.49	0.25	<0.001	2.57	0.43	<0.001
Global longitudinal strain	0.09	0.42	<0.001	0.42	0.63	<0.001

ESL: early systolic lengthening, LV: left ventricular, TAPSE: tricuspid annular plane systolic excursion.
All analyses are adjusted for age and sex.

and that the prognostic value was greater in women. As of today, several studies have indicated the usefulness of ESL in myocardial ischemia[5–7,16,18–20], but none have examined it in a specific CABG cohort.

Tennant et al demonstrated that during ischemia, systolic shortening is gradually replaced by stretching of the myocardial fibers in proportion to LV pressure[21]. A similar finding was made by Tyberg et al, who plotted regional segmental length against cavity pressure and found passive stretching during systole[22]. Once myocardial tissue is exposed to ischemia, the composition, structure, and mechanical properties are gradually altered as it is replaced by scar tissue[23,24]. Segments with impaired contractility have decreased capability to generate active force, which is recognized as reduced systolic strain. However, segments with no contractile function behave passively, and will stretch when the LV pressure rises during systole, known as ESL. This is in line with our results, where ESL amplitude and duration was significantly associated with higher wall motion score index, indicating that ESL occurs when myocardial wall segments are impaired. Consequently, ESL indicates the degree of impairment relative to the original myocardial tissue and one study even suggested that ESL provides a measure of the infarct size[6]. This hypothesis was supported by Vartdal et al, who found that duration of ESL increased significantly with degree of myocardial injury and time course of LV remodeling[25]. In a recent study from our group of low-risk individuals from the general population, median duration of ESL was 22 ms, whereas it was 32 ms in the present cohort[7]. As it appears, the degree of ESL increases with ischemic burden, and considering that ESL remained a significant predictor in our multivariable models, it may represent a useful tool for risk stratification of CABG patients. The clinical usefulness of ESL is supported by the moderate to good reproducibility we found in intra- and interobserver analyses. Interestingly, the prognostic value was enhanced in women, indicating an even greater benefit for this group of patients.

This finding is in contrast to other studies, where speckle tracking parameters had reduced prognostic value in women, specifically in patients with heart failure and in the general population [9,26]. It is reported that women display more concentric remodeling during and after ischemia and in conditions with increased afterload [27–29]. Sex specific differences in physiology, such as lower muscle mass and volumetric dimensions[30], and hormone status [27] have also been demonstrated. This may lead to sex specific differences in speckle tracking parameters [10,31]. Despite the myocardium in women has a greater ability for remodeling and maintaining compliance in ischemia [32], women still have worse survival after myocardial infarction compared to men [33], and face higher risk of mortality following CABG [3]. We found no difference in the distribution of ESL parameters between men and women, however, women experienced more endpoint events, although this was not significantly more. While the exact mechanisms underlying our findings are unclear, it could be that ESL represents a more sensitive measure for the extent of ischemia in women, as preserved compliance and tissue remodeling are related to the degree of ESL [34]. In combination with a potentially worse prognosis and more endpoint events, this could have enhanced the predictive value of ESL in women. This finding should be seen as hypothesis-generating and future studies exploring this are encouraged.

As the subendocardial fibers are the most susceptible to ischemic changes, assessment of longitudinal strain is of increasing importance. However, when applying the conventional approach of assessing strain from end-diastole to end-systole in patients with ischemia, which involves myocardial regions with infarction, it becomes more difficult to interpret strain findings correctly. Under these circumstances, and as supported by the present results, phenomena such as ESL and postsystolic shortening may contain beneficial clinical information and should be taken into consideration. Novel deformational patterns cannot replace established risk prediction models or a conventional echocardiographic examination, but may complement these to improve patient care in CABG.

4.1. Strengths and limitations

Tissue structure and mechanical properties evolve during myocardial ischemia, explaining why assessment of strain, including ESL, also may change[24]. As we had no follow-up information on ESL after the CABG procedure nor consecutive measurements of ESL, we could not determine the most optimal time for assessing this phenomenon with regard to risk stratification. The EuroSCORE II risk model is originally constructed for in-hospital outcome following cardiac surgery, however, we applied this when assessing long-term mortality, which represents a source of bias in our results. The nature of this study was retrospective, hence residual confounding may be present. A major limitation is that we had no data available from 12-lead electrocardiograms, including QRS width above/below 130 ms or bundle branch block, which may represent sources of ESL. Because the population is heterogenous, and we had no data available on viability such as myocardial scintigraphy, this could affect the amount of ischemic/necrotic myocardium and the values of ESL. Both ESL and postsystolic shortening add to wasted myocardial work and affects the myocardial work efficiency, and although assessment of wasted work seems to be a promising measurement for characterizing LV remodeling, we had no data on LV pressure-strain loops available[38,36]. Considering that only 15% of the population were women this could potentially have affected our sub-group analyses and stability of multivariable models.

5. Conclusion

Early systolic lengthening, a paradoxical stretch of myocardial fibers in systole, provides independent prognostic information on long-term cardiovascular death and all-cause mortality in CABG

patients when evaluated preoperatively. Furthermore, we found that the prognostic value was incremental to the EuroSCORE II and greater in women.

6. Funding sources

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijcha.2021.100799.

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